FRAMEWORK FOR THE SCIENCE TECHNOLOGY AND INNOVATION DECADAL PLAN

RISING TO THE CHALLENGE

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INTRODUCTION

The period between 2014 and 2019 has been characterised by critical reflection on science, technology, and innovation (STI) policy and policy implementation, towards a better understanding of the National System of Innovation (NSI) and its role in shaping the future of South Africa. Government, with other NSI actors, including the National Advisory Council on Innovation (NACI), carried out or commissioned initiatives such as reviews of the 1996 White Paper on Science and Technology, the 2002 National Research and Development Strategy and the Ten-Year Innovation Plan (2008-2018), an analysis of the NSI's performance, the first phase an STI institutional landscape review, and a national STI foresight exercise looking towards 2030. A new White Paper on STI was developed, and was approved by the Cabinet in March 2019. The White Paper is to be implemented through decadal plans, and this document provides a framework for the development of the first decadal plan.

The White Paper was informed and shaped by the National Development Plan (NDP), which identifies science, technology, and innovation as critical for the creation of a competitive and sustainable economy and for addressing societal challenges such as education and health. It advocates a strong, coordinated, coherent and effective STI system that promotes networks and partnerships between different actors in the public and private sectors, contributes to transformation, and 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 calls for the expansion of STI outputs by increasing government expenditure on research and development (R&D) and encouraging increased expenditure by the private sector.

Building on previous successes and adopting new approaches where required, the White Paper 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.

The White Paper proposes minimum requirements for the decadal plan. First, it is expected to take into consideration not only the policy intents of the White Paper; but also the reviews of the Ten-Year Innovation Plan (TYIP) and the National Research and Development Strategy (NRDS), both of which have seen the attainment of significant milestones; the results of the NACI foresight exercise; and the priority outcomes of government. Second, the decadal plan should offer guidance in respect of (a) technology focus areas, (b) priority initiatives, (c) institutional arrangements, (d) partnerships, (e) funding and proposed sources for funding, (f) time frames, and (g) indicators to measure progress.

This framework takes the above requirements and the objects of the White Paper as its point of departure to ensure alignment. However, its limitation is that it did not benefit from the review of the NRDS and TYIP and Institutional Landscape, which remain ongoing. The development of the STI decadal plan process will need to consider the review results as soon as they are available.

CHALLENGES AS OPPORTUNITIES

Harnessing STI to tackle societal challenges, as the White Paper proposes, is a challenging task. South Africa is one of the most inequitable societies in the world, and there are growing demands for development and a better life. As in the rest of the world, many people feel left behind, excluded, and treated as unimportant. They do not see a future for themselves but have "accumulate disadvantages", in part because their children "do not have equal opportunities to reach their full potential", as Ángel Gurría, OECD Secretary-General, said in a speech in 2018. Gurría explained how many people live precarious lives, or have already fallen through the cracks of society into poverty and unemployment. They feel at the "mercy of big impersonal forces of globalisation, technological change, large corporations, and financial institutions." Public trust towards STI is important to the responsible development of advanced and emerging technologies as illustrated by ongoing discussions around gene drive or Artificial Intelligence (AI).

South Africa has embraced the Fourth Industrial Revolution (4IR) by establishing the Presidential Commission on 4IR and ensuring that it features prominently in the White Paper on STI. 4IR is seen as radical and disruptive technological change that will impact on production and quality of life across the world. Human beings have always identified and developed tools to augment their constraints or limitations. In this regard, 4IR represents such tools. 4IR will have both positives and negatives. It will create new jobs and, at the same time, destroy existing jobs. Technological change demands better management of the transition to ensure that old institutions are not ruined while new institutions are established.

Countries have diverse views on the future challenges and opportunities presented by 4IR, depending on their own present situation and objectives, and their STI interests. Some developed countries (such as Germany, Italy, Japan, and the USA) have articulated and determined how they seek to exploit 4IR to meet local needs. The decadal plan offers the opportunity for South Africa to set out how it intended to exploit and leverage 4IR to meet national imperatives. This is a challenging task. It is therefore proposed that the process of drafting the decadal plan should solicit broader stakeholder engagement and political consensus; select a few (not all) key technologies associated with 4IR, and then determine the nature of investment and capabilities required. In this regard, the CSIR based Centre for the Fourth Industrial Revolution, for example, will play a critical role. The future may necessitate the establishment of additional centres or capabilities of different forms.

Since the White Paper is explicit about Artificial Intelligence, the issue of principles will be an important consideration in the decadal plan. The G20 countries (of which South Africa is a member) adopted human-centred AI principles that draw from the OECD AI principles, which are as follows: (a) AI should benefit people and the planet by driving inclusive growth, sustainable development, and well-being. (b) AI systems should be designed in a way that respects the rule of law, human rights, democratic values, and diversity, and they should include appropriate safeguards, for example, enabling human intervention where necessary to ensure a fair and just society. (c) There should be transparency and responsible disclosure around AI systems to ensure that people understand AI-based outcomes and can challenge them. (d) AI systems must function in a robust, secure and safe way throughout their life cycles and potential risks should be continually assessed and managed. (e) Organisations and individuals developing, deploying or operating AI systems should be held accountable for their proper functioning in line with the above principles (OECD 2019).

The decadal plan will need to articulate and operationalise inclusivity and transformation in a manner that brings dignity and integrity to the marginalised and enables good governance and service delivery. It must also identify clear actions to support small, medium and micro-enterprises (SMMEs) and stimulate innovation in all regions of the country.

The inclusion of non-traditional R&D actors (such as civil society and the informal sector) in all STI processes, not merely as beneficiaries, is vital, as is the promotion of social and grassroots innovations. The White Paper's wider concept of innovation must be given concrete expression in practice.

To ensure that the decadal plan and the NSI secure broad support, the views of the public should be solicited on the nature of the plan and what should be done to address their issues.

The current situation (characterised by limited resources, pressing development challenges and a sluggish economy) demands critical reflection on the nature of support required to facilitate knowledge production and targeted research and development. The tension between basic and applied research has existed since the advent of the second mission of the university (that is, economic development) at the beginning of the 20th century. The research systems are getting more complex, and the capacity of government to influence the orientation of research and innovation for public missions is increasingly challenged. Under these circumstances, NSI actors cannot act as they please, but priority should be on development challenges. To this extent, there is an urgency in reintroducing mission-oriented research programmes into national research strategy. The intention is to enhance the impact of research on society.

Mission-oriented research programmes will require a flexible decision-making matrix. In moving forward, some of the questions to be addressed will include the following: How can government efficiently involve the business sector in research and innovation for public missions? How can basic research be included in mission-oriented programmes?

A strategic compact between government and the private sector will be critical for the success of the decadal plan. There is a need to improve the rate of systemic efficiency and quality to stimulate growth. Conditions must be created to enable effective allocation for appropriate impact. The shortage of human resources for STI is a key constraint to the performance of the NSI and the economy. The internationalisation and transformation of human resources for STI should not be seen as conflicting goals but as complementary imperatives. The challenge is to exploit the complementarity in a way that contributes to meeting national objectives and the country's international commitments, especially in the rest of Africa.

Finally, the focus in the White Paper on open science and open innovation may affect the future of the current intellectual property rights regime, and the decadal plan should take this into account. One aspect to be considered relates to the adaptability of the intellectual property system in respect of the protection of data and AI challenges.

VISION AND OBJECTIVES

The decadal plan's vision and objectives should be those of the White Paper. The vision is "Science, technology, and innovation enabling inclusive and sustainable South African development in a changing world". The objectives are improved coherence and coordination; increased partnering in the NSI between business, academia, government and civil society; strengthened and transformed NSI institutions; increased human capabilities; an expanded research enterprise; an enhanced enabling environment for innovation; and improved funding across the NSI.

CONCEPTUAL KERNEL: NSI, KNOWLEDGE AND DIGITAL ECONOMY

The 2019 White Paper proposes a transition towards an STI system that puts humanity at the centre rather than products and processes. Societal needs or challenges define the agenda and focus of STI policy. It is therefore important to develop a better understanding and interpretation of the transition in order to develop cohesive, effective and implementable actions. It needs to be emphasised that, even during transition, there will be continuities and discontinuities. This is more important in developing countries (such as South Africa) where the STI system continues to be developed.

This document proposes to use the notion of the Three Framings of Innovation policy by Schot and Steinmueller (2016) as a heuristic tool to analyse and understand transition as proposed by the White Paper. As Schot and Steinmueller argue, there are two established frames in contemporary innovation policy discussions. The first, which began after World War II, is the "institutionalisation of government support for science and R&D with the presumption that this [will] contribute to growth and address market failure in private provision of new knowledge".

The second, which emerged in the 1980s in the context of globalisation and the need for competitiveness, sees STI policy focusing on building a national system of innovation "through links, clusters and networks, and on stimulating learning between elements in the systems, and enabling entrepreneurship". While the first two framings remain relevant, Schot and Steinmueller argue that the third framing they identify, which is "linked to contemporary social and environmental challenges such as the Sustainable Development Goals (SDGs)" and "transformative change" (with transformation referring to 'socio-technical system change as conceptualised in the sustainability transitions literature'), should be given priority.

Schot and Steinmueller argue that transformative change framing involves questioning how to use science and technology policy to meet social needs and address the issues of sustainable and inclusive societies at a more fundamental level than previous framings or their associated ideologies and practices. One key feature of the transformative frame "is its focus on experimentation and the argument that the Global South does not need to play catch-up to follow the transformation model of the Global North" (2016). The transformative change framing is still underdeveloped and does not necessarily replace the other two framings. However, the three framings compete with one another for the imagination of policymakers and, ultimately, citizens. The legitimacy of rationales and arguments for particular policies and the actions that follow from them is influenced by the prevalence and understanding of the framings. (Schot and Steinmueller, 2016)

The 2019 White Paper retains the NSI as its organising framework because of its continuing relevance and the wish of most actors, including NACI, that it be retained. The original motivation for the adoption of NSI in the 1996 White Paper was that it would, among other things, (a) promote interactions among actors (including higher education institutions, science councils and research institutions, research entities within the state-owned enterprises, statutory bodies, businesses, and not-for-profit organisations) to promote coherence and the integration of national STI activities; (b) include people in the knowledge economy to secure buy-in; (c) identify needs independent of institution or organisational agendas; (d) focus on innovation; and (e) respond to broader societal needs.

The new White Paper proposes a range of actions that will need to be translated into practical steps by the decadal plan. The ongoing challenges facing the NSI include the need – identified in the 2012 report of the Ministerial Review Committee on the Science, Technology and Innovation Landscape – for the NSI to be "publicly re-endorsed by government as a potentially decisive driver of national economic and social development, indicating clearly that the NSI must be pervasive and truly systemic in its design and functioning, and that its functionality is core to any systematic national approach to creating jobs, addressing poverty and providing fulfilling life opportunities to all South Africa's people and communities". Other challenges are the fact that the notion of innovation – in all its dimensions, including technical, economic and social – is poorly understood, especially on the demand side; the functioning of the NSI is seriously impeded by the deficit in high-order skills, particularly in the area of design, engineering, entrepreneurship and management; and STI measurement capacity is inadequately institutionalised.

Furthermore, the NSI is not yet making an adequate contribution to poverty reduction and wider inclusion in the mainstream economy. There is no single funding agency or consolidated funding mechanism overseeing the use and spread of funding across the innovation value chain, and the lack of coordination and limited sectoral alignment of research agendas, outputs and desired outcomes in health, minerals beneficiation and agriculture, for example, could be limiting success. The private sector also needs to play a bigger role in the NSI.

Therefore, NSI must be supported and marshalled towards deepening and building a socio-technical system's transition.

The 2019 White Paper does not refer much to the knowledge economy, which was the key focus of the Ten-Year Innovation Plan (TYIP). However, the knowledge economy should be considered a critical aspect of the decadal plan, as it is essential for accelerated and sustained economic growth.

The decadal plan will need, as indicated in the TYIP, to increase the proportion of national income derived from knowledge-based industries, the percentage of the workforce employed in knowledge-based jobs and the ratio of firms using technology to innovate. Human capital development, knowledge generation and exploitation (R&D), knowledge infrastructure and enablers to address the "innovation chasm" between research results and socio-economic outcomes will continue to play an important role.

The demand for human capacity in science, technology, engineering, and mathematics (STEM), for example, computer scientists, engineers, chemists, biologists, mathematicians, and scientific inventors, will increase in years to come.

If the new decadal plan retains the knowledge economy as its focus, it will need to articulate how this aligns with the traditional economy and development of measurements for the NSI.

SENSE OF URGENCY. SOUTH AFRICA SHOULD NOT LAG BEHIND

South Africa's success with the Square Kilometre Array (SKA) is an indication of the country's STI presence in the world. The project brings together a wealth of the world's finest scientists, engineers and policy makers, and has the potential to enhance South Africa's strength in STI international collaboration. The MeerKAT array is to be integrated into SKA Phase 1 (2019-2024) with an additional 133 antennas in the Karoo, making it a 197-dish mid-frequency array.

However, in comparison with other countries, South Africa's NSI is not operating efficiently. In fact, there is evidence that the efficiency of the NSI has been declining.

The best indicator of inefficiencies at the system level is provided by the Global Innovation Index (GII). The GII measures innovation inputs and outputs for 126 countries. The overall score is the simple average of the two. The table below summarises South Africa's 2018 GII ranking.

CATEGORY	RANK	SCORE
Innovation inputs	48	45.36
Innovation outputs	65	24.87
Overall	58	35.13

There is a considerable difference between the input and output scores. The GII calculates the efficiency ratio by measuring the degree to which innovation inputs are transformed into innovation outputs, and in terms of this South Africa comes in at 83 out of 126, with a score of 0.55. Of the 57 countries that have a higher overall GII score than South Africa, only one, the United Arab Emirates, has a lower efficiency ratio.

According to a 2018 study performed by Cornell University, INSEAD, and the World Intellectual Property Organisation, South Africa is a significant negative outlier in terms of its overall innovation performance relative to its stage of development – with only four countries faring worse (the United Arab Emirates, Qatar, Kuwait, and Brunei).

While South Africa's efficiency in translating innovation inputs into outputs is very low overall, there are significant differences between the science, technology and innovation components of the NSI.

In terms of science, the indicators suggest that the system is working well. Since 2004/05, research output measured in terms of publications and citations has been increasing steadily. As the White Paper notes,

although the number of university research staff did not increase between 1996 and 2014, research output trebled. South Africa grew faster than the world average; the country has increased its global share of publications and citations. While inputs in terms of researchers remained static, outputs have increased significantly, indicating that the efficiency of the science system has been improving.

Of course, there are still challenges. South Africa's world ranking is far higher in social sciences (18) and the arts and humanities (18) than in life sciences (33), physical science (38) and technology (40). Moreover, with the number of researchers increasing very slowly, and growing pressures on teaching in universities as student enrolments grow and many of the most productive researchers reach retirement age, there is no room for complacency. However, the science system has been working well and it is possible to identify several policy measures that have contributed positively to this outcome – the South African Research Chairs Initiative, for example.

In terms of technology, several indicators suggest that the system is not working well. South Africa's share of patents at the United States Patent and Trademark Office (USPTO) has declined significantly against the global total. The country's share of total foreign patents at the USPTO declined by more than 50% between 1996 and 2015, which does not compare well with Brazil, the best comparator country for South Africa[2]. Likewise, South Africa's share of high technology exports does not compare well with Brazil's. The World Bank's development indicators show that South Africa's share stagnated while Brazil's grew significantly, and by 2016, high technology exports as a share of total manufactured exports were almost three times more for Brazil than South Africa.

South Africa's receipts from the sale of intellectual property show an overall trend of decline. In the first half of the 1990s, South Africa's receipts were higher than those of Brazil, but by 2015, Brazil's were more than six times higher than South Africa's. The decline in receipts from the sale of intellectual property between 2013 and 2016 is of particular concern.

In terms of innovation, there is also evidence that the system is not working as required. Measured in terms of the introduction of new products for export and/or new export markets, established firms are becoming less innovative, and there are fewer new firms entering the export market. These two indicators show clearly that innovation outputs are in decline.

Despite new policies and additional resources, technology and innovation outputs have stagnated or risen only very slowly. There is an urgent need to ensure that policies and resources are used more effectively.

ALIGNMENT OF STI POLICY WITH OTHER GOVERNMENT-WIDE SOCIO-ECONOMIC POLICIES

Governments everywhere face a major challenge in getting government departments to ensure that their actions and policies are assessed and evaluated for their impact on innovation. There is a further challenge – namely how to get government departments, particularly the large "service" departments such as health, education, and transport, to themselves adopt practices that spur innovation (NACI, 2016).

[2] Brazil and South Africa have comparable GDP per capita, comparable economic growth rates and comparable rates of growth of manufacturing.

Most STI systems across the world are still learning how to harness STI for societal benefit. South Africa is therefore not alone in facing this challenge but needs to find its own approach through the decadal plan. The approach should reflect new thinking and offer practical solutions to the perennial problems of coordination (vertical and horizontal), coherence, planning, and resource problems. For instance, it should look at ways in which STI can be integrated into national industrial policy (beyond the current arrangement in which the Department of Science and Technology writes a chapter in the Industrial Action Policy Plan) and how to ensure that all government departments use STI in service delivery and their analysis and development of strategies and policies. Science, technology, and innovation remain on the periphery of most government policy making, despite their recognition in the NDP. The decadal plan should look at matters such as whether the absence of a central STI-oriented planning mechanism will be a hindrance, and what could be achieved through the National Planning Commission (NPC) and/or the new policy unit planned for the Presidency, as well as what other opportunities the reconfiguration of government might offer.

INNOVATION AND ECONOMIC DEVELOPMENT

The 6th Administration set economic transformation and job creation as key priorities. It promotes the broader and cross-cutting role and contribution of innovation. The decadal plan will need to improve institutional capacity and the catalytic role of STI in stimulating sustainable and inclusive growth and competitiveness, productivity and job creation. Innovative partnerships between government and business will be vital to address a range of barriers or constraints. The clearest indicators of the state of innovation in the business sector are derived from the export market. Increasing innovation results in an increase in the number of exporting firms, new export products, and new export markets.

In South Africa, very few firms are significant exporters, and entry rates are below those of comparator countries. According to the World Bank's 2014 South Africa Economic Update – Focus on Export Competitiveness, "South Africa has one of the lowest new firm entry rates into exporting among its peers". The same report shows that by far the largest share of South Africa's export growth is accounted for by existing firms selling into existing markets.

It is concerning that South Africa's top exporting firms, which are responsible for the overwhelming share of South African exports, are developing and selling fewer products into global markets. Few new firms have entered the export market, and established exporters are developing and selling fewer products into global markets. It is innovative and competitive firms that enable economic growth, diversify the economy and exports, raise productivity and enhance employment. Economic growth and employment creation are the highest priorities of the government, but South African firms are becoming less rather than more innovative. The decadal plan should therefore, aim to ensure that business sector innovation grows.

In South Africa, one of the critical constraints – and indeed there is some evidence to suggest that it is the binding constraint – lies in the paucity of skills and their deployment. South Africa's lowest GII scores are in education (83) and tertiary education (87), and a 2018 World Bank report identifies the skills constraints in South Africa as a major deterrent to innovation in general, and to the vitality of the manufacturing sector. There should be a continuous investment in education and skills development encompassing a range of areas, including mathematics, science, engineering, data coding and analytics, and robotics, which are critical to the technological age necessary to put the economy on a new growth trajectory.

INNOVATION AND SOCIETAL DEVELOPMENT

Unless South Africa can better use its scientific and technological capacity, capability and competence to confront enduring and persistent economic, social, and political challenges, the country could worsen its domestic situation while declining in relation to comparator countries in world systems. A more compassionate and responsive system of STI is required to balance between the current stock of capacity, capability, and competence in the NSI, new and expanded demands for support from local enterprises and households, and the dynamics of international geopolitics.

A more compassionate and responsive STI system will ultimately seek the realisation of a better life for all within planetary boundaries based on social, economic and political justice. It is therefore imperative that the NSI be further transformed to embrace a people-centred orientation and an ecologically sensitive stance. Service delivery can be greatly enhanced through STI and the application of 4IR technologies.

STI for inclusive development needs to receive far more emphasis, within a future South African NSI and in any proposed STI interventions going forward. Listening to, understanding and acting on the needs of people (both their collective and individual needs) will be vitally important in harnessing STIs to tackle societal challenges.

Holistic and cross-cutting initiatives are required.

- Rebuilding trust within the NSI (between state and citizens, the public and private sectors, and the knowledge-worker and research community), to support the building of an inclusive and sustainable society and economy.
- Redressing the systemic and structural barriers which reproduce inequalities in access and participation in the various enterprises of STI and to ensure that STI delivers sustainable benefits to all.
- Embracing the value of engaged progressive scholarship and encouraging greater utilisation of STI in generating high quality social public goods.
- A strong, capable, and developmental state that provides an enabling environment for STI development by all players within the NSI.
- Resilient communities, with knowledge-seeking capacities, organisational capabilities, and leadership competences to adopt and adapt STI more speedily for domestic benefits, including spatial integration and municipalities and district-based developments.
- Self-driven, lifelong learning as a social and cultural value.
- Critical, constructive, confident and respectful South Africans, building a cohesive united non-racial, non-sexist and non-homophobic society together in line with the Constitution and Bill of Rights.
- Building a society that is proud of indigenous knowledge and locally produced technologies and innovations.
- Building an NSI that supports not only structures of state but also self-sufficiency at individual and community level, with active participation and contributions from citizens to improve their lives.
- Building a pan-African system of innovation which encourages pro-African thinking and collaboration.
- Preparing for the labour transition that is imminent in the 4IR. Many existing jobs, especially low-skilled jobs, will be more efficiently performed by machines, while new opportunities for employment will emerge, but will typically require higher skills. It is necessary to empower a wide range of actors, existing and new, in the digital age.

- Building innovation capabilities within marginalised communities through technology pilots.
- Scaling up existing (successful) pilots within prioritised areas – these need to be identified and efforts made to replicate successful models on a national scale.
- Developing enabling instruments that will stimulate active participation of communities in becoming technology providers, e.g. preferential procurement programmes, incentives, or a technology appropriation fund for marginalised and vulnerable groups.

FUTURE CHALLENGES AND OPPORTUNITIES FOR STI

What emerging topics will affect the science and innovation landscape of tomorrow?

PRIORITISATION

This will be the most critical aspect of the decadal plan. The focus is on priorities to meet societal priorities in keeping with the orientation of the White Paper. Future investments in STI will depend on the final list of priorities decided on, and the process of identifying and selecting STI priorities is therefore of the utmost importance. The White Paper states that the selection process will use the results of the foresight exercise, the reviews of the National Research and Development Strategy and the Ten-Year Innovation Plan, and government priority outcomes as the basis for crafting the first decadal plan. The results of the TYIP review are not yet available, and neither are the priorities of the 6th administration. However, provisional proposals will be made based on the results of the foresight exercise. Once the review results are available, the government will make a final determination of priorities for the new decadal plan.

The general approach proposed is as follows:

- The final determination of priorities based on NACI's 2030 Foresight Exercise results will be critical.
- A review of existing initiatives should assist in determining areas that should be continued, upscaled or terminated. The NACI review of the NRDS and the TYIP will provide a comprehensive reflection on the progress made on the objectives of the two policies and will reflect on what has been achieved and what has not been achieved.
- Areas of existing competitive advantage like high-value agriculture, mining inputs and downstream processing innovation, innovation to meet environmental and energy efficiency objectives, and financial services should be assessed as proposed in the NDP.

In making the final selection of priorities, mapping resource and infrastructure requirements will be key. It will also be important to prioritise programmatic areas that make it possible to bring different stakeholders together to work towards a common goal. Successful countries are known for having developed distinct specialisations, capabilities or niches inspired by STI. The Fourth Industrial Revolution and digitisation should be exploited for the benefit of the country. The decadal plan should therefore, identify two or three key capabilities or big projects that can serve as game changers or catalysts for well-being and inclusive and sustainable development. The Square Kilometre Array offers evidence of the impact that big projects can have on the system and its ability to inspire confidence, mobilise stakeholders and bring in investments.

The alignment of the final priorities selected with existing capacity should be assessed in order to develop relevant and appropriate initiatives that will contribute to the achievement of the NDP and White Paper goals. It is vital that the new decadal plan set clear indicators and targets.

FORWARD LOOKING AND STI PRIORITIES FOR SOCIETAL CHALLENGES

A detailed report of the 2030 Foresight Exercise can be used to provide context for the STI domains and thrusts/priorities proposed below. The underlying idea of the foresight exercise was to see how STI could be leveraged to address key societal challenges, and a number of STI areas were identified in the process. These were prioritised using a set of criteria related to their (a) potential for new impact. (b) association with global and STI trends. and (c) contribution to socio-economic development. As a result of online and offline consultations with the stakeholders of the STI system in South Africa, nine STI domains[3] were selected. Then thrusts were determined. A long list of possible thrusts[4] was presented at a foresight workshop, and a shortlist was then drawn up using a new set of prioritisation criteria to consider their importance and feasibility.

The criteria included the socio-economic impact, new impact, and strategic value of each thrust. 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 required policy and regulatory environment. (e) social and ethical acceptability. (f) the amount of relevant funding currently allocated. and (g) the ease with which obstacles could be addressed. The proposed nine STI domains are as follows:

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. **The high-tech industry domain** (Fourth Industrial Revolution). 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 technologies like robotics, artificial intelligence, the Internet of Things, and additive manufacturing. This will transform old industries and give rise to new industries. Industry actors, including SMEs, will need to equip themselves with the necessary skills, infrastructure, and capacity for a successful transition.

3. **Education for the future.** Education is the basis for a fair society and a successful economy. By the 2030s, South Africa needs to be providing all its citizens with the 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

[3]In the foresight exercise, the term "STI domain" was used to refer to a relatively broad but bounded area of STI, such as water security, or nutrition and agriculture.
[4]The term "STI thrust" was used to refer to the STI priorities that were the intended outputs of the foresight exercise. The STI thrusts were expected to be related to one or more of the selected STI domains, but were not limited to the STI domains.

access to quality education. Technology provides an ever-growing range of opportunities to provide this access. New and alternative learning technologies will not only give people basic education but will also equip them with the necessary skills for the future, while reducing divides in society. Curricula should be developed to enable people to be more creative with skills for idea generation and problem solving.

4. **Nutrition for a healthy population.** Nutrition is essential for a healthy population. There are currently serious issues around malnutrition and stunting 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.

5. **The opportunities, threats and social impact of information and communication technologies (ICTs).** 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 several 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 developments. 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 necessity 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.

6. **Health technologies to prevent and treat ill-health and advance well-being for those who are marginalised.** Overall, the healthcare system needs to be optimised in order to deliver better diagnostic and treatment services. Drug development and the use thereof 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.

7. **Sustainable technologies for the marginalised.** 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.

8. **Future of society.** STI for inclusive development needs to receive far more emphasis than it has previously in the NSI and in any proposed STI interventions going forward. Listening to, understanding and responding to the collective and individual needs of people will be vitally important in harnessing STIs 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.

9. **Integrated solutions for 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 levels. (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 Fourth Industrial Revolution is characterised by the intersection of physical, digital and biological spheres through technology. Cyber-physical 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.

Each domain must be analysed and understood in relation to its thrusts or priorities. The foresight exercise breaks down the thrusts into various important topics or concerns that will assist in the development of specific interventions. For instance, a "low-carbon and climate-resilient economy" is one of the thrusts under the circular economy. An analysis of this thrust produced six important concerns, namely, the economic impact of sustainability, energy efficiency and renewable energy, low carbon and low emissions, climate change, biodiversity conservation, and land use, and African environmental policy.

New technologies serve the needs of society, and society is changed by new technologies. STI and society must evolve together. Comparing South Africa's scientific output with the domains and thrusts identified in

the foresight study, it emerged that South Africa's research position in ICT is relatively low, even though most STI domains are closely linked to the development of ICTs. The country has strengths and potential in the agricultural, astronomical, biological, microbiological, veterinary, environmental, immunological, water, and earth and space sciences, as well as in business management and accounting, the health professions, the decision sciences, and the social sciences and humanities. Areas that show potential or recent improvement include renewable energy. Areas that require urgent attention in terms of knowledge generation and human capital development include engineering, mathematics, and computer sciences, transport and neuroscience.

The analysis demonstrated the feasibility of the White Paper's goals, but the decadal plan needs to ensure that research capacity, skills, and infrastructure are developed in a balanced manner.

Over and above specific STI priorities, the decadal plan must include actions responding to the broad systemic challenges identified by the White Paper, such as the need to (a) promote innovation culture in government, business, and society. (b) expand the human resource base of the NSI and the research system, and transform it in favour of the youth, black people and women. (c) improve the education pipeline and education outcomes, especially mathematics and science. (d) increase investment in STI. and (e) create an enabling innovation environment and a coherent and inclusive system.

CRITICAL ENABLERS

INCREASED INVESTMENT IN STI

The government has long stated that its goal for gross expenditure on R&D (GERD) is 1,5% of GDP. However, GERD is currently only a little over half the desired figure. For a number of reasons, it is very unlikely that there will be significant progress towards this goal, at least in the short to medium term. Funding for STI is likely to remain limited, restricting the implementation of STI policy. Although it is projected that growth will improve slowly, GDP growth will remain below population growth, resulting in declining average incomes. In the longer term, growth may pick up, but a long period of stagnation has reduced the long-term growth potential of the South African economy.

At the same time, government debt levels are high. With the government committed to reducing debt, and with low growth rates limiting income from taxation, government expenditure will be severely restricted. As an indication of governmental priorities, expenditure by government on STI as a share of the total budget declined from 1,87% in 2014/15 to 1,71% in 2017/18.

The business sector's share of GERD has also been declining. In 2008, at the onset of the financial crisis and the commencement of the last decadal plan, business expenditure on R&D (BERD) was 58,6% of GERD. By 2016/17, BERD was only 41,4% of GERD. However, given the severe constraints on government funding, an increase in business investment in R&D is essential if the NSI is to survive. The White Paper on STI states that "government funding on its own is insufficient for growing the NSI to its full potential. Increased private sector involvement in resourcing the NSI is vital, both to advance private sector objectives and to support the government in RDI initiatives for the public good."

HUMAN CAPABILITIES FOR STI

Education (across all levels) is a critical component of the NSI and can enable many South Africans to escape unemployment and poverty. Student enrolment at universities has grown, but the number of academics has not. Furthermore, unless universities retire older academics or find funding to create new posts, there will be no place for the next generation of black and/or female academics. Resources are required to expand the system, but the nature and form of the expanded system also need to be determined. The development of the decadal plan should consider the establishment of international programmes, looking at models used by India and China, among others.

The decadal plan should address the current and future reality of human resource supply and demand, and the type of education and training appropriate for 4IR and digitisation. The key challenge that lies ahead includes determining future 4IR related skills for jobs that are unknown. It should articulate the STI sector contribution to the 4IR Skills Master Plan that is to be developed by the Department of Higher Education and Training in consultation with other departments. Alignment with the Human Resource Development Strategy is equally important.

Artisanry or technical skills are the backbones of infrastructure development and maintenance. Continuing focus on and increased support to technical and vocational education and training (TVET) colleges will be vitally important. The teaching and development of 4IR and digital skills will be critical. It will be important to find synergy between the content of the decadal plan and post-school education and training system strategy and plan. The role of state-owned enterprises and local municipalities in offering in-service training to students and new entrants to the labour market should be explored. The production of a critical mass of artisans is vital to the reinvigoration and sustainability of the economy and job creation.

The establishment of well-functioning and effective TVET colleges must be complemented by a serious reconsideration and repurposing of universities of technology to accelerate the nation's industrial revolution. They should become a place in which young people with ingenuity and drive are enabled to invent fundamental technologies and launch new industries, thus creating jobs. Universities of technology should not become traditional universities, although traditional universities must also be subjected to critical analysis in respect of their capacity, orientation, efficiency, and outcomes.

Dedicated focus and support for the development of black and female South Africans in order to transform the demographics of scientists, engineers, and technologists in higher education, industry, and the private sector must continue.

Discussion around the role of historically disadvantaged institutions should not be confined to the old debate about differentiation, but as having greater potential for the expansion of the system of education, research and innovation. The decadal plan should offer concrete proposals for such expansion. A consolidated systemic analysis of existing capacities and mapping of future requirements may be necessary.

The decadal plan needs to be bold and firm about the establishment of international training programmes to complement the limited capacity of local universities to enrol more students. Such programmes could involve other sectors (including health) which are in dire need of additional capacity. Costing and quantification of this programme will be essential in order to improve its potential to succeed. The Indians, Chinese and Brazilians had similar programmes which were based on projected future skills demands. The BRICS forum provides opportunities for such collaboration.

Other possibilities for the expansion of the system and the pipeline problem include the following:

- Stimulating innovation culture at all levels of schooling and society.
- Revitalising the Dinaledi Schools initiative or establishing similar initiatives, but with a more intensive focus.
- Increasing the number of specialised schools or academies focusing on STEM, which should help to improve the Grade 12 pass rate in mathematics and science. The national numbers for university entrance pass in Mathematics and Science are stagnant. Perhaps beneficiaries of broad-based black economic empowerment programmes could be mobilised to fund these schools as way of giving back to the community.
- Establishing more joint programmes between the Departments of Science and Technology, Higher Education and Training, and Basic Education to focus on priorities such as mathematics, science, and entrepreneurial skills.
- Making a concerted effort to bridge the knowledge transfer gap between local companies (big and small) and public sector researchers and administrators, in order to ensure that the nation's considerable human resources are better used. As recommended by the Ministerial Review Committee, there should be focused research on building skills to boost South Africa's collaborative abilities across all sectors within the NSI.
- Further programmes are needed to increase the number of women studying and entering employment in STEM-related fields. The funding structures should take into consideration the potential effects of having and caring for children on women in STEM to ensure their equitable promotion and improved research ratings.
- Support training in digital skills for science.
- Have innovation agencies support the improvement of assessments of skills required for the digital transformation.
- Support proper management and organisational structures in firms for digital innovation.
- Support wider involvement in innovation by disadvantaged groups, through engagement and training

According to the World Economic Forum's 2016 report on the Future of Jobs, the top three skills required for jobs in 2020 will be complex problem solving, critical thinking and creativity. Arts-infused learning, creativity, and an entrepreneurial mindset should be nurtured from school level to ensure that the next generation thrives in the unpredictable times ahead.

Postgraduate education at SETIs: The White Paper noted that there were unique facilities at the science councils which could be used for training and postgraduate education. The involvement of SETI staff or facilities in postgraduate education should be encouraged, provided that (to avoid competition with the universities) the following principles are observed:

- SETIs can offer postgraduate education and training only through formal agreements with universities or other tertiary level educational institutions.
- All staff operating costs related to research activities undertaken in the SETIs own facilities and involving postgraduate students must be borne by the regular budget of the SETI concerned, with the exception of payment of stipends for postgraduate students or salaries for academic faculty who are jointly supervising students (to be paid by the university or the National Research Foundation.
- Tertiary level education institutions involved in such agreements should grant the SETI staff involved an adjunct appointment at an appropriate academic level, and such staff should be eligible to receive additional remuneration from the institution involved for any activities (for example lecturing) which are additional to the normal duties of the SETI staff member as a researcher. Similar arrangements should be made for academic staff who take on additional duties on behalf of a SETI.

INTERNATIONAL COOPERATION

The African Union's Agenda 2063 is inspired by the desire to create a prosperous Africa, based on inclusive growth and sustainable development. It set several goals, including (a) well-educated citizens and a skills revolution underpinned by STI, and (b) transformed economies. Linked to these goals are priorities such as STI-driven manufacturing/industrialisation and value addition.

South Africa is expected to continue pursuing the Sustainable Development Goals (SDGs), and science, technology, and innovation are central to their achievement. Several initiatives have been implemented to enhance bilateral, multilateral and continental cooperation. Global trends in 4IR and societal challenges are receiving attention in most countries, and there is a possibility of identifying and advancing cross-country common interests in addressing similar research questions and following similar avenues. International cooperation makes even more sense when it comes to addressing common challenges, be they economic, societal or environmental. Important concerns include research cooperation and the development of consensus technical and ethical standards.

In developing the STI decadal plan, the following questions can be considered:

- What societal issues or research areas should be given priority when developing international cooperation?
- What are the main obstacles to strengthening international cooperation and how can these be addressed?
- How can new multilateral cooperation programmes be established, and existing ones be opened to more countries?

REGULATORY REFORM AND INNOVATION

State bureaucracy remains untransformed after centuries. Transforming and establishing an innovative bureacracy geared to serving the needs of people and improving their material conditions is an essential step of building South Africa as a developmental state and gaining people's trust and confidence in the state. There will be economic spin-offs as well.

Regulations are meant to ensure that all the actors within a certain ecosystem comply with a predefined set of rules, behaviours, and actions to ensure suitanability and benefit for all affected. On the other hand, regulations can be used to change the behaviour and actions of those being regulated. Different types of regulations exist, as is the case with various types of regulators. At government level, there are regulations from all spheres (i.e. national, provincial and local). Private regulations also exist for different types of organisations with similar interests.

A recent OECD study explored the diverse and complicated links between regulation and innovation. A motivation for this study was based on an observation that regulation and regulatory reform can affect technological development in all sectors ranging from biotechnology to banking, and can influence the innovation process from research through technology diffusion.

Some of the regulatory reforms suggested by the OECD in support of innovation include understanding of regulation and technology linkages (effects of technical change), the introduction of competition (competition among firms is essential to the innovation process), the removal of duplicate onerous and inefficient regulations, particularly to aid SMMEs, the use of technology-driven approaches (making use of regularatory approaches or alternatives which are technology-friendly, such as economic instruments, voluntary agreements and performance rather than design standards), and harmonisation with other international regulations to remove uncertainities, inefficiencies and market barriers which can slow innovation.

The Competition Act, 1998 (Act No. 89 of 1998), to some extent seeks to introduce competition and foster an innovation-friendly regulatory environment. In approving company mergers, the Competition Commission takes into account, among other factors, the promotion of innovation. However, the changes in the technological landscape through digitisation (the introduction of Uber in the South African market, the use of cryptocurrency by Facebook, etc.) calls for constant readaptation of the country's regulatory environment in a manner that promotes rather than inhibit these new technologies.

In most cases, regulatory experts encourage innovation to precede regulation as opposed to the other way around. This principle is important to allow innovators to build the supporting innovation-value chains unhindered, or to integrate seemlessly into the established ones without being blocked through the regulations. A culture of regulatory experimentation and evaluation is also important with regard to technological innovations.

INSTITUTIONAL LANDSCAPE

The development of the decadal plan must consider whether institutional architecture is appropriate for the White Paper objectives. A determination is required as to whether there are enough institutions, whether more need to be established, whether they are adequate to deliver on and oversee/steer STI programmes, and whether the mandates of the current institutions are suited to deliver on the White Paper objectives. Hopefully, the results of the Institutional Landscape Review will be available before the finalisation of the decadal plan.

Given that NSI underlines the White Paper, specific proposals are required to ensure that various institutions or agencies, at various levels, achieve complimentary in their functions and to achieve a coordinated impact by making the best use of the resources invested in them. In particular, greater clarification of the roles of various agencies is needed to sharpen their mandates and prevent the duplication of functions. Improved impact can be achieved if the efforts of specialist capacities in addressing complex challenges are coordinated. and expertise from all quarters of the system should be gathered in setting priorities and deploying resources. Stronger reciprocal channels of communication are needed, with more strategic evaluations of the performance of the system and its constituent agencies.

A key issue in the research-performing science councils is the governance arrangement introduced in 2004 with the Strategic Management Model (SMM) for public research organisations. Fragmentation and a distinct lack of systemic coherence are but two of the symptoms of dysfunction associated with the SMM. The tension between strategic autonomy and a government laboratory service role is not fully resolved. The SETI review system revives and recycles the unresolved problems, is unpopular, and is tending to run down because of lack of support. Therefore, this is one of the challenges that should be addressed in the process of developing the decadal plan.

CRITICAL SUCCESS FACTORS FOR THE DECADAL PLAN

One of the lessons learnt in the last 25 years is that the process of developing longer-term plans should include all key NSI actors from the beginning and its outcomes should be for society as a whole. This is important to secure buy-in and ensure that all sections of NSI and society at large take responsibility for making the plan a reality. The following critical success factors should be taken into consideration in the development of the decadal plan:

a. **Deeper levels of transformation:** As a catalyst for the eradication of silo mentality and re-engineering of government to function in a cohesive, coherent and coordinated manner necessary to achieve national imperatives especially the creation of an inclusive and sustainable economy and improvement of quality of life and well-being. In this regard, the recent reconfiguration of government structure should be welcomed as an important step. The amalgamation of the former Departments of Science and Technology and Higher Education and Training offers a new context and an opportunity to rethink the NSI, role, and functions of various actors (including new department). It is also critical to reflect on how best to improve decision-making from conception to execution. In others, the STI decadal plan will need to reimagine the STI policy process shifting from the periphery to centre of government wide policy and ultimately impacting the economic, environmental and societal outcomes.

b. **Focused leadership or leadership and responsibility throughout society.** Because the plan is designed to bring about a fundamental change in the long term, it requires a degree of policy consistency that straddles changes in leadership in government, business, and labour. Many aspects of the plan, like research itself, may require years of effort to deliver results. Policy changes should be approached cautiously and based on experience and evidence so that the country does not lose sight of its long-term objectives.

c. **A plan for all.** Broad support across society is needed for the successful implementation of the plan. In a vibrant democracy, this support is critical. Vigorous debate is essential for building consensus and broad-based ownership of the plan. Constructive debate will also contribute to nation building by enabling South Africans to develop a better understanding of STI issues and to take ownership of priorities. Different parts of the plan will require buy-in, resources, and efforts from different sectors. When there are disagreements, it is important that the reasons for these are debated and clearly explained, so that there can be broad consensus going forward. NACI could assist in bringing stakeholders together to facilitate dialogue and develop solutions.

d. **Resource mobilisation and agreement on trade-offs.** Investment in STI by both public and private sectors is far less than needed, which will make implementing the decadal plan difficult. The plan can shape resource allocation over the next decade or so, but it will not determine annual budgets. The best way to generate resources to implement the plan is to grow the economy faster. The first policy priority will be to raise the levels of funding and resources for STI with a strong focus on the business sector. It is important to recognise that the low rate of economic growth will also serve to discourage businesses from increasing investments in innovation. Policies to support and enhance business sector innovation are very necessary, but they are likely to have only limited success in the context of low economic growth. The further development of the NSI will, in all likelihood, remain constrained by the lack of finance and the resulting limited resources. It is critical to ensure that, whatever policy initiatives are adopted, they are adequately financed. The resources – both financial and human – that are required to develop or implement any policy initiative must be in place or forthcoming. South Africa has a severe shortage of skills, and acquiring the requisite skills is a major challenge, even when finance is available.

e. **Integrated planning, monitoring and evaluation, and funding.** One of the lessons learnt from the past 25 years is that the efficacy of policy depends on integrated planning, monitoring, evaluation, and funding. The STI decadal plan must be based on SMART indicators and targets and clear deliverable timelines. These should be informed by baseline data, and less guessing or gut feel. Where possible, responsible stakeholders should be identified. There should be a clear monitoring and evaluation framework. In this regard, the White Paper has assigned the development of systemic monitoring and evaluation to NACI. Finally, the cost implications of the STI Decadal plan should be determined in advance. Discussions with National Treasury and Department of Planning, Monitoring, and Evaluation will be encouraged prior to Cabinet approval of the Plan.

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