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A Holistic Barometer for Measuring the Impact of Science, Technology and Innovation in South Africa

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Abstract

In South Africa, adopting a paradigm of "Futuristic Science Engagement" is particularly important. It is about finding that intricate balance between hindsight, insight and foresight. In other words, such a paradigm can be synthesised through the combination of learnings from the past, accurate analysis of the present, and a holistic vision for the future. Indeed, the world is changing rapidly, evolving in real-time, partly due to the ingenuity and innovations of science practitioners. However, within the broader context of Science, Technology and Innovation (STI), there are *many* actors and agents, experts and laypeople alike, who feed into the country's National System of Innovation (NSI). Inputs into the NSI to cultivate and generate synergistic outputs include the political, economic, and social, over and above the STI aspects. This paper proposes a holistic barometer for measuring the impact of STI interventions. It argues that a synthesis of futuristic science, if defined as a convergence of hindsight, insight and foresight, requires an integrated approach that includes policy imperatives, socio-economic imperatives, epistemological imperatives, and ethical imperatives. To this end, the historical journey of South Africa's NSI, its policy frameworks, and its continental commitments based on African Union policies are traced as the hindsight component; the socio-economic status as well as South Africa's current standing in the 2023 Global Innovation Index (GII), are engaged to draw out relevant insights. Discourse on knowledge production that has contextual integrity, which speaks to the epistemological foundations of the system, as well as the role of the ethical in the era of a Fourth Industrial Revolution (4IR), are the foresight components to be considered.

Keywords: Policy; socio-economic; epistemological; ethical; STI; 4IR

Introduction

This paper seeks to address the theme of "Futuristic Science Engagement" by taking a "bird's-eye-view" macro approach to interrogate what the "futuristic" entails. The paper proposes a "hindsight-insight-foresight" paradigm for this interrogation, which is constituted of learnings from the past (hindsight), accurate analysis of the present (insight), and a holistic vision for the future (foresight). In the context of a world that is changing rapidly, evolving in real-time, due in part to the ingenuity and innovations of science practitioners, Science, Technology and Innovation (STI) is driven by many actors and agents, experts and laypeople alike, who feed into the country's National System of Innovation (NSI). The term "national system of innovation", according to Manzini (2012, p. 1), "is used to characterise a country's collective efforts towards fostering technological innovation. Since appearing in the 1996 White Paper on Science and Technology, the term has been used widely in South African policy discourses." There are numerous inputs that feed into the NSI, for example "institutions, policies, infrastructure, logistics, technology, culture, communications, marketing, knowledge production, business environment, entrepreneurship, intellectual property protection and information and communication technology connectivity" (Manzini, 2012, p. 5). They all provide a foundation and support structures for technological innovation that cultivates

and generates synergistic outputs. What has to be appreciated is that they include the political, economic, and social, over and above the STI aspects. In addition, Manzini (2012, p. 7) asserts that there are three fundamental aspects of the NSI: i) "The NSI comprises a network of interacting policies, institutions and organisations whose holistic functionality depends on the quality of co-operation between the various component parts"; ii) "The synergy of the interacting elements of the NSI brings about technological learning. Technological learning is the net improvement in the capacity of the NSI to innovate."; iii) "Globalisation, particularly as manifested in the expansion of the knowledge economy, has made it essential for nations to support technological innovation by creating supportive domestic institutional frameworks and macroeconomic environments; hence the evolution of the NSI."

Moreover, Manzini maintains that the concept has made the relationship between science and economic performance more explicit; it has demonstrated the need for coherence and integration of STI, and it has centred innovation in scientific efforts towards converting ideas into useful products and services. As such, the NSI is an integrated and holistic system, and in the context of this conference, this paper aims to propose a holistic barometer for measuring the overall impact of STI within the context of the NSI. The aim is to offer a lens through which hindsight, insight and foresight are synthesised through an integrated approach of four elements: policy imperatives, socio-economic imperatives, epistemological imperatives, and ethical imperatives.

To this end, the historical journey of South Africa's NSI, its policy frameworks, as well as its continental commitments based on African Union policies are traced as the hindsight component; the socio-economic status as well as South Africa's current standing in the 2023 Global Innovation Index (GII) are engaged to draw out relevant insights. Discourse on knowledge production that has contextual integrity, which speaks to the epistemological foundations of the system, as well as the role of the ethical in the era of a Fourth Industrial Revolution (4IR), are the foresight components to be considered. More specifically, the discussion will be divided into four sections, namely: policy imperatives, socio-economic imperatives, epistemological imperatives, and ethical imperatives.

With respect to the first section, the socio-political African and South African contexts will be analysed to understand the historical evolution of STI and the contemporary, as well as the present interventions that have been made based on past learnings. Regarding socio-economic imperatives, the 6th Administration has committed to economic transformation and job creation by positioning STI for the catalytic role of "stimulating sustainable and inclusive growth and competitiveness, productivity and job creation" (DSI, 2019a, p. 8). Analysis of the various strategies proposed by the government will be done. The epistemological imperative will be the subject of the third section, and given how vast this debate is, including for example, discourse around indigenous knowledge systems, decolonisation of knowledge and education, diversity, inclusivity and representation in STI, the discussion will be limited to reviews of the Indigenous Knowledge Systems Framework (2004) and the illuminating Clapperton Chakanetsa Mavhunga edited volume, *What do Science, Technology and Innovation Mean for Africa?* (2017), which we argue is a useful springboard for contemplating our future engagement with science. The ethical imperative speaks to South Africa's ethical orientation towards the 4IR, as it embraces the latest iteration of the world's evolution towards a more technologically-driven society that has to somehow remain humane and life-affirming. Considering the ethics around artificial intelligence, robotics, big-data, the cyberworld, the internet-of-things, and the future of work, among other advancements, requires foresight and anticipation of opportunities and threats, particularly those that directly impact people's lives. By employing analysis of relevant policy documents, academic literature and thought leadership, this paper hopes to synthesise the stated overarching paradigm that organises the minutiae of the NSI and STI in South Africa.

Policy Imperatives

My analysis of STI policy imperatives encompasses STI in Africa and STI in South Africa. The focus is on one continental policy document, the African Union's (AU) Science, Technology and Innovation Strategy for Africa (STISA-2024); and four South African pieces of policy and frameworks, namely, Ten-Year Innovation Plan (TYIP) (2008-2018), the Framework for the Science Technology and Innovation Decadal Plan (2019a), the White Paper on Science, Technology and Innovation Science (2019b), and the Decadal Plan (2022-2032). The rationale for selecting these pieces of policy is because at the continental level, the STISA-2024 is the highest level document on STI formulated by the AU; and from the South Africa policy perspective, the TYIP, the 2019 Framework and the 2019 White Paper inform the concrete implementation Decadal Plan. What should be borne in mind is that there are many other relevant

policies that could be included in the discussion. However, the ones identified are high-level and largely comprehensive. After briefly outlining the objectives and scope of each, I will offer a measured view from other scholars and myself on its contribution to the suggested "hindsight-insight-foresight" paradigm.

STI in Africa (STISA-2024)

The AU strategy for STI (STISA-2024) on the continent was developed in 2014, and it focuses on Africa's socio-economic development and growth towards a broader and long-term AU Agenda 2063. Its predecessor is Africa's Science and Technology Consolidated Plan of Action (CPA), launched in 2005. The AU Agenda 2023 charts the continent's growth, competitiveness, and path of economic transformation. The role of STI in Africa's development goals is engaged, and the STISA-2024 policy states that this could be achieved through new technologies and innovation in agriculture, energy, education, and health, among other sectors. To this end, the STISA-2024 is intended to impact critical sectors, which include "agriculture, energy, environment, health, infrastructure development, mining, security and water" (AU, 2014, p. 10). Its six priority areas are: "eradication of hunger and achieving food security; prevention and control of diseases; communication (physical and intellectual mobility); protection of our space; living together and building the society; and wealth creation." (AU, 2014, p. 10). Additionally, it has four pillars that are mutually reinforcing at continental, regional and national levels, namely: "building and/or upgrading research infrastructures; enhancing professional and technical competencies; promoting entrepreneurship and innovation; and providing an enabling environment for STI development in the African continent." (AU, 2014, p. 10). From a funding perspective, the AU Commission and the New Partnership for Africa's Development (NEPAD) Agency were envisaged to facilitate and coordinate resources for technical support while also mobilising public, private and donor resources for the coordinated implementation of national and regional programmes. The stated sectors and accompanying priorities and pillars have a broad reach, with a strong focus on the role of STI in the economy, particularly as a means of improving the quality of life for the continent's citizens, as well as the integration and funding of the implementation of the strategy at various levels.

Whereas the meaning of the acronym and term "STI" is taken for granted and adopted liberally throughout policy documents, Clark and Frost (2016), in their interesting article, "It's not STI: It's ITS - the Role of Science, Technology and Innovation (STI) in Africa's Development Strategy", critique the use of the term in its popular iteration. They challenge the notion that science and technology precede innovation, particularly in the African continent. They argue that the term STI "as a proxy for innovative activity in low-income countries is not only conceptually wrong, it is also misleading" (Clark & Frost, 2016, p. 3), as it implies the allocation of resources to scientific institutions at the expense of more pressing development and economic interventions. Their study analyses the Department for International Development (DFID) aid programme, which provides the empirical foundation for their conclusion. Moreover, Clark and Frost (2016, p. 4) contend that when innovation is defined according to Joseph Schumpeter's famous theory of innovation, which argues for more efficient ways to turn inputs into outputs; this conflates science and technology with innovation, and this is evidenced by popularity of inserting the innovation ("I") to create what appears to be the linked concept of "STI". They question: "Why has 'I' suddenly appeared after 'S' and 'T'? They are, after all, quite different concepts. In some cases, they are linked closely (say, in industries with a strong science base, such as pharmaceuticals), but much innovation has little to do with formal research and may indeed be only marginally linked to new technology?" (Clark & Frost, 2016, p. 4). This is an interesting deconstruction of an otherwise widely accepted term. However, when the complex position of Africa in the global scientific community is considered, many concepts cannot merely be accepted if they are found to be unsuitable in the context. However, simultaneously, Africa and its countries do not operate as silos, apart from the rest of the world. Thus, a measure of universalisation and internationalisation is required for its participation in global politics and economies in terms of STI. I engage this debate further in the epistemological imperative section of this paper.

Clark and Frost (2016, p. 4) also insist that the STISA-2024 is a flawed policy document "insofar as it relegates 'innovation' to a secondary category linked largely to expenditure on science", which appears to reinforce outdated stereotypes that "the only proper type of knowledge is that derived from research in laboratories." They suspect that some nefarious vested interests are at work, which promotes greater funding for science regardless of its utility. They point out that "Best Bet" projects were usually innovative activities that subsequently used technology as one part of a process that included many other inputs (Clark & Frost, 2016, p. 8). At times, the

science aspect of the projects had only a small R&D component within the context of a bigger value chain context.

They do not merely point out the conceptual problem with the "STI" term and paradigm but also suggest that the proper acronym should actually be: "ITS" (Clark & Frost, 2016, p. 12). By this, they mean that innovation policies should instead focus on mechanisms directly connected to economic production. As such, relevant institutions would be funded according to new incentives for conducting scientific research. Examples of this recommended approach would include "foreign technology acquisition, the use of national and international development banks and aid agencies, fiscal policies encouraging national private sector investments, and a revised role for higher education bodies to establish wider skills among young people, including entrepreneurship" (Clark & Frost, 2016, p. 11). Notwithstanding their critiques, they do not debunk the importance of good science, arguing that it will always be an input, where necessary, to economic development, but not by placing it at the centre of policy.

Clark and Frost are not the only scholars who critique the STISA-2024. Among others, Nordling (2014) conveys how the policy was received by some scientists who raised concerns about its proposal to prioritise research to drive economic and social development across the continent. This argument further reinforces Clark and Frost's contention about having science as the point of departure, with innovation towards tangible socio-economic benefit being relegated to a third step in the process. Nordling explains that critics view the strategy as a top-heavy administrative structure which lacks firm pledges that would make it effective. Another concern is that its aims go beyond the continent's limited resources, given the few financial commitments made towards it at the time of adoption.

Notwithstanding the criticisms against the STISA-2024, Nordling notes that it is still considered an improvement on Africa's Science and Technology Consolidated Plan of Action (CPA), its predecessor, launched in 2005 and adopted by the AU in 2006. Nordling mentions that the CPA failed to link with other Pan-African policies and fell short of raising the funds needed for its full implementation. She also cites John Mugabe, a technology-studies specialist at the University of Pretoria in South Africa, as one of the sceptics of the CPA. According to Nordling, the funding problem is something that Mugabe also predicts will be a problem for STISA-2024 due to the absence of financial commitments from African governments (Mugabe in Nordling, 2014, p. 453). Nordling explains that conversely to Mugabe, Daan du Toit, head of international co-operation and resources at South Africa's Department of Science and Technology, is more optimistic. Du Toit, she says, argues that "the CPA generated political support for science that paid off in the continent's successful bid to co-host the Square Kilometre Array, a US$2-billion radio telescope project being built in South Africa and Australia" (du Toit in Nordling, 2014, p. 453). As such, du Toit thinks that STISA-2024 will provide a similar political basis to build future partnerships because it provides the overall continental vision. The funding towards implementing STI policies on the continent appears to be consistently plagued by inadequate funding and insufficient fiscal commitments from its member countries. This aspect will be discussed in more detail in the section on the socio-economic imperatives, particularly the GII Report (2023).

From an implementation effectiveness and impact point of view, Kahn (2022) argues that while there is some evidence of the progress of STI policy in Africa, this tends to have greater rhetorical than operational outcomes. This raises concerns about African states' capability to attain the Sustainable Development Goals (SDGs) and secure their participation in the 4IR. Kahn (2022), like the previously mentioned scholars, also questions the role of 'science' as a key driver of Africa's post-independence modernisation. He also tracks the evolution of this advocacy for prioritising science. He finds that it dates back to the Organization of African Unity (OAU) Lagos Plan of Action (1980), where African governments were called upon to mobilise 1% of GDP towards building their scientific and technological capabilities. More than two decades later, the African Union Ministers' Conference 2003, captured in Africa's Science and Technology Consolidated Plan of Action (2005), reaffirmed this call and subsequently in the STISA-2024.

The role of STISA-2024 in my proposed paradigm is that it serves as a high-level document that has benefitted from the experience and hindsight of a post-colonial continent dating back to the OAU, the AU's predecessor. As is characteristic of high-level policies, they tend to be thin on concrete implementation strategies, which make them easy to adopt by, for example, each AU signatory, as they do not bind them in terms of measurable specifics.

STI in South Africa

In this section on the STI policy imperatives in South Africa, I examine how and if the country is faring better at a national level than at the continental level. As the continent's second-largest economy and, arguably, the leader in most of the STI indicators, it would be assumed that this is because the country is doing a better implementation in its context. An overview of South Africa's NSI and STI policies shed more light, as well as reviews from various NSI actors, government leaders and practitioners.

In his review of the book, "Innovation: Shaping South Africa through Science" (2015), Tim G.B. Hart (2016) asserts that the author, Sarah Wild, argues that prior to 1990, science, technology and innovation in South Africa was primarily focused on the military-industrial complex and labour-intensive commodity production. Wild's retrospective study is constituted of 30 concise articles that are derived from personal interviews and encounters over a decade. According to Hart, Wild highlights five areas of STI transformation and application: environment, energy, health, industry, and education. Whereas Hart (2016, p. 18) finds the book to have a positive outlook, his one criticism is that "it does not place much emphasis on how innovation in South Africa can tackle the three primary socio-economic challenges of inequality, poverty and unemployment - all of which have increased since 1994."

Hart also questions Wild's heavy focus on high-tech scientific solutions led by NSI actors while the poor are positioned as passive recipients. His concern is that Wild confines her analysis of this demographic to their uptake or adoption of innovations and scientific solutions while failing to indicate their ability to innovate in the broader sense of inventing and adapting. Effectively, Hart contends that what is necessary is matching the right solutions to specific problems, and such solutions may not necessarily be scientific or technical in nature. This appears to be a recurring concern when considering the scholars' previous critiques of the STISA-2024. As such, Hart finds that Wild's account of South Africa's retrospective STI journey and the hindsight it offers also tends to centre science and promote a high-tech paradigm. However, from a science centre context and in particular the scope of this conference, it could be argued that there is a need for more, and not less, focus on policies, strategies and funding towards R&D, high-tech, formal and informal STI education. From a hindsight perspective, a brief review of key policies in South Africa's STI landscape will arguably demonstrate more nuance and appreciation of the political, economic and social context within which the NSI needs to be deployed.

Review of Selected South African STI Policies

Ten-Year Innovation Plan (TYIP) (2008-2018)

The governmental review of South Africa's STI policies included an evaluation of the Ten-Year Innovation Plan (2008-2018), which was formulated with the goal of transformation towards a knowledge-based economy. It was also aimed at tackling specific societal grand challenges (SGCs) in the areas of life sciences and health, space science and technology, energy security, human and social dynamics, and a science and technology response to global change. Its main objectives were to inculcate innovation as a national competence, human capital development and knowledge generation, integrate science and technology across government and incorporate international relations and technology transfer strategies.

Framework for the Science Technology and Innovation Decadal Plan - Rising to the Challenge - 30 June 2019

The Framework for the Science Technology and Innovation Decadal Plan (2019) maintains that the period between 2014 and 2019 was characterised by critical reflection on science, technology, and innovation (STI) policy and policy implementation. This was towards a better understanding of the NSI and the role it would play in shaping the future of South Africa. To facilitate this process, the government and other NSI actors commissioned reviews of the White Paper on Science and Technology (1996), the National Research and Development Strategy (2002), and the Ten-Year Innovation Plan (2008-2018). Moreover, the NSI's performance was analysed in the first phase, and an STI institutional landscape review was conducted to inform a national STI foresight exercise looking towards 2030. Subsequently, the Cabinet developed and approved a new White Paper on STI in March 2019.

The conceptual framework for a new White Paper (2019) was informed by a number of conceptual kernels that would undergird the NSI as well as the knowledge and digital economy in a way that puts humanity at the centre rather than products and processes. To this

end, "Three Framings of Innovation Policy" by Schot and Steinmueller (2016) was employed as a heuristic tool to analyse and understand the necessary transition to new policies. Specifically, the argument by Schot and Steinmueller (2016) was adopted, holding that there are two established frames in contemporary innovation policy discussions. The first 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" (A. DSI, 2019, p. 4), which was adopted globally after World War II. The second frame, as per the authors, emerged in the 1980s in the context of globalisation and the need for competitiveness. The proposed approach was that STI policy should focus on building a national system of innovation "through links, clusters and networks, and on stimulating learning between elements in the systems, and enabling entrepreneurship" (A. DSI, 2019, p. 4).

In addition, Schot and Steinmueller argue that the third framing is "linked to contemporary social and environmental challenges such as the Sustainable Development Goals (SDGs)" and "transformative change" (DSI, 2019, p. 4). In this sense, transformation refers to prioritising "socio-technical system change as conceptualised in the sustainability transitions literature." Furthermore, Schot and Steinmueller (A. DST, 2019, p. 4) argue that "transformative change framing involves questioning how to use science and technology policy to meet social needs and [to] address the issues of sustainable and inclusive societies at a more fundamental level than previous framings or their associated ideologies and practices." As such, the transformative frame focuses 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 (DST, 2019a, p. 4). However, the authors concede that the transformative change framing does not necessarily replace the other two previous framings, as it is still underdeveloped. Nonetheless, the three framings tend to compete as frameworks formulated by policymakers, depending on their interpretation and understanding of the framings.

White Paper on Science, Technology and Innovation Science: Technology and Innovation Enabling Inclusive and Sustainable South African Development in a Changing World (2019)

The first White Paper on Science and Technology, adopted in 1996, informed South Africa's National System of Innovation (NSI), which was aimed at employing STI to overcome the legacy of apartheid. STIs are also identified as primary drivers of economic growth, job creation and socio-economic reform in the National Development Plan (NDP). More than two decades later, the White Paper on Science, Technology and Innovation Science (White Paper 2019) was developed after the review of its predecessor and associated policies.

In the recent White Paper (2019) foreword, former Minister of Science and Technology, Mmamoloko Kubayi asserts that the policy "emphasises the core themes of inclusivity, transformation, and partnerships" (B. DSI, 2019, p. i). In addition, it addresses "policy coherence, the development of human capabilities, knowledge expansion, innovation performance and increased investment," as it aims "to build on our successes and adopt new approaches where required, to foster an NSI in which creativity, learning and entrepreneurship can flourish" (DSI, 2019b, p. i). Furthermore, she states that the "White Paper will be implemented through a series of decadal plans, which will also be developed in partnership with the relevant role players in industry, academia, civil society and government" (DSI, 2019b, p. i). The Minister highlights that the advent of the 4IR has presented many opportunities and threats. As such, this technologically-driven new industrial era has necessitated a review of the NSI and associated policies and frameworks. The ultimate goal is for STI to play a more central role in re-industrialisation, modernising key economic sectors, making service delivery more efficient, and mitigating environmental degradation.

Director-General of the Department of Science and Technology, Dr Phil Mjwara, adds that the White Paper 2019 "sets the long-term policy direction for the South African government to ensure a growing role for science, technology and innovation in a more prosperous and inclusive society" (B. DSI, 2019, p. iii). It will do so by focusing "on using STI to help South Africa benefit from developments such as rapid technological advancement and geopolitical and demographic shifts, as well as responding to the threats associated with some of these global trends" (B. DST, 2019, p. iii). He also raises the significant changes brought on by the 4IR, which are also engaged in the White Paper.

The indicators to measure the achievement of the policy objectives expressed in the White Paper will be included in these decadal plans in order to realise the intended impacts of STI. This is "in terms of sustainable and inclusive development (as envisaged in the SDGs and the NDP), progress will be measured in inputs (e.g. investment in STI), outputs (e.g. increases in graduates, publications and patents) and outcomes (e.g. improved partnerships between NSI actors and increased policy coherence, yielding improved innovation performance)" (DST, 2019b, p. xiii).

Decadal Plan 2022-2032

After the review of South Africa's overall NSI, the NRDS (2002), the TYIP (2008-2018), and various other STI-related policies, the latest White Paper (2019) was drafted. However, from the learnings of its 1996 predecessor, it was found that a clear implementation plan had to be crafted, and this process gave rise to the Decadal Plan (2022-2032). At a Parliamentary Monitoring Group (PMG) session held on 31 August 2022, Mjwara presented the scope of the plan. He indicated that the Decadal Plan (2022-2032) is driven by four systemic enablers, namely the Science and Innovation Inter-Ministerial Committee (IMC), the Innovation Compact, the Strategic Management Model (SMM), and STI Public Budget Coordination. The STI Priorities identified to address the SGCs speak to climate change and sustainability; education, skills and the future of work; ICTs and Smart Systems; high-technology industrialisation; nutrition security; water security; health innovation; and sustainable energy. In addition, Mjwara specified four new sources of growth in the areas of circular (green) economy, digital economy, ICT-based applications, towards modernisation of mining, manufacturing, agriculture, and the creation of a hydrogen economy through a Hydrogen Valley. At the PMG session, it was indicated that the Cabinet had already approved the Decadal Plan, that the National Treasury had approved the intended STI budget coordination strategy, and that the plan would, going forward, be integrated into departmental Annual Performance Plans (APPs).

Subsequently, on 1 December 2023, Minister of Communications and Digital Technologies, Mr. Mondli Gungubele, announced that while the draft plan was approved in March 2021, the final Decadal Plan would take effect. Five thematic focus areas were highlighted by the Minister, which are the modernisation of agricultural, manufacturing and mining sectors; the exploitation of new sources of growth, particularly the digital and circular economies; conducting large research and innovation programmes in the areas of health and energy; utilising STI to support a capable state; and addressing three societal grand challenges, namely climate change and environmental sustainability, the future of education, skills development and work, and the future of society.

The Decadal Plan, as the implementation tool of the White Paper (2019), offers a systematic, integrated and coordinated approach to South Africa's NSI on the back of three decades of learnings derived from various pieces of policy. The introduction traces the development of South Africa's NSI by clustering it into three distinct periods: Development of the NSI through setting up institutions and policies to serve the interest of all of South Africa (1994-2005); ramping up the NSI's response to the demands of a democratic South Africa (2006-2018); and an increased focus on the NSI's contribution to socio-economic development, environmental sustainability and a capable state in the context of rapid technological change, social disruption and climate change.

The guiding values of the Decadal Plan are inclusivity, excellence, sustainability and entrepreneurship, which are, in turn, based on the principles of transformation, developmental responsiveness, partnering and efficiency. The envisaged long-term outcomes of the Decadal Plan are a productive NSI contributing to: "(a) economic growth and inclusivity; (b) social development; (c) environmental sustainability; (d) strong institutions, and (e) a capable state" (DSI, 2021, p. 17).

It is also informed by the 2020 Ministerial Review of the Higher Education, Science Technology and Innovation Institutional Landscape (HESTIIL). Furthermore, recently, under the Sixth Administration, the Department of Science and Technology (DST) became the Department of Science and Innovation (DSI), and the Department of Higher Education and Training (DHET) and the Department of Science and Innovation now report to one Ministry of Higher Education, Science and Innovation. This enables closer collaboration between the two departments and an improved coordination of STI and Post-School Education and Training (PSET) initiatives. The government is still held primarily responsible for the implementation of the Decadal Plan, which is envisaged to optimise synergies among STI-intensive government departments while being a thread throughout the rest of government through joint programming

and co-funding for STI priorities. There is also an imperative to maximise contributions from business, civil society, academia and STI-related investments and initiatives.

Socio-Economic Imperatives

Whole-of-Government and Whole-of-Society Approach

Regarding socio-economic imperatives, the STI Framework (2019) committed the 6th Administration to economic transformation and job creation, and this would be done by positioning STI for the catalytic role of "stimulating sustainable and inclusive growth and competitiveness, productivity and job creation" (DSI, 2019a, p. 8). When considering that the potential for STI to address South Africa's socio-economic challenges has not yet been fully realised, Mjwara (DSI, 2019b, p. iii) states that several policy shifts have been made in order to surmount the remaining challenges to STI policies. These interventions relate to a) Increasing the focus on inclusivity, transformation and linkages in the NSI; b) Enhancing the innovation culture in society and government; c) Improving policy coherence and budget coordination across government; d) Developing a more enabling environment for innovation; e) Developing local innovation systems; f) Supporting social and grassroots innovation; g) Expanding the research system; h) Developing human capabilities; i) Accelerating the implementation of the pan-African STI agenda; and j) Increasing investment in the NSI (DSI, 2019b, p. iii).

Interestingly, the STI Framework also speaks of a "compassionate" and more responsive STI system that balances 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" (DSI, 2019a, p. 9). The word "compassionate" evokes the idea of a system that is not merely clinical or technical but one that is based on social, economic and political justice. It is imperative that the NSI be further transformed to embrace a people-centred orientation that factors real human beings, their experiences and the better life that they all hope for while also being ecologically sensitive.

One strategic way of doing so is by forging innovative partnerships between government and business, with one of the indicators being the innovation of the business sector related to exports, measured by an increase in the number of exporting firms, new export products, and new export markets. In addition, one of South Africa's constraints, according to the framework, is the paucity and deployment of skills. With reference to the country's GII (2019), its lowest scores were in education (83) and tertiary education (87), with a World Bank (2018) report identifying the skills constraints as a major deterrent to innovation in general and to the vitality of the manufacturing sector. To address this deficiency, the STI framework recommends "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" (DSI, 2019a, p. 8) The Decadal Plan also integrates with the NDP 2023, setting STI priorities and thematic focus areas as mentioned in the PMG briefing (2022). Overall, it seeks to advance a whole-of-government and whole-of-society approach, which addresses some concerns about positioning science and R&D while neglecting innovation as the priority intervention in socio-economic challenges such as inequality, unemployment, and poverty.

Resistance to New Technologies

In the ambit of socio-economic imperatives, the issue of how STIs are embraced by a society is debated. The renowned Juma (2016) wrote a book on how technological innovations impacted socio-economics, titled, *Innovation and Its Enemies: Why People Resist New Technologies*", where he tackled the long-standing debate on the impact of artificial intelligence on technology and employment. In the abstract (Juma, 2016, Abstract) of the book, he makes a number of arguments. Firstly, the exponential advances in technology "signal both hope and fear, leading to public controversy." Secondly, his book explores the framing of the debates concerning new technologies based on the "risks to moral values, human health, and environmental safety." However, thirdly, he finds that behind these legitimate concerns lies deeper but unacknowledged socio-economic considerations, which include perceptions that "the benefits of new technologies will accrue only to small sections of society while the risks will be more widely distributed." This is largely due to the perception that innovations will threaten or alter cultural identities, which is a great source of social concern and technological contro-

versies. To address these concerns, Juma (2016, Abstract) draws on 600 years of technology history to identify "the tension between the need for innovation and the pressure to maintain continuity, social order, and stability as one of today's biggest policy challenges." As such, the book employs, fifthly, "lessons from history to contextualise contemporary debates surrounding technologies such as artificial intelligence, online learning, 3D printing, gene editing, robotics, drones, and renewable energy." The book encourages greater collaboration between public leaders and scientists, engineers, and entrepreneurs to manage technological change, for institutional adjustments, and for expanding public engagement on scientific and technological matters.

In his review of Juma's (2016) book, Mokyr (2017, p. 968) observes that while technological progress is considered by most as the main engine of economic growth, it is also a rather "untidy and highly non-linear historical process" and this is because "many old and bad ideas are retained for many years, even centuries, and many good ideas are rejected, resisted, maligned, and at times abandoned." Furthermore, Mokyr explains that resistance to new technologies usually has three major origins: "First, there are the incumbents who fear a threat to the stream of rents generated by their physical capital, human capital, market power, or political influence. Innovation inevitably disrupts such rents. Second, there is the concern about broader repercussions: innovations have unintended ripple effects on a host of social and political variables that may generate additional costs and pain to people even if they themselves have no direct say over whether to adopt the innovation. Beyond that, there is risk-and-loss loss aversion, the often well-founded fear that a new technique may have unanticipated and unknowable consequences. These three motives often merge and create powerful forces that use political power and persuasion to thwart innovations. As a result, technological progress does not follow a linear and neat trajectory. It is, as social constructionists have been trying to tell us for decades, a profoundly political process" (Mokyr 2017, p. 968). Notwithstanding these resistances, it appears that humanity has managed to overcome them because creative minds often seek out areas hospitable to these innovations. Thus, superior ideas tend to subsequently catch on.

Mbiza and Sinha (2023) enquire in their article whether the 4IR is merely a conceptual paradox or catalyst for achieving the Sustainable Development Goals, given its significance in South Africa from 2017, through advocacy, amongst others, by the University of Johannesburg and subsequently through the appointment of the Presidential Commission on 4IR. They observe that while the preceding industrial revolutions each focused on a single technology at a time, 4IR, on the other hand, "speaks to a confluence of technologies and a synergy of computing, data, and communications technology, with artificial intelligence rapidly redefining the world of work" (Mbiza & Sinha, 2023, p. 1). Despite the conceptual and geopolitical challenges and potential negative societal implications of 4IR, they argue that the 4IR paradigm shift is critical to South Africa and realising the Sustainable Development Goals (SDGs).

The authors trace the evolution of the respective global industrial revolutions: "The First Industrial Revolution occurred during the late 1700s and early 1800s and was characterised by the rise of steam-powered machinery and widespread utilisation of the power loom. The Second Industrial Revolution, from the late 1800s to the early 1900s, introduced mass production techniques and the widespread adoption of electricity. The Third Industrial Revolution during the latter half of the 1900s was propelled by advancements in computer and digital technologies. 4IR, conversely, is characterised by the convergence of multiple technological breakthroughs, particularly in AI and machine learning. It enables physical, digital, and biological systems to converge, leading to smart factories, integrated workflows and new lifestyles" (Mbiza & Sinha, 2023, p. 1). They find that the 4IR is significantly different from past industrial transformations because of the intricate combination of technologies that are involved in this iteration. As such, the 4IR is expected to impact people's lives significantly more than previous industrial revolutions.

Additionally, AI integration into several industries is anticipated to bring considerable benefits in terms of driving productivity and efficiency by augmenting repetitive tasks processing massive amounts of data and creating new fields such as data analysis and software engineering, as well as novel services on the product-service continuum. While doing so, Mbiza and Sinha (2023) highlight that the 4IR also facilitates rapid technological evolution, which presents a range of open questions in terms of conceptualisation and societal implications. These developments will provide novel solutions to existing problems while causing disruption. Hence, stakeholders must be prepared to navigate this complex dynamic going forward. In concert with the holistic "hindsight-insight-foresight" paradigm that this paper proposes, the authors call for proactivity in the areas of understanding the impact of technology on society; undertaking a multifaceted approach that considers its implications upon society; drawing on the insights of various disciplines and

stakeholders, such as governments, businesses, civil society; and the formulation of "an innovative framework for developing technology with an ethical underpinning which emphasises fairness, sustainability, and justice" (Mbiza & Sinha, 2023, p. 3). These remarks touch upon the four imperatives engaged in this paper towards a holistic measurement of the impact of STI.

Global Innovation Index Rankings 2023

The 2023 Global Innovation Index Rankings (GII), serve as a barometer in the context of innovation, which measures the fluctuations of countries based on particular indicators with social and economic implications. The current rankings situate South Africa as one of the top three innovation economies in the Sub-Saharan Region, together with Botswana and Senegal. According to the GII (2023), South Africa's performance is above expectation for its level of development, as it is considered one of the innovation overperformers in 2023, and it falls under the upper middle-income bracket, ranking at number 11 in the world, in this respect (WIPO, 2023, p. 56). This demonstrates that by many accounts, the country has been making strides since its initial White Paper commitments in 1996, with an overall global ranking of 59 and six years of innovation over-performance. The index also reveals that South Africa heads the region in knowledge and technology outputs as demonstrated by its performance in software spending (28), patents by origin (34), PCT patents (40), and valuation of its two unicorn companies (37) - Promosidar Holdings in the consumer and retail sectors; and Cell C in mobile and technologies sectors.

Seven specific innovation pillars inform the GII, which together are considered for the overall ranking. Firstly, South Africa's institutions take position 88 with respect to institutional, regulatory, and business environments. Human capital and research is at number 84 pertaining to education, tertiary education, research and development. Infrastructure is the third pillar, and at number 68, this is the ranking of information and communication technologies (ICTs), general infrastructure, and ecological sustainability. Fairing relatively competitively in market sophistication at number 45, the fourth pillar relates to credit, investment, trade, diversification and market scale. Business sophistication (61) is the fifth pillar and includes the performance of knowledge workers, knowledge impact, and knowledge diffusion. The sixth pillar of knowledge and technology outputs, at number 56, speaks to knowledge creation, impact, and diffusion. Finally, creative outputs of intangible assets, creative goods and services, and online creativity rank at 63.

Epistemological Imperatives

Indigenous Knowledge Systems Framework

In a study of indigenous knowledge systems (IKS) in South Africa and Australia and their implications for doctoral education, Keane, Raciti, van der Westhuizen, Motala, Stanton, Gilbey, Manathunga, Qi & Msimango (2023) found that IKS usually receives support for its integration into higher education, but amidst much tokenism. Keane et al., (2023) note that at a policy level, the DSI developed the Indigenous Knowledge Systems Framework in 2004 after engaging with stakeholders in science, technology, social development and across government departments. The policy aimed to recognise, affirm, develop, promote and protect IKS in South Africa, with the understanding that indigenous knowledge could enhance human understanding and well-being. IKS policy has four primary policy drivers: "the affirmation of African cultural values in the face of globalisation; the development of the services provided by traditional healers; promoting the contribution of indigenous knowledge to the economy; and interfacing with other knowledge systems" (Keane et al., 2023, p. 587).

Keane et al. (2023) highlight that Catherine Odora Hoppers (2001, 2002, 2014, 2015, 2016, 2021), UNISA SARCHI Chair in Development Education, has devoted two decades to studying cognitive justice, particularly in the academy, and this research has served two purposes: "to clarify concepts and theories of IKS as bases of Government IKS policy by the Department of Science and Technology and guide the implementation of IKS policy and contribute to setting the research agenda for transforming higher education—research as well as the science industry" (Keane et al., 2023, p. 586). One of the findings in this process by Odora Hoppers is that negative influences on African education have a dual source - firstly, the legacy of colonisation, and secondly, the current process of globalisation, which she argues is driven by individualism, indifference to others and competitiveness.

However, the authors also found that together with this transformation process, there was also the challenge to develop "appropriate protocols, codes of conduct and terms for any dialogue and integration" (Keane et al., 2023, p. 586). As such, "at a systems level, IKS require establishing an ethically sound and ecologically constituted way of thinking; affirming the multiplicity of worlds and forms of life; creating a shared paradigm shift of how we come to know; developing a self-reflexive praxis; establishing new evaluation criteria; and a transformation to new futures" (Keane et al., 2023, p. 586). This kind of transformation introduces an interesting concept - cognitive justice - which is prevalent in education, pedagogy and research. According to Odora Hoppers, Astrand and Van der Westhuizen (2016), cognitive justice challenges the "mono-epistemic world that modernity has created worldwide" and emphasises the "plurality of learning and knowledge creation and its dissemination", and the "consequences for the plurality of values, diversity, history, culture, creativity and fairness in society" (Keane et al., 2023, p. 587).

What Do Science, Technology, and Innovation Mean for Africa?

In terms of what the knowledge imperatives of STI in the country constitute, the groundbreaking book, *What Do Science, Technology, and Innovation Mean from Africa?* (2017), edited by Clapperton Chakanetsa Mavhunga, has elicited much engagement from scholars, scientists and industry. A sample of three book reviews (Grace, 2019; Emeagwali, 2017; Edward, 2018) offers some insight into what STI means for Africa. In Grace's (2019, p. 489) review, he raises Mavhunga's paradigmatic question: "Africa clearly needs histories and philosophies of technology, but which ones?" Grace subsequently asserts that the nine-chapter volume with contributions from interdisciplinary scholars provides compelling answers that span across the deep past to the present. The theme of the contributions engages the term "Intellectual Africa", which conveys the notion that we "should take Africans as intellectual agents whose perspectives constitute authoritative knowledge" (Grace, 2019, p. 489). This is an epistemological claim that touches on prevalent calls for decolonisation of knowledge production. As such, notes Grace, for "Mavhunga, this means scholars should not only emphasise the ability of African societies to actively appropriate, make, and remake the 'white' tools and ideas most readily associated with science, technology, and innovation (STI) in Western scholarship" (Grace, 2019, p. 489). Further engagement with the term, according to Grace, emphasises the "from Africa" in the title, which serves two purposes. Firstly, it "provides an opportunity to reframe the definition and constitution of STI, in scholarship and in policy" (Grace, 2019, p. 489), which speaks to the dilemma of knowledge production in Africa, that tends to formalise and centre structures, practices, and concepts that are European, while informalising African equivalents. The challenge is to "combat narrow Eurocentric definitions of STI — and their privileging of northern spaces, timelines, and ontologies" in order to "reconceptualise familiar terms and stories from deeper historical perspectives, from an era before societies from the Global North made monopolistic claims upon science, technology, and innovation" (Grace, 2019, p. 489). The second purpose of the term "Intellectual Africa" is to encourage a move beyond critiquing Western narratives, and to instead focus on writing, researching, theorising and planning from what Mavhunga refers to as "African self-perception" perspective, without seeking external validation. Grace argues that this purpose is the book's most important contribution. In this respect, the narrative of "Africa rising", which positions the "continent's societies as relevant knowledge communities only when they adopt the tools and institutions deemed important by foreign modernisers and African elites", is debunked (Grace, 2019, p. 489). Conventional definitions of STI are challenged, new conceptual models are proposed, and the histories of science and technology on the continent are foregrounded.

In her review of the Mavhunga edited volume, Emeagwali (2017, p. 258) adds that "Eurocentric assumptions about the history of science and technology, entrepreneurship, epistemology, and scientific methodology are directly challenged in this scholarly collection of essays that masterfully document the historical and contemporary scientific contributions of Africans". She highlights that the book is a substantial departure from conventional accounts of STI as it challenges the West's definition of science in its own image "at the expense of generations of makers and innovators around the world" (Emeagwali, 2017, p. 258), while not acknowledging multi-directional knowledge transfers throughout history. Mavhunga maintains that the story of STI in Africa is one of resilience and creativity, and this is, for example, characterised by the cultivation of expertise from a wide spectrum of contributors such as "healers, metallurgists, computer gurus, and musicians" (Emeagwali, 2017, p. 258). As such, innovation does not stem exclusively from laboratories.

Edward (2018) concurs with Grace (2019) and Emeagwali (2017) in his review of the book, insisting that STI in Africa has been

characterised by mono-disciplinarity, where economists predominantly, are more concerned with how African economies should modernise and benefit by importing technology from outside the continent. The problem with this approach, argues Edward (2018), is the continent has deteriorated from the imported technologies thus entrenching post-colonial relations between the Global North and South. He, like Mavhunga, questions the emphasis on Schumpeterian innovation frames of technology which undermine the societal component and he argues that the Schumpetarian analysis arguably "fits better in the Global North and its industrial economies than in African socio-economic contexts" (Edward, 2018, p. 815). Edward asserts that the book examines the epistemological foundations of African STI through theories, methods and analytical tools that "support the premise that African STI should employ unique methodologies and philosophies because it stems from different historical, social, spatial, economic, and epistemological foundations" (Edward, 2018, p. 815).

Whereas Edward (2018) is of the opinion that Mavhunga's edition is correct in critiquing the methodological poverty of several STI works, he also reserves his own criticism for the volume. He finds that "the critique does not provide a sophisticated and detailed discussion of alternative methods and theories to readers" because the argument for the revolutionising of "colonial" theories of knowledge in order to employ "novel ones", paradoxically, reduces the complexity and diversity of Africa (Edward, 2018, p. 815). Edward advocates that STI research, writing, and debates by Africanists should be encouraged and should elaborate and produce executable policies. These critiques are indeed a challenge to decolonial theory in general, as they recognise the significance of the epistemological imperative for the African continent, which is the deconstructive aspect of the process. However, they also call for a pragmatic and practical approach to the SGCs that harnesses what is useful without ideological limitations toward the reconstruction of a holistic future.

Moreover, Dosso, Cassi & Mescheba (2023) advocate regional scientific integration as a critical pathway for the development of an integrated African research area and knowledge-based society. They observe that progress in scientific production has largely been led by a global or international agenda due to high-level policy commitments, benefitting only a few top publishing nations. The study thus "builds upon the proximity approach to analyse the determinants of scientific collaboration between African countries, using co-publications data from Thomson Reuters' Web of Science database as a proxy of such collaboration" (Dosso et al., 2023, p. 1). Their findings indicate that "the majority of African regional economic communities (RECs) have not yet had a significant effect on scientific co-publication" (Dosso et al., 2023, p. 1). The indicators for potential success in this respect are, for example, shared ethnical language, membership in the African and Malagasy Council for Higher Education (CAMES), and a common European partner as a third partner in co-publication. Dosso et al. (2023: 7) highlight the correlation between common colonial heritage, which is higher (0.57) than that of ethnical language (0.4). This means that colonial heritage plays a larger role in fostering collaborations than ethnical heritage and language. However, there is also a decreasing trend in geographical proximity as a prerequisite for African collaboration, which offers promise of increased integration and intensification of collaboration networks, whether based on colonial ties or ethnical language (Dosso et al., 2023:10). The authors' recommendation is the development of an Africa-wide research area to leverage existing and emerging regional excellence networks and novel coordination models to accelerate the process of scientific integration in Africa.

Ethical Imperatives

Africa, STI and the Fourth Industrial Revolution

Regarding the ethical imperative that informs this paper's hindsight-insight-foresight measurement barometer, Bassey (2019, p. 116) makes a case for the "precautionary principle" as Africa intensifies its STI drive, arguing that "the balance of nature needs to trump the immediate profit of innovation." Specifically, this means that while technology gains traction in Africa, there should be caution with potentially reviving old stereotypes about the continent, colonisation-type hegemonic dynamics, and the eruption of social conflicts due to profits and corporate interests preceding the interests of people and the environment. Bassey promotes a "right to life" principle where Africa will not become the dumping ground for risky or obsolete technologies. This right to life requires, according to Bassey (2019, p. 120), "the enforcement of the precautionary principle on all technologies - be they for energy or genetic manipulations." This means that "new technologies and innovations must be subject to adequate tests and regulations because it is better to err

on caution than to proceed in a way that can lead to cataclysmic incidents" Bassey (2019, p. 120). Here, Bassey is referring to 4IR-related technologies that are employed as interventions to address various socio-economic challenges. Further to Bassey's precautionary principle, this section is devoted to discussing the ethical imperatives and implications of the 4IR and how this imperative is also a component of this paper's proposed holistic barometer for measuring STI impacts.

Gwagwa, Kazim & Hilliard (2022) engage the role of the African ethic of Ubuntu in global AI inclusion discourse, and they propose a normative ethics perspective in this respect. They find that while other global and regional blocks have progressively been formulating ethical guidelines and principles, or AI ethics forums, Africa seems to be far behind in this process. To address this vacuum, they recommend that the African relational approach of Ubuntu should be considered in devising frameworks that assist with the implementation of values such as justice, fairness, and solidarity in this 4IR era. Examples of the tangible principles that could be formulated are offered by the authors, which include "guidance on reconciling competing and often conflicting cultural values and ethical dilemmas in AI design, development, and audits" (Gwagwa et al., 2022, p. 1). However, the authors caution that Ubuntu, which proposes moral and ethical principles that advance harmony and consensus, can only play a key role in the conception of ethics that encompasses broader social and political themes when not overshadowed by the current domination of discourse by the Global North. This concern speaks to the epistemological imperative discussed in the previous section. They maintain that such an approach would broaden the ethics discourse and allow emerging technologies' psychological, social, and political impact to be assessed holistically. However, they argue that that could "only have an impact if forums are created for interdisciplinary discourses between policymakers, technologists, ethicists, and philosophers to ensure that the African context is being considered in their work" (Gwagwa et al., 2022, p. 1).

Related to this interdisciplinarity that Gwagwa et al. raise, in an illuminating article titled "Science vs Philosophy" (2021), written by Ehtesham Shahid for the *Khaleej Times* media platform, he interviews several philosophers throughout the world, who help to support this paper's proposal for a holistic barometer for measuring the impact of STI. In the article, Slovenian philosopher and psychoanalyst Slavoj Zižek calls for collaboration between scientists and philosophers towards asking the big metaphysical questions about what reality truly is to surmount the era of relativism that seems to have taken hold. In Zižek's opinion, "scientific advancements of recent decades present the picture of a rudderless ship with little control." This concern is about (western) science taking on a hegemonic role that monopolises the domain of "knowledge" to exclude other disciplines and the dimensions that add to a more holistic discourse about what societal progress truly means.

Further to the supposed monopoly of science, Shahid (2021) cites Lou Marinoff, an American philosopher, who raises the issue of political correctness in the article and whose view is that "the more questions science answers, the more it raises." Because even as science succeeds in establishing reliable knowledge, it is still "subject to modification or revision by subsequent discoveries." The danger here, Marinoff maintains, is that "today's science runs the risk of becoming tomorrow's fiction," and so, "one often needs to go back to philosophy to find context." At a practical level, he also points out that "accelerating developments in computer science and information technology raise philosophical questions across a spectrum of global issues, ranging from identifying ethical versus unethical harvesting and reselling personal data to constructing moral compasses that govern machines in their increasing contact with humans."

The unfortunate underbelly of this process is that while business, for example, will drive technological and cultural evolution, without the requisite moral compass, as much harm can be done as good. South African philosopher Sarah Setlaelo argues that this moral compass is derived from philosophy more than science. She asserts that "science needs philosophy to critically examine its foundations, assumptions, aesthetics, and ethics." This is because "science is fundamentally descriptive or factual, whereas philosophy is speculative and often normative or judgemental." Therefore, argues Setlaelo, this "suggests a symbiotic relationship instead of a zero-sum game" given that "progress in science often raises philosophical questions that bear ethical, epistemological, and metaphysical implications."

In the article (2021), German philosopher Benedict Beckeld is concerned about the lack of tolerance for alternatives when appeals to "science" become a way of excluding that with which one disagrees. He cites the example of the Covid-19 restrictions global debate, where some argued that "science" requires lockdowns or forced vaccinations in order to address the pandemic. He finds that such pol-

icy choices are, in fact, philosophical and not scientific. Marinoff adds to the hindsight evaluation of Covid-19 policies as an example of how opposing politicians could describe mutually contradictory policies as "following the science", leading to unilateral policies, where "even the well-educated laypersons could not assess what was 'scientific' versus unscientific."

Shahid concludes the article with the note that "both scientists and technologists, along with the cadres of their consumers, can benefit from philosophical inquiry and dialogue with philosophers." He quotes Marinoff again to summarise the science vs philosophy debate as follows: "By safeguarding the foundations of education, reading, writing, and reasoning, philosophy's fingers are plugging the failing dikes, helping to forestall a deluge of delusion and an inundation of ignorance unrivalled since the Dark Ages descended on Europe following the collapse of the Western Roman Empire."

Whereas Marinoff calls for a forestalling of the "Dark Ages", Africa is entering an enlightenment period that requires the synergistic co-operation of scientists, artists, politicians, business and industry, and the youth. This paper is a contribution of a holistic understanding of the policy-governed past that we are emerging from and the foresight of the future that will help Africa, and South Africa specifically, address multidimensional challenges that colonial history and the legacy of apartheid have caused. However, regarding where we are, it is a synthesis of hindsight and foresight that could yield the insights we need to re-look, re-construct, and revitalise our NSI, STI and 4IR efforts.

South Africa, STI and the Fourth Industrial Revolution

South Africa has embraced the Fourth Industrial Revolution (4IR) by, among other commitments, establishing the Presidential Commission on 4IR and ensuring that it features prominently in the 2019 White Paper on STI. According to the STI Framework (2019), the "4IR is seen as radical and disruptive technological change that will impact on production and quality of life across the world" (DSI, 2019a, p. 2). At a more philosophical level, the 2019 Framework considers 4IR as humanity's effort to identify and develop tools that augment their constraints or limitations. However, as with all evolutionary progressions, the 4IR has advantages and disadvantages. While it will create new jobs, it will simultaneously render others obsolete. Thus, the intricate balance going forward will ensure no wholesale destruction of old institutions in attempts to establish new ones. Concurrently, with increasing reliance on new technologies to improve quality of life, this very life should not be placed in the path of danger, so to speak, due to unethical practices that compromise human well-being.

One of the stated values in the Framework (2019) is that, while it is "explicit about Artificial Intelligence, the issue of principles will be an important consideration in the decadal plan" (A. DSI, 2019, p. 2). As a result of this value, the G20 countries, of which South Africa is a member, adopted human-centred AI principles that are in turn inspired by the Organisation for Economic Co-operation and Development (OECD) AI Principles. The OECD is an international organisation that works with governments, policymakers and citizens to establish evidence-based international standards and find solutions to a range of social, economic and environmental challenges. Specific to the 4IR, the OECH AI Principles 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 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).

These are self-explanatory principles. However, the tension between technological disruption and progress and a human-centred approach is a constant struggle that requires monitoring to ensure that a line that cannot be redrawn is not crossed. Given that our concerns in this conference are on the scientific aspects of 4IR, which tends to fall under STI-specific disciplines, ethics are an area in which the humanities or arts could be incorporated. As such, the "A" in the "STEAM" acronym could arguably represent the ethical imperatives.

Conclusion

This paper contributes to a holistic understanding of the policy-governed past that we are emerging from, the foresight into the future that will help Africa, and in particular South Africa, address multidimensional challenges that colonial history and the legacy of apartheid have caused. However, in terms of the present, it is a synthesis of hindsight and foresight that combine to produce insights we need to re-look, re-construct, and revitalise our NSI, STI and 4IR efforts. The paper proposes a simple (yet hopefully not simplistic) barometer for measuring the impact of science, technology and innovation interventions in South Africa. To this end, the paper claims that at least four categories of imperatives should be considered - policy imperatives, socio-economic imperatives, epistemological imperatives and ethical imperatives. These imperatives are usually considered and factored in STI research, development and policy. However, this paper sought to extract and organise them in a way that offers a "bird's eye view" of what we need to measure the impact of the country's NSI efforts at the macro continental, national, disciplinary and micro science centre levels.

In the first section on policy imperatives, firstly, in terms of the African context, the African Union's (AU) Science, Technology and Innovation Strategy for Africa (STISA-2024) was discussed as it represents policy at a continental and regional level. Regarding specific policy imperatives of South Africa, four pieces of policy and frameworks, namely, the Ten-Year Innovation Plan (TYIP) (2008-2018), the Framework for the Science Technology and Innovation Decadal Plan (2019), the White Paper on Science, Technology and Innovation Science (2019), and the Decadal Plan (2022-2032) were engaged as cornerstones of the country's NSI.

The socio-economic imperatives were the second component that essentially speaks to the UN Sustainable Development Goals at an international level; addressing the Societal Grand Challenges at the continental level; and incorporating the National Development Plan 2023, as well as South Africa's current ranking in the Global Innovation Index (2023). All these policies address the human and economic subject, who is the proposed beneficiary of STI, within the larger context of the 4IR, offering insight into the status quo.

The third section on the epistemological imperative touched briefly on a broad debate about the decolonisation of knowledge and knowledge production; as well as the incorporation of Indigenous Knowledge Systems that have contextual integrity, towards a vision for the future. Together with the epistemological imperatives, the ethical imperatives discussed in the fourth section speak to the kind of foresight that all agents of the NSI need to harness in order to pre-empt and mitigate threats while creating an ethical, morally responsive and humane future society.

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