NATIONAL ADVISORY COUNCIL ON INNOVATION

Towards the Next-generation Science and Technology White Paper for South Africa: Innovation for Transformative Change and Inclusive Development Situational Analysis

A Discussion Document of the National Advisory Council on Innovation

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Executive Summary

The Minister of Science and Technology requested the National Council on Innovation (NACI) to review progress in the National System of Innovation (NSI) since the publication of the White Paper on Science and Technology (WPS&T) in 1996 and to generate inputs for the development of a Next-Generation White Paper on Science and Technology in 2017 and a Science, Technology and Innovation Decadal Plan in 2018.

This document is a contribution to the formulation of the Next-Generation White Paper on Science and Technology. It presents a situational analysis of the contemporary conjuncture, identifying global and local trends that influence society, the economy and the governance landscape. Specific attention is paid to ecological challenges, the role of social innovation, and the demands for the 'decolonisation' of higher education and training in South Africa. These latter aspects were found wanting in the original White Paper on Science and Technology.

The specific terms of reference for the situational analysis have been refined and reworked through a consultative process between the NACI Secretariat and experts appointed by NACI, and in multiple engagements with both a task team of NACI and external advisors appointed by NACI. The experts also engaged in discussions with the senior management of the Department of Science and Technology (DST), and participated in a stakeholder workshop organised by the NACI Secretariat.

While use was primarily made of existing data, information and knowledge, it became necessary to commission a Science, Technology and Innovation (STI) Megatrends Foresight Report. The STI Megatrends Foresight Report was conducted by a team based at the Higher School for Economics in Moscow, Russia, and is incorporated into the narrative of this situational analysis. Feedback received from the various stakeholder and role-player engagements have ultimately contributed to the structure of this version of the situational analysis.

It comprises six sections. The first section provides a background to the situational analysis. This is followed by an overview of the methodological outline, a discussion of the shaping of the contemporary global conjuncture, the periodising of South Africa's transitions and transformations, and highlights of the STI Megatrends Foresight Report. The situational analysis concludes with points to consider in developing a Next-Generation White Paper on Science and Technology.

The situational analysis provides a deep, yet succinct narrative of the global and domestic forces that shape our contemporary conjuncture. In developing such a historically contextualised account of the current situation, this analysis draws on mixed social science methodologies from across the disciplines of anthropology, history, philosophy, political economy and sociology.

The shaping of the contemporary global conjuncture considers the accelerated impacts of human activities on the environment that result in a growing awareness of the objective biophysical limits to economic growth (as currently framed), the earth system's planetary boundaries, the emergent discourses on sustainable development and the framing of a universal set of goals, the Sustainable Development Goals (SDGs) of the United Nations (UN), which aim for the realisation of a future for all humanity. These components of the objective features of our contemporary conjuncture pay particular attention to their implications for science, technology and innovation.

An aspect that was also considered was the need for transformative change as a means to redress the economic, environmental and social challenges of the UN Agenda for Sustainable Development. Some of the novel variations in innovation that would help constitute transformative change include policy innovation, institutional innovation, social innovation, technological innovation and conceptual innovation. The Next-Generation White Paper on Science and Technology would, therefore, be enhanced by the utilisation of a wider range of interpretations that transcend the narrower research and development-based linear paradigm that continues to haunt South Africa's application of the concept of innovation.

Furthermore, the situational analysis considered the African Union's Science, Technology and Innovation Strategy for Africa, and the emergence of Brazil, Russia, India, China and South Africa (BRICS) and the possibilities of alternative geopolitical developmental perspectives.

Moving from the global to the local, the situational analysis proceeds to periodise South Africa's socio-economic and political history. Its various transitions and the country's transformative journey are considered across a historical span of time, reaching back approximately to the end of the last glacial period and the beginning of the Holocene, through Pre-colonial southern Africa, Colonisation, the Post-colonial period and Post-apartheid South Africa.

Attention is also paid to the relationship between ideology, politics and the mode of production. Some of the revolutionary transitions that were induced to accelerate the processes of change over time include those that consider the political economy, the dominant ideology, the governance framework, and macro- and micro-economic politics.

It is noted that our current conjuncture reflects our historical past and contemporary challenges, and obscures progressive possibilities in our emergent futures. Contemporised with the rise in environmental degradation is the expansion of world systems that largely represent a variety of capitalist formats through which globalisation has engendered an integrated, interdependent and hierarchical international economic order.

This section concludes with a critical analysis of the various efforts at reconstruction and development advanced by the democratic government since 1994, and which culminated in the forging of a National Development Plan and an elaboration of its Vision 2030 in 2012. It also considers multilateral climate change agreements and constraints on policy sovereignty, which impact on the development of a Next-Generation White Paper on Science and Technology.

The STI Megatrends Foresight Report provides global megatrends in science, technology and innovation, which could impact on the country's future development. By developing trends, it becomes possible to identify certain trajectories into various possible future scenarios. This renders the Foresight Report an invaluable supportive policy-determining tool in the NSI.

Key changes that can be anticipated to affect the development of a new White Paper relate to the bio-economy and food security, climate change and energy, social cohesion, safety and security, space sciences, engineering and services, and water resources and sustainability.

The situational analysis is concluded by drawing together emergent issues that require policy attention in the Next-Generation White Paper on Science and Technology and in the Science, Technology and in the Innovation Decadal Plan. These issues include the following:

- The emergence of the concept of 'post-truth'. These are circumstances in which the objective facts are less influential in shaping public opinion compared to appeals to emotion and personal belief.

- The celebration in 2016 of the 20th anniversary of the adoption of South Africa's White Paper on Science and Technology. This provides the vantage point upon which this situational analysis is premised, which makes it necessary to revisit the epistemological influences on the White Paper on Science and Technology and to update the empirically determined contextual factors that shaped its orientation and form.

- The profound impacts that are generated by the combination of individual cognitive capacities for social learning, our scientific and technological capabilities for transforming our ideas into methods and tools, and our innovative competencies in sharing our knowledge across society and generations.

- Recognition of the fact that South Africa requires a dynamic innovation engine if it were to seriously seek to ensure that it is to redress the legacies of apartheid, decolonise the science, technology and innovation institutional landscape, and ensure a better life for all.

- The need for a more intense examination of the relevance and appropriateness of the science, technology and innovation institutional landscape if it is to succeed in identifying the gaps in coverage and the levels of interlinkages and societal participation, especially in determining investment priorities.

- The call in the National Development Plan for two major transformations of the NSI in South Africa. Firstly, for a larger, more effective innovation system that is closely aligned with enterprises that operate in sectors that are consistent with the growth strategy. Secondly, for consideration to be paid to widening the system of innovation to ensure greater linkages between universities, science councils and other research and development role players in priority areas of the economy.

- Recognition that the enormity of the ecological challenges poses problems associated with maintaining our survival as a species on the planet. The Next-Generation White Paper on Science and Technology would need to pay attention to the ways in which local policy sovereignty is curbed and constrained by the various multilateral and international regimes that have emerged, and which all derive from science and technology competencies.

The necessity, nearly two decades later, to consider the establishment of a new social accord for science, technology and innovation between the citizens of South Africa and the role players that constitute the country's NSI.

The presentation of selected megatrends in science, technology and innovation, together with aspects related to transformative change and inclusive development, illustrates the proliferation of new and emerging opportunities over the medium- to long-term planning horizons, which need to be considered in the development of a Next-Generation White Paper on Science and Technology and in the Science, Technology and Innovation Decadal Plan. It also supports the idea of embedding a permanent Science and Technology Foresight competency within the NSI.

1. Background

1.1 The Minister of Science and Technology requested the National Council on Innovation (NACI) to review progress in the National System of Innovation (NSI) since the publication of the White Paper on Science and Technology (WPS&T) in 1996 and to generate inputs for the development of a Next-generation WPS&T (NWPS&T) in 2017 and a Science, Technology and Innovation (STI) Decadal Plan in 2018. This document is a contribution to the formulation of the NWPS&T. It presents a situational analysis of the contemporary conjuncture, identifying global and local trends that influence society, the economy and the governance landscape. Specific attention is paid to ecological challenges, the role of social innovation, and the demands for the 'decolonisation' of higher education and training in South Africa. These latter aspects were found wanting in the original WPS&T.

1.2 The specific terms of reference for the situational analysis have been refined and reworked through a consultative process between the NACI Secretariat and experts appointed by NACI, and in multiple engagements with both a task team of NACI and external advisors appointed by NACI. The experts also engaged in discussions with Department of Science and Technology (DST) senior management, and participated in a stakeholder workshop organised by the NACI Secretariat. While use was primarily made of existing data, information and knowledge, it became necessary to commission an STI Megatrends Foresight Report. The STI Megatrends Foresight Report was conducted by a team based at the Higher School for Economics in Moscow, Russia, and is incorporated into the narrative of this situational analysis. Feedback received from the various stakeholder and role-player engagements has ultimately contributed to the structure of this version of the situational analysis, which comprises six sections.

1.3 Following this Background, Section 2 provides a brief methodological overview, which covers the theoretical basis for the construction of the situational analysis. Section 3 provides a broad and deep narrative account of the shaping of the contemporary world system. Included as subsections to this section are the accelerated impacts of human activities on the environment that result in a growing awareness of the objective biophysical limits to economic growth (as currently framed), the earth system's planetary boundaries, the emergent discourses on sustainable development and the framing of a universal set of goals, the Sustainable Development Goals (SDGs) of the UN, which aim for the realisation of a future for all humanity. These components of the objective features of our contemporary conjuncture pay particular attention to their implications for STI. Moving from the global to the local, Section 4 periodises the socio-economic and political history of South Africa. South Africa's various transitions and the country's transformative journey are considered across a historical span of time, reaching back approximately to the end of the last glacial period and the beginning of the Holocene[1]. The reasons why attention is devoted to introducing elements of the long durée into our narrative of the history of STI in southern Africa are to be found in the emerging consensus that the history of the territory and its peoples have, for far too long, been limited to events following the arrival of European settlers and their colonisation of southern Africa in the mid-17th century. Because of the consequent power dynamics forged in the creation of the Union, then the Republic of South Africa (RSA), the telling

1 This is the term used to indicate our current geological time at the time of the development of the WPS&T. Dating back to approximately 11 700 years ago, the geological epoch contained the history of human beings during the Palaeolithic, Mesolithic and Neolithic Ages. Subsequent discussions within the International Commission on Stratigraphy of the International Union of Geological Sciences has seen the introduction of a break in this time series to accommodate global changes caused by human activity. This change is resulting in the truncation of the Holocene into the Anthropocene Epoch.

of history has been orientated along a false narrative that started in 1652 and continued across colonial, post-colonial and neo-colonial times, becoming normative and epistemologically hegemonic.

1.4 This situational analysis eschews that dominant narrative account. Rather, it locates the historical evolution of southern Africa in general, and South Africa in particular, within a longer time span. The objective in utilising such a long durée has been to specify the rupture in development induced by the capture of the territory from its indigenous population. It also seeks to recognise that the struggles of those subjugated must be acknowledged as critical to the formation of the contemporary dispensation. In other words, the narrative account of South Africa's evolutionary development is rendered as a dynamic of contestation and crises. The periodisation runs from the Late Palaeolithic Era (approximately 12 000 years ago) until the submission by South Africa of its intended nationally determined contribution (INDC) to the UN Framework Convention on Climate Change (UNFCCC) on 1 November 2016. This narrative also provides a critical analysis of the various efforts at reconstruction and development advanced by the democratic government since 1994, and which reaches its nadir in the forging of a National Development Plan (NDP) and an elaboration of its Vision 2030 in 2012. Section 5 presents global STI megatrends, which could impact on the country's future development. Section 6 concludes the situational analysis by drawing together emergent issues that require policy attention in the NWPS&T and in the STI Decadal Plan.

2. Methodological outline

2.1 This situational analysis provides a deep, yet succinct narrative of the global and domestic forces that shape our contemporary conjuncture. In developing such a historically contextualised account of the current situation, this analysis draws upon mixed social science methodologies from across the disciplines of anthropology, history, philosophy, political economy and sociology. Critical to this situational analysis is the concept of the conjuncture. While noting that the use of conjuncture was largely established in the work of Marx (1857, amongst others), earlier antecedents include Khaldun (1377) and Machiavelli (1513 and 1517). Subsequent iterations and variations have resulted in a wide-ranging diversity of applications.

2.2 The utilisation of the concept of conjuncture in this situational analysis, however, derives mainly from its interpretation and utilisation by the great scholar, activist and Fellow of the British Academy, Stuart McPhail Hall (Clarke, 2014). Recognition is also given to important work by progressive intellectuals such as Antonio Francesco Gramsci, Louis Pierre Althusser, and Nicos Poulantzas, while Harold Wolpe played a key role in popularising the concept and making it relevant to understanding the situation in South Africa. Hall defines the conjuncture as reflecting "a period during which the different social, political, economic and ideological contradictions that are at work in society come together to give it a specific and distinctive shape" (Hall and Massey, 2010: 57). Thus framed, history may be read as a series of conjunctures, interpolated by crisis. The notion of crisis permeates the utilisation of conjunctures to describe situations. For Hall, "Crises are moments of potential change, but the nature of their resolution is not given. It may be that society moves on to another version of the same thing, or to a somewhat transformed version; or relations can be radically transformed." (Hall and Massey, 2010: 57).

2.3 By invoking the concept of the conjuncture, we are seeking to identify the concrete state of the political economy in a specific society at a particular point in time. In determining the contemporary conjuncture, we also signal our intention to "expand [our] capacity to act politically by helping to examine the conditions of a political intervention in their complexity; that is, to trace the displacements and condensations of different sorts of contradictions, and thus open up possibilities for action" (Koivisto and Lahtinen, 2012: 267). The crisis between the conjunctures may result in resolutions that open up alternative trajectories because "…conjunctural crisis is when these 'relatively autonomous' sites which have different origins, are driven by different contradictions, and develop according to their own temporalities – are nevertheless 'convened' or condensed in the same moment. Then there is crisis, a break, a 'ruptural fusion.'" (Hall and Massey, 2010: 59-60).

2.4 As this situational analysis presents a concrete analysis of a concrete situation, it is necessary to flag difficulties in separating objective and subjective factors that define a conjuncture. While objective factors tend to circumscribe what subjective actions are possible within any situation, their interpenetration allows us to push beyond such perceived limitations. Because of subjective actions, objective conditions may be reformed and/or transformed. Objective conditions are, therefore, not necessarily fixed or permanent. Thus, objective and subjective factors act within a dialectical relationship. The utilisation of such a dynamic approach thereby allows us to respond to some prescient challenges identified by Wolpe (1985: 78) when he framed research questions, then particularly for the national liberation movement, but nonetheless important today, such as: "what are the structural limits of reforms? What are the transformations in ideological and political structures? What are the factors generating new definitions of interests and what are the sources of opposition to these?" It is on this methodological footing that we now establish a new narrative to explain the origins of the contemporary conjuncture by explaining its global and domestic manifestations.

3. Shaping the contemporary global conjuncture

3.1 Our starting point in this situational analysis is the emergence of human beings, their social organisation and their evolutionary quest to reproduce themselves. Alvarez, a geologist and advocate of the emerging field of Big History,[2] has argued that "Almost 14 billion years of Cosmic history, more than 4 billion years of Earth and Life history, a couple of million years of Human history, all of it constrained by the laws of nature but playing out in an entirely unpredictable way because of countless contingencies – this history has produced the human situation in which we live" (Alvarez, 2016). Our contemporary conjuncture was inaugurated in an interglacial period where, "Like clockwork, 11 700 years or around 400 generations ago, a regular and predictable realignment of heavenly bodies in our solar system conspired to push Earth out of a long ice age and into a new equilibrium, a warm and extraordinarily stable interglacial period" (Nakicenovic et al., 2016: 9). Such biophysical conditions afforded modern human beings evolutionary opportunities for adaptation, social organisation and revolutionary transformations. Rodney specified that a "society develops economically as its members increase jointly their capacity for dealing with the environment. This capacity for dealing with the environment is dependent on the extent to which they understand the laws of nature (science), on the extent to which they put that understanding into practice by devising tools (technology), and on the manner in which work is organised." (Rodney, 1972: 10).

3.2 Through the metabolic rift[3], the natural world became an object capable of being transformed to satisfy human wants by the application of productive forces, such as labour power, technological knowledge, and tools to produce goods and services that fulfilled the requirements of reproducing human beings. These productive forces developed over time and benefited from the accumulated learning derived from praxis and transmitted across generations through oral mediums and later in codified formats. Thus, the development of productive forces tends to reflect the historical condition within which they arise and are utilised. Control over productive forces reflects the political and social organisation of the individuals and communities. The level of development of productive forces essentially explains the nature of the productive relations as much as the nature of productive relations describes the levels of development of productive forces.

3.3 Over time, the development of productive forces generates conflicts between the forces of production and the relations of production. Resolving such crises has historically resulted in epochal changes in the mode of production. Existing relations of production adjust to the new forces of production, notwithstanding that it is often the existing productive relations that constitute fetters on the forces of production and thereby hinder the effective utilisation and further expansion of the forces of production. This dialectic relationship drives the emergence of new configurations for production and reproduction. Evolutionary changes accumulate and revolutionary advances become possible as modes of production are consolidated, mature and become exhausted. Such profound transformative changes are not, however, necessarily linear and complete. Notwithstanding the relentlessness of change developed from within productive forces, it is sometimes necessary for social revolutions to advocate and accelerate such changes. It is also important to concede that change does not merely continue in a mechanical fashion. Rather, various historical modes of production have fundamental resiliencies

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2 Big History is described as an emerging interdisciplinary field that aims to tie everything in our planet's past – its cosmic ancestry, its geological and paleontological evolution, and the pageant of human societies – into a coherent understanding of the grand sweep and character of history.

3 This refers to a disruption in the exchange between social systems and natural systems. Some people argue that the metabolic rift widened and expanded, while contributing to the contemporary crises in the planet's ecology, especially since the advent of the Industrial Revolution in England and Europe in the 18th century. (Bellamy Foster, 1999; Bellamy Foster et al., 2010; Maharajh, 2011, 2015a, 2015b; Moore, 2000, among others).

and can at times articulate with the incoming mode without liquidating itself. Thus, accumulated wealth and privilege continue across modes of production, deepening inequalities and preventing social justice from redistributing the benefits in an egalitarian form.

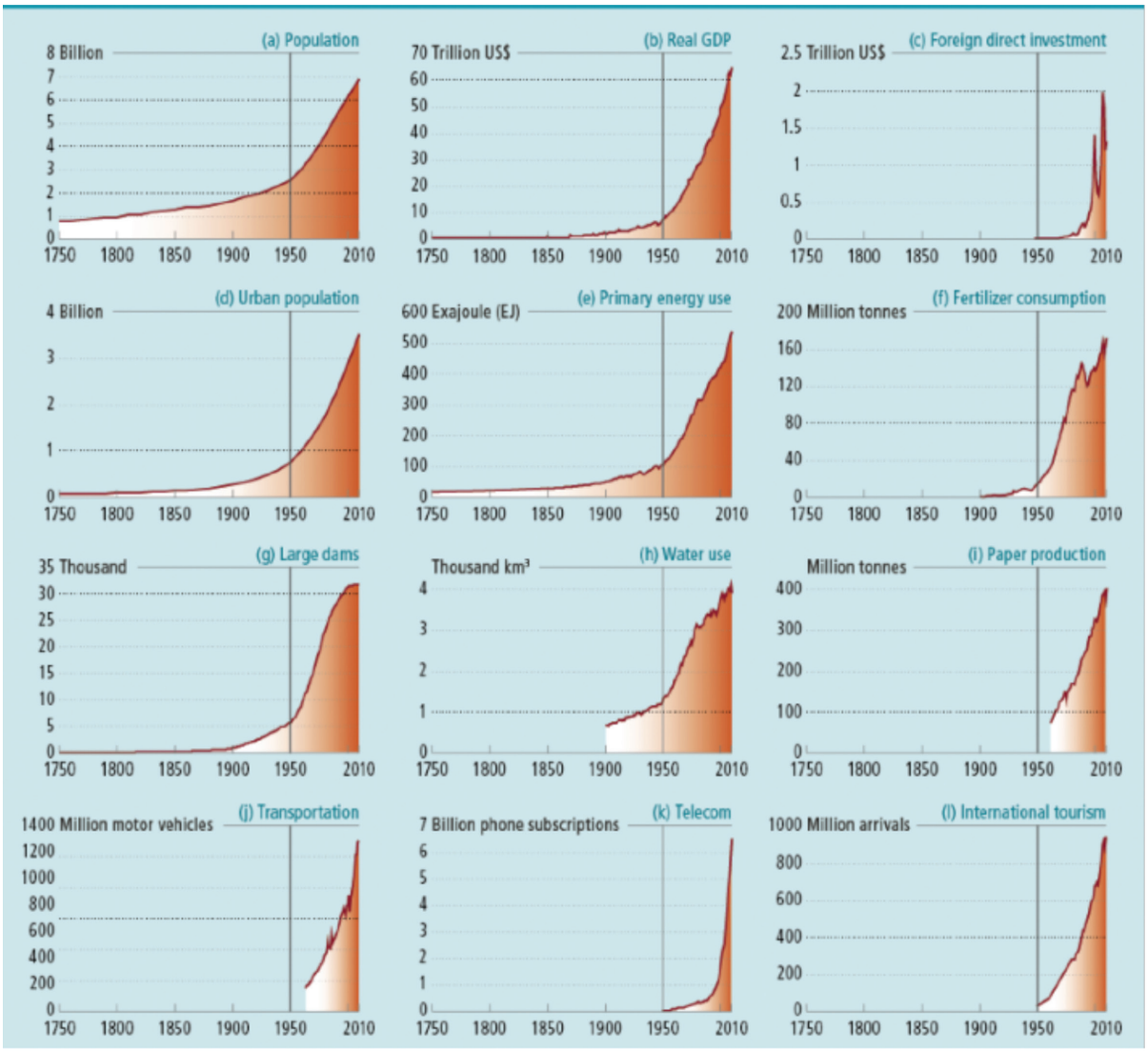
3.4 While the initial diffusion of human beings across the planet was achieved over a very long timescale, "the world population reached 7.3 billion as of mid-2015, implying that the world has added approximately one billion people in the span of the last twelve years. Sixty per cent of the global population lives in Asia (4.4 billion), 16 per cent in Africa (1.2 billion), 10 per cent in Europe (738 million), 9 per cent in Latin America and the Caribbean (634 million), and the remaining 5 per cent in Northern America (358 million) and Oceania (39 million)" (UN, 2015a: 1). Figure 1 shows how the accelerated rise in the global human population has been accompanied by equivalent increases in other socio-economic variables such as real gross domestic product (GDP[4]), expansions in trade (measured via foreign direct investments), urbanisation, energy use, more intensive agriculture (noted in fertilizer consumption), large dams, water use, paper production, transportation, telecommunications and international tourism.

3.5 The quantities reported in all 12 of the indices in Figure 1 show the acceleration of 'taking-off' in the period after the end of World War II (WW II) in the 1950s. It is this period in world history that also inaugurated a wave of globalisation, which superseded the imperialist phase of colonisation and firmly enwrapped the world into its combined and uneven contemporary form. While longevity and quality of living have improved for some, the massive expansions in socio-economic factors have not rendered the world an equitable space. The primary beneficiary of such increases has been the US. Secondary beneficiaries were those countries that benefited from the European Recovery Programme (Marshall Plan), which channelled over US$13 billion to finance the economic recovery of Western Europe between 1948 and 1951 (now estimated to be worth US$120 billion in current dollar value as of June 2016) and who were organised into the Organisation for European Economic Cooperation (OEEC). In 1961, the OEEC became the Organisation for Economic Cooperation and Development (OECD[5]). Also included as a secondary beneficiary of post-WW II capitalist expansion was Japan (see Freeman, 1987 and Lastres, 1994 for elaborations on the NSI of Japan). This triad of the USA, Europe and Japan would constitute the core capitalist countries in world systems post-WW II.

4 The final value of all its goods and services produced during a year within a defined country.

5 As of 2016, the OECD comprises the following 35 members: Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Luxembourg, Mexico, The Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom and the USA. Except for Chile, Mexico and Turkey, the other 32 countries are considered highly advanced capitalist economies with high incomes, developed infrastructures and similar governance regimes. South Africa, together with Brazil, India, Indonesia and the People's Republic of China are considered key partners of the OECD and are involved in various 'enhanced engagement' programmes, including on STI matters.

Figure 1. Accelerated socio-economic trends



Source: Steffen et al., 2015.

Long waves of development: techno-economic paradigms and the fourth Industrial Revolution

3.6 While we have indeed been shaped by evolutionary processes of change, we have also occasionally accelerated and diffused such adaptations through revolutionary transitions. Human and social progress has also been moderated by ecological constraints and the balance of socio-economic and political forces. While our relationship to the production, distribution and consumption of the means of our everyday existence shapes our lives through structuring the social and political apparatus of our mode of production, we simultaneously generate impacts on the ecology and the environment that envelops us. Nikolai Dmitriyevich Kondratiev researched long periods of economic expansion and contraction in the development of capitalist economies (1998, for works of 1923 and 1928). Long waves (Kondratiev waves) provide a useful explanatory model for the crises, depressions and upswings in the world economy since the beginning of the Industrial Revolution in Britain at the end of the 18th century. Inspired by Schumpeter (1934) and his theories of 'creative destruction' as a driver of capitalist expansion, Freeman and Pérez developed a systemic representation of technological revolutions and techno-economic paradigms (1988). Pérez has, in recent publications and presentations, sketched how 'long waves and great surges' have emerged over time (Pérez, 2009). These are represented in brief form in Table 1.

Table 1: Long waves and great surges

Core country	Starting	Great surges in development and successive technological revolutions
Britain	1771	Industrial Revolution, machinery, factories
Britain	1829	Age of steam, coal, iron and railways
Britain, USA and Germany	1875	Age of steel, heavy engineering (electrical, chemical)
USA	1908	Age of the automobile, oil, petrochemicals and mass production
USA	1971	Age of ICT
USA? Europe? Both? *BRICS*?	*2007/8*	Age of biotechnology, nanotechnology, bioelectronics and new materials

Source: Adapted from Pérez, 2009

3.7 Freeman recognises a vital characteristic of techno-economic paradigms (TEPs) in that they have "pervasive effects throughout the economy, i.e. it not only leads to the emergence of a new range of products, services, systems and industries in its own right; it also affects, directly or indirectly, almost every other branch of the economy as in the example of mass production. The expression 'techno-economic' rather than 'technological paradigm' emphasises that the changes are interactive, involving organisational, as well as technical changes, which go beyond specific product or process technologies. They affect the input cost structure and conditions of production and distribution throughout the system." (Freeman, 1991: 223-224). All the adaptations to the mode of production that have ensured that capitalism persistently revitalises itself are captured in the six techno-economic paradigms.

3.8 Mathews has suggested that the sixth techno-economic paradigm is currently emergent (2012). According to him, the "current renewable energy surge can be best comprehended as a secondary surge in the fifth long K-wave, coinciding with the shift from gestation to the installation of a new sixth techno-economic paradigm within the matrix of the fifth. It is argued that this emergent sixth paradigm is a continuation and fulfilment of the fifth, where IT and ICT are applied to the electric power grid, and that both are in conflict with the still-incumbent fourth paradigm based on fossil fuels and centralised power generation. The emergent sixth paradigm portends a renewable energy speculative financial boom and bubble that could burst sometime in the period 2015 to 2020, ushering in a period of sustained development of renewables and energy-efficiency services by productive rather than financial capital" (Mathews, 2012: 2). This considered reflection contrasts with the overly populist rendition of the fourth Industrial Revolution by the World Economic Forum (WEF), which has captured headlines and found its way into policy dialogues across the world (WEF, 2016; Schwab, 2016).

3.9 Numerous alternative framings of the transition in the productive sector already exist (including TEPs), but the WEF formulation is an extension of *Industrie 4.0,* which is "a German government-sponsored vision for advanced manufacturing" (GTAI, 2014). Both the German and WEF versions are premised on a convergence of cyber-physical systems, the Internet of Things and cloud computing. With respect to the WEF, it is useful to note the concerns of the European Parliament, "To its proponents, the organisation – through its meetings – enables business, NGOs and political leaders to meet and debate possible solutions to key issues of global concern. To its critics, the Forum, and specifically its annual meetings, is nothing more than an opaque venue for political and business leaders to take decisions without

having to account to their electorate or shareholders." (EPRS, 2016: 1). The European Parliament is also explicit that "the Forum's influence in shaping global economic policy generally, and in facilitating the spread of neo-liberal ideas more specifically, has attracted criticism from civil society organisations" (EPRS, 2016: 6).

3.10 Earlier antecedents for the WEF version include Carr, who coined the phrase 'fourth Industrial Revolution' as a way of explaining the inclusion of modern communications within industrial processes (Carr, 1940: 142). Subsequent iterations include a techno-optimistic version by sociologist Rose (1956), and a more sustained dystopian perspective by Joy who, after meeting Kurzweil, recognised that "Our most powerful 21st-century technologies – robotics, genetic engineering, and nanotech – are threatening to make humans an endangered species" (Joy, 2000). For Garbee, the WEF framing represents a meaningless phrase used by 'government and industry professionals' every few decades seeking "Each time, the framing of 'the next best thing' in technological development as a 'fourth Industrial Revolution' has failed to garner any sort of economic, social, or political capital, despite continued attempts to make it fit that mould" (Garbee, 2016). Garbee, therefore, concludes that "Schwab and co. fail to acknowledge – or worse, knowingly ignore – the massive efforts of those in the communities of responsible innovation, anticipatory governance, and science and technology studies, who for decades have been grappling with the moral and ethical questions our world leaders gathered to discuss… The coming decades of human technological innovation represent a social and political problem, not just a technological one, and demand expertise in finding social and political solutions – not just the vapid pontifications of professors and economists" (ibid.). A further critic, albeit from an inside track, is presented by Maynard, who argues that "Despite the many international initiatives, journals, conferences, think tanks, books and research programs – too many to list separately – dedicated to the responsible and beneficial development of emerging technologies, the fourth Industrial Revolution reads as if it were written in a vacuum. The ideas are interesting, and in many cases important – but are rarely informed by current activities or thinking." (Maynard, 2016).

3.11 The TEP literature has gained from the various experiments and results that now constitute socio-technical systems (Rip and Kemp, 1998; Geels, 2005, among others) and transition theories (Elzen et al., 2004; Kemp, 1994; Geels, 2006; Rotmans et al., 2000, among others). Besides recognising the requirement of ensuring that both top-down and bottom-up STI policy approaches converge, socio-technical systems and transition studies afford us the opportunity of recognising the consequences that emanate from technological change on humanity, society and, increasingly, the ecology. Figure 2 illustrates some of the biophysical impacts of the accelerating socio-economic trends.

Figure 2. Accelerated earth-system trends

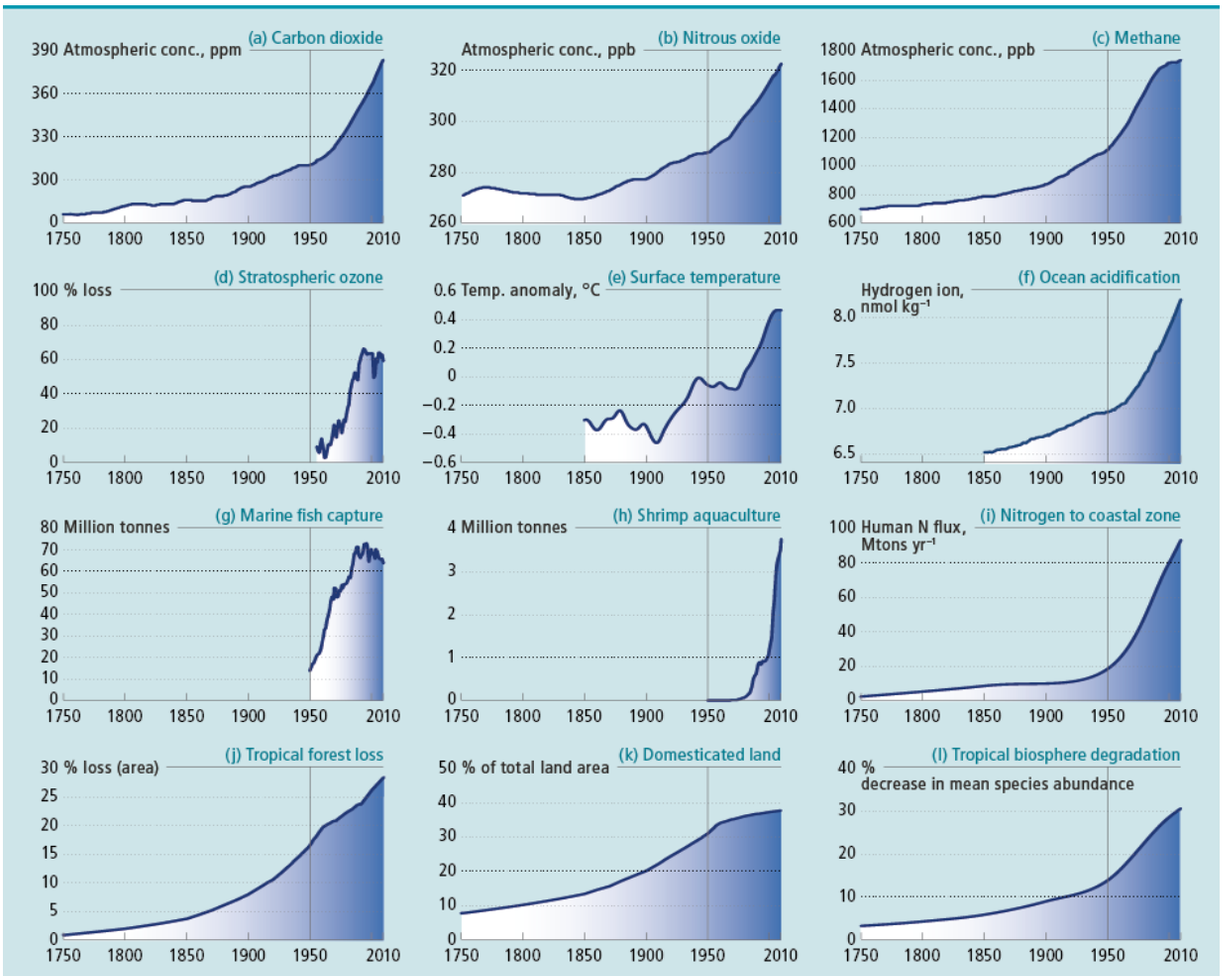


FIGURE 6 The Great Acceleration – Earth system trends in (a) carbon dioxide, (b) nitrous oxide, (c) methane, (d) stratospheric ozone, (e) surface temperature, (f) ocean acidification, (g) marine fish capture, (h) shrimp aquaculture, (i) nitrogen to coastal zone, (j) tropical forest loss, (k) domesticated land (land use change) and (l) tropical biosphere degradation. *Source*: Steffen et al. 2015.

Source: Steffen et al., 2015.

The Anthropocene: common but differentiated impacts on the planet

3.12 As illustrated in Figure 2, the rapid acceleration in socio-economic impacts has significant correlates with the massive increases in biophysical impacts on the planet. According to Attenborough, he first understood that climate change was driven by human activity while attending a lecture in the 1980s, when "The professor produced a series of graphs about the contents and changes in the atmosphere over the last 500 years plotted against the industrial revolution and changes in human population… You simply could not deny that a) the world was changing climatically and b) humans were involved in bringing that change about" (in Cardwell, 2013). The accelerated path of globalisation has also exacerbated the contradictions of unbound needs, articulated demands and the aspirations of human beings within a mode of production that is premised on infinite growth, but which is vested in a planetary system that is finite. As famously articulated by the eloquent Attenborough, "We have a finite environment – the planet. Anyone who thinks that you can have infinite growth in a finite environment is either a madman or an economist." (in Cardwell, 2013).

3.13 According to the annual *Greenhouse Gas Bulletin* of the World Meteorological Organisation (WMO),

"Globally averaged concentration of carbon dioxide in the atmosphere reached the symbolic and significant milestone of 400 parts per million for the first time in 2015 and surged again to new records in 2016 on the back of the very powerful El Niño event" (WMO, 2016). The WMO argues that these "high greenhouse gas levels mark the start of new era of climate reality" (WMO, 2016). The WMO shows that between 1990 and 2015, there was a "37% increase in radiative forcing – the warming effect on our climate – because of long-lived greenhouse gases such as carbon dioxide, methane and nitrous oxide from industrial, agricultural and domestic activities" (WMO, 2016).

3.14 Besides the unpredictable climate change, our contemporary conjuncture is also characterised by a spectacular and accelerated loss of biodiversity. Lambertini, the Director General of the World Wildlife Fund (WWF), is quoted in their major report as arguing that the "Wildlife populations have already shown a concerning decline, on average by 58% since 1970, and are likely to reach 67% by the end of the decade" (WWF, 2016: 6). The subsequent geospatial distribution of our species through expansion and extension has generated significant ecological impacts over time. These impacts have accumulated to the extent that the activities of our species can now be traced within the stratigraphic record of our geological timescale. Thus, the 35th International Geological Congress held in South Africa in 2016 considered a proposal to rename our current epoch as the Anthropocene or the 'Age of Humans'. This follows the recognition that human and social activities have generated discernible traces in the planet's stratigraphic record. It is increasingly evident that our impacts are accelerating and generating outcomes on a planetary scale.

3.15 According to the UN, "The central challenge in designing the post-2015 development agenda is to ensure that efforts to improve the quality of life of the present generation are far-reaching, broad and inclusive, but do not compromise the ability of future generations to meet their needs. Accomplishing this goal hinges on the ability of the international community to ensure access to resources for growing numbers of people, eradicate poverty, move away from unsustainable patterns of consumption and production and safeguard the environment." (UN, 2015b). Humanity is only just beginning to appreciate the limits of the earth's carrying capacity. Our species continues to expand both in terms of population and with respect to developmental needs. The system of global capitalism has enveloped the planet and is marked by a distinct pattern of combined and uneven development. The resulting inequalities, marginalisation and exclusion require a fundamental reassessment of some of the life-defining aspects that characterise our social, economic and political paradigms as the edge of the ecological catastrophe we have generated. Converging global living standards between the more developed and the rapidly developing parts of the world further strain the planetary thresholds, while the vast majority of countries remain outside the realm of benefits. Epochal changes are required, though such agitation may still be ascribed as demanding the impossible.

Sustainable development and planetary boundaries

3.16 The ecological challenges of our contemporary conjuncture are indeed non-trivial and, as argued by Gerst et al. (2014: 124), "Perhaps the key theme in the story of the 21st century will be how humanity addresses multiple threats to the stability of the planetary social-ecological system". These challenges are of such a scale that they transcend the boundaries of national states and impose significant constraints upon domestic policy and planning sovereignties. It is on this basis that we shift to a brief exploration of the emerging international and multilateral convergences in determining our collective

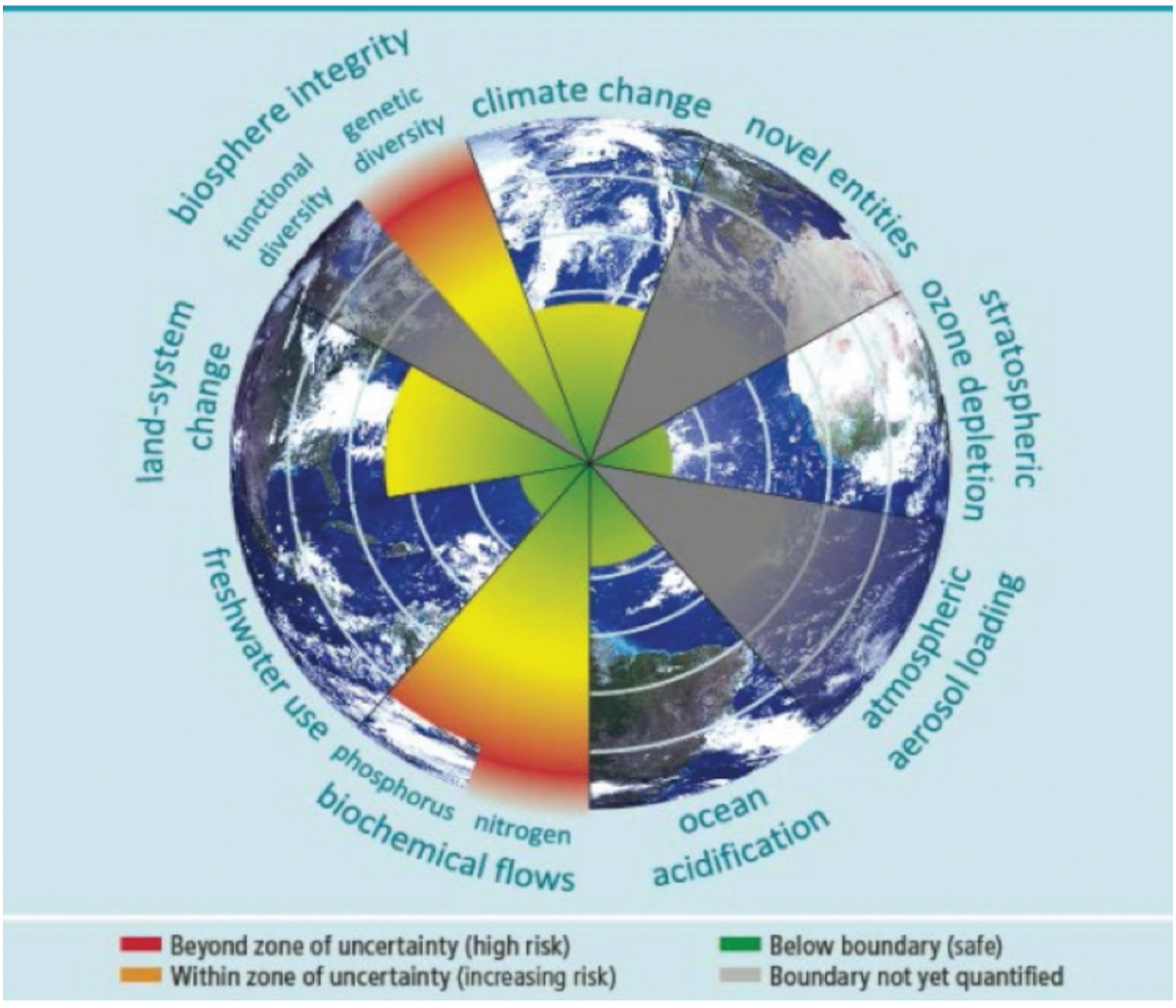
responses to the looming ecological catastrophe. While sustainable development was already framed in the Brundtland Report titled 'Our common future' in 1987, the concept would gain global traction at the UN Conference on Environment and Development (known as the Earth Summit) convened in Rio de Janeiro, Brazil, in 1992. This summit was seized by evidence of the interconnected environmental challenges of global warming, pollution and biodiversity, and the social challenges of poverty, health, population growth and mobility. The delegates committed to "a programme of action for sustainable development worldwide", known as Agenda 21; and also adopted the Rio Declaration on Environment and Development, which comprised 27 principles (UN, 1992). A major guiding principle for development that was derived from the Earth Summit is the notion of common but differentiated responsibilities. While this principle would largely influence the various positions of the global South, the global North, represented by the more advanced and mature capitalist countries, such as the USA, Japan and those in the European Union (EU), largely sought to relegate the concept to essentially environmental and climate change issues.

3.17 At the World Summit on Sustainable Development, it was argued that "In view of the different contributions to global environmental degradation, states have common but differentiated responsibilities" (UN, 2002). The twentieth anniversary of the Earth Summit (Rio +20) generated an outcomes document titled 'The future we want' (UN, 2012). This reasserted the principle of international environmental law, establishing that all states are responsible for addressing global environmental destruction, yet are not equally responsible. For Stockholm Resilience Centre, the invocation of the Anthropocene represents a scientific idea that fundamentally alters our worldview (WWF, 2016). Rockström argues that "This single word encapsulates the fact that human activity now affects Earth's life support system. It conveys the notions of deep time – the past and future – and the uniqueness of today. Beyond geology and Earth system science, it captures the profound responsibility we now must shoulder. It provides a new lens to see our human footprint, and it communicates the urgency with which we must now act. The dominant worldview of infinite natural resources, of externalities and exponential growth is at an end. We are no longer a small world on a big planet. We are now a big world on a small planet, where we have reached a saturation point. Unsustainability at all scales, from localised deforestation to air pollution from cars, hits the planetary ceiling, putting our future at risk" (WWF, 2016: 4).

3.18 According to Rockström, the previous five decades of exponential growth have accumulated to such an extent that humanity has not only reached the biophysical thresholds (planetary boundaries), but in many vectors actually "crashed through them" (WWF, 2016: 4). Recent advances in science and technology have improved our competencies to understand the geophysical and biological processes that afford us and all other living organisms the capacity to survive within finite boundaries. Thus, having established that our planet does indeed have boundaries, we now recognise that "Transgressing a boundary increases the risk that human activities could inadvertently drive the earth system into a much less hospitable state, damaging efforts to reduce poverty and leading to a deterioration of human wellbeing in many parts of the world, including wealthy countries" (Steffen et al., 2015). As recognised by the United Nation's Intergovernmental Panel on Climate Change (IPCC), "there's a more than 90 percent probability that human activities over the past 250 years have warmed our planet. The industrial activities that our modern civilisation depends upon have raised atmospheric carbon dioxide levels from 280 parts per million to 379 parts per million in the last 150 years" (IPCC, 2007). The panel also concluded that there is a more than 90% probability that human-produced greenhouse gases such as carbon dioxide, methane and nitrous oxide have caused much of the observed increase in the earth's temperatures over the past five decades.

3.19 The planet currently faces multiple tipping points that will ultimately signal the failing of some of the world's ecosystems with life-threatening consequences for all. The IPCC maintains that "with increasing warming, some physical systems or ecosystems may be at risk of abrupt and irreversible change" (IPCC, 2014). According to an international team of scientists examining numerous interdisciplinary studies of physical and biological systems, nine environmental processes were determined that could disrupt the planet's ability to support human life (Rockström et al., 2009).

Figure 3. Status of the control variables for the nine planetary boundaries



Source: Steffen et al., 2015.

3.20 Figure 3 presents the current status of the control variables for the nine planetary boundaries. It is important to recognise that seven of these processes have clear boundaries established by science, while complying with the uncertainty principle. Three of those boundaries – for climate change, ocean acidification and stratospheric ozone depletion –represent tipping points, and the other four signify the onset of irreversible degradation. The remaining two processes, atmospheric aerosol pollution and global chemical pollution, have no determined limits due to their recent age and lack of long datasets. According to the most recent update to the seminal study, four of the boundaries (climate change, biological diversity, nitrogen input to the biosphere and change in land use) may now have already been transgressed (Steffen et al., 2015). The last-mentioned parameter refers to deforestation, whereby vegetation is cleared for agriculture.

3.21 Current changes to the climate and potentially irreversible climate change implies the loss of productive land, extreme weather conditions, rising sea waters, the massive dislocation of people, desertification, and serious economic and social upheaval. Other resource shortages, like fresh water, forests, agricultural land and biodiversity, are being severely impacted on. The depletion of oil and gas reserves impacts directly on the lives of the billions of people of the world and the fragile biosphere. The current production paradigm remains locked into fossil fuel dependencies that include long-distance transportation, mass factory production systems and many other aspects of the subsystems and commodities. The mineral endowments of the planet are being extracted at a rate whereby the net effect is that the stocks of planetary resources are being depleted faster than natural processes can replenish them. This decline is being undertaken with little apparent intergenerational concern. According to Bellamy Foster et al. (2010), the source of our present ecological crisis lies in the paradox of wealth in a capitalist society, which expands individual riches at the expense of public wealth, including the wealth of nature.

3.22 According to Nakicenovic et al. (2016), four key socio-economic megatrends will determine the trajectory of the Anthropocene (energy, food, water and urbanisation). Decarbonisation of the global energy system is now of critical importance for a 1.5 to 2 °C future global temperature increase in line with the Paris Agreement (21st Conference of the Parties (COP 21) to the UNFCCC) reached in 2015. Food, which is critical to human survival, has become the world's single-largest user of fresh and underground water. This has made the production of food the single-largest reason for transgressing planetary boundaries on nitrogen/phosphorus, land and biodiversity. Transformation of the food system has the potential to improve personal, societal and planetary health and wellbeing. By 2050, 75% of the world's population will live in urban areas. This global shift requires a major focus on transformation to sustainable and liveable urban environments, transportation and a circular economy. Water, the source of life, is under severe pressure, and water stress and scarcity are increasing in many parts of the world (Nakicenovic et al., 2016).

Innovation, innovation systems and the state

3.23 Under such dire ecological constraints, it is eminently evidenced that continuing with the existing developmental paradigms will not be in the enlightened self-interest of ourselves as a species. We need transformative change to transcend 'business-as-usual' practices. Innovation may constitute an important driver of the socio-economic and political development that creatively destroys the hitherto existing regimes of production and exchange, enabling us to inaugurate an alternative pathway to sustainability. Efforts at organising innovation have generated systemic possibilities. The policy framework of the NSI has largely been co-determined together with the heterodox discipline of evolutionary economics. The Neo-Schumpeterian framing of 'creative destruction' bridges both literatures of evolutionary economics and NSI policy studies. In its original formulation, Marx had recognised that 'creative destruction' formed a critical dynamic of the capitalist mode of production, whereby the economic structure incessantly destroys its older version, while constantly creating a new variety. Schumpeter (1934) built on this literature and further defined 'innovation' as being the result of the introduction of a new good or a new quality of the good, the introduction of a new method of production, the opening of a new market, the conquest of a new source of supply, and the carrying out of the new organisation of an industry.

3.24 Lundvall and Borras (1997: 14), among others, have argued that "The increased importance of innovation reflects the fact that it represents a major response to intensifying competition by enhancing

the learning abilities of firms and workers. Neither firms nor regions can establish sustainable growth without innovation and learning". The utilisation of the NSI framework may, therefore, suggest two diametrically opposed, although intrinsically contested, opportunities. On the one hand, the NSI may assume the role of reproducing the hegemonic relations of production that form the political economy, and should thereby act to preserve the inequalities inherent in trajectories of capital accumulation. On the other hand, and especially because the practices of the NSI tend to identify the embedded constraints on development, the discourse holds the possibility of radical systemic and structural transformation.

3.25 As established by Lundvall and Borras (1997), "the innovation process is an interactive process of a social nature". They determined at least three levels of interaction: between different steps of the innovation process, between organisations, and between different departments of the same firm (Lundvall and Borras, 1997). Lazaric and Lorenz (1997) have also argued that, at each of these levels, "agents and individuals communicate and cooperate". They need to develop a common language and modes of interpretation and, above all, trust, in order to overcome some of the uncertainties characterising the innovation process. For Lundvall and Borras (1997: 30), this establishes a key reason "why the learning economy cannot function without a minimum of social cohesion". They argue further that "Afirm's capacity to learn and transform in this new context is a crucial competitiveness factor. There is a definite need to constantly rebuild the skills of the individual and the technological and organisational competencies of the firm" (Lundvall and Borras, 1997: 35). This results in the fact that "The main reason why learning has become more important has to do with the dialectics between learning and change. Rapid change implies a need for rapid learning, and those involved in rapid learning impose change on the environment and on other people." (Lundvall and Borras, 1997: 35). The increased pace of technological change and innovation is in itself embedded in a larger context of the knowledge production process and its relation to economic activity.

3.26 As Nelson has argued, "There is, first of all, greater need for large-scale public and private investments to create a technologically sophisticated cadre of indigenous engineers and applied scientists. While in the early stages of catch-up, much of the needed technical sophistication can be gained by sending students to study abroad, as development proceeds, and the sheer quantity of engineers and scientists needed increases, a large share of the education is going to have to be undertaken indigenously. I propose that in the current environment, catch-up will be impossible unless a country builds up its education system, from bottom to top. This poses a major challenge both for financing and for institution building." (Nelson, 2008: 16). His reminder about the critical importance of improving the education and training system correlates well with the OECD's assertion that "Developing countries are still accumulating capital and labour, but they are also improving their capabilities and increasingly using and producing innovations. However, mastering technology and knowledge in order to move up the value chain is still a goal to be achieved for most of them." (OECD, 2013: 5).

3.27 Ussher's preface to Mazzucato's seminal work on the entrepreneurial state identifies two major insights: the recognition that "networks and connections really matter" and that "even where the network exists, it takes a nimble, interventionist, knowledge-hungry state to catalyse them into action. If it is in the public interest for innovation to occur, there is a role for the public sector to require it to happen, rather than sitting back and hoping it will happen of its own accord provided the conditions are right. Countries playing economic catch-up are able to do this relatively easily by having government strategies that

copy what has happened elsewhere in the world" (Mazzucato, 2011: 13-14). In seeking to represent the 'real' story of the intersection between innovation, and economic growth and development in the economic history of the USA, Mazzucato exposes that "not only was this knowledge economy guided by government, but, strikingly, it was done as the leaders of industry were, on the one hand, privately demanding government intervention to facilitate the industry's development, and, on the other hand, publicly declaring their support for a free market. It is no wonder given this hypocrisy that so much confusion now exists among policy makers and the general public regarding the development of economic innovation, resulting in the failure to recognise the significance of government involvement" (Mazzucato, 2011: 59).

3.28 Mazzucato has also cogently argued that "The role of the state in modern capitalism has gone beyond fixing market failures. Those regions and countries that have succeeded in achieving 'smart' innovation-led growth have benefited from long-term visionary 'mission-oriented' policies – from putting a man on the moon to tackling societal challenges such as climate change and the wellbeing of an ageing population" (Mazzucato, 2015). In our contemporary global conjuncture of financialised neo-liberal capitalism, Mazzucato and Perez argue that "debates about innovation policy, financial reform and corporate governance should go hand in hand" (2014: 13). They recognise that the "main characteristic of innovation is uncertainty and it is only in the context of a revolution or when a direction has been clearly chosen and made reality through policy action that the risks will diminish and innovations proliferate in that space and start to create synergies for each other".

The UN, Millennium Development Goals and Sustainable Development Goals

3.29 At the transition to the new millennium, a new set of international developmental goals was discussed and adopted. The Millennium Development Goals (MDGs) set out a set of targets that became due in 2015. The MDGs had sought to generally redress conditions of absolute poverty and deprivation. Whereas it sought to enable a less inequitable international order, the shaping of the eight international development goals by the development financing instruments of the Bretton Woods agreement saw them being implemented as mainly objectives of the global South. This was largely the consequence of their articulation as being focused on poverty reduction. MDG 7 directly targeted ensuring environmental sustainability. It was translated into the following four results: integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources, reduce biodiversity loss, achieving, by 2010, a significant reduction in the rate of loss, halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation, and by 2020, have achieved a significant improvement in the lives of at least 100 million slum dwellers (UN, 2000). In its penultimate report, the UN noted that "Major trends that threaten environmental sustainability continue, but examples of successful global action exist. Global emissions of carbon dioxide continued their upward trend and those in 2011 were almost 50 per cent above their 1990 level. Millions of hectares of forest are lost every year, many species are being driven closer to extinction and renewable water resources are becoming scarcer. At the same time, international action is on the verge of eliminating ozone-depleting substances and the proportion of terrestrial and coastal marine areas under protection has been increasing" (UNDP, 2014: 4).

3.30 Work on the successor regime began in 2011. This post-MDG package is radically different from the previous two iterations (Agenda 21 and the MDGs). The successor regime to the MDGs was a range of

SDGs. In September 2015, 193 world leaders agreed to 17 global goals for sustainable development and its 169 targets. The following table presents the current goals that were acceded to by all members of the UN, including South Africa, in 2015. Figure 4 presents the 17 SDGs.

Figure 4. The Sustainable Development Goals

Source: UN, 2015b.

3.31 The International Council of Scientific Unions (ICSU) and the International Social Sciences Council (ISSC) have argued that "Science plays an important role for sustainable development from informing the formulation of evidence-based targets and indicators, to assessing progress, testing solutions, and identifying emerging risks and opportunities. In recent decades, Earth-system research has provided critical inputs into our understanding of the interlinkages and interdependencies between natural and social systems which can support integrated policy-planning, monitoring and review at different scales" (ICSU, 2015). While this reflects their specific enlightened self-interest, the wider implications of the SDGs are also to be realised in the domains of technology and the NSI more broadly. Among the challenges that emerge are the requirements of building domestic capacities to monitor and evaluate the biophysical changes taking place and in forging the necessary capabilities for 'integrated policy-planning, monitoring and review' under combined, but uneven world systems. This converges with the requirements of NSI to invest in expanding competencies for managing Big Data to "increase significantly the availability of high-quality, timely and reliable data disaggregated by income, gender, age, race, ethnicity, migratory status, disability, geographic location and other characteristics relevant in national contexts" (ICSU, 2015).

The United Nations and transformative change

3.32 The UN Research Institute for Social Development (UNRISD) identified 'transformative change' as the means to redress the economic, environmental and social challenges of the UN's 2030 Agenda for Sustainable Development. According to UNRISD, this requires transformative changes in "economic

structures to promote employment-intensive growth patterns that ensure macro-economic stability and policy space. In order to make this economic change environmentally sustainable, profound changes are required in production and consumption patterns and energy use through legislation, regulation and public policies. But most importantly, it requires changes in social structures and relations, including addressing the growing economic and political power of elites and patterns of stratification related to class, gender, ethnicity, religion or location that can lock people (including future generations) into disadvantage and constrain their choices and agency. It also means changing norms and institutions, both formal and informal, that shape the behaviour of people and organisations in the social, economic, environmental and political spheres" (UNRISD, 2016: 3-4). Table 2 presents some of the novel variations of innovation that would help constitute transformative change.

Table 2: Innovations for transformative change

Innovation	Description
Policy	Policy innovation is particularly apparent in several regions in the global South. Over the last two decades, many developing countries have adopted policies that extend the coverage of social services or social protection schemes to formerly excluded groups, and have implemented innovative financing policies through progressive tax reforms or the more effective capture of mineral rents. At the global level, in the wake of the 2008 financial crisis, new policies have been conceptualised to promote employment creation and social protection floors, and the Rio +20 and COP 21 processes have triggered policy innovation in the area of sustainable development.
Institutional	Policy innovation at national, regional and international levels has been coupled with institutional innovation. This includes new normative, regulatory and judicial instruments, changes in governance arrangements associated with participatory democracy, public-private partnerships and multi-stakeholder standard-setting where new stakeholders or combinations of actors engage in service delivery, financing and decision-making processes, 'multi-scalar' governance, where such processes and institutions are articulated at local, subnational, national, regional and international levels, and institutional complementarities that reconfigure institutional arrangements (for example, state and market) and policies (such as economic and social) at the macro level. Transformative institutional innovations help overcome inequalities and structural disadvantages, and help empower weaker actors.
Social	Non-state actors, in particular non-governmental organisations (NGOs), but also the private sector, are increasingly associated with social innovation. This is said to occur when organisations and networks adopt new ideas, strategies and practices that aim to meet social needs better and build relationships that are conducive to social and environmental improvements. Social innovation frequently occurs at the local level, where community organisations and social enterprises, often enabled by civil society networks and decentralisation, organise to greater effect in order to mobilise resources and defend their rights. This is also apparent in social movement activism or 'glocal' networking that connects local actors with change agents across scales, as well as across North and South, such as women's movements that aim to change gender-based stereotypes and discrimination that are entrenched in social norms and practices.
Technological	From the perspective of development and empowerment, important synergies can arise when social and technological innovations combine. This is seen, for example, in the case of networking (including transnational migrant activism) that is facilitated by information and communication technologies, when farmer cooperatives move up the value chain by adding processing and quality control to their business activities, or when decentralised renewable energy supply reduces the drudgery of unpaid work by women.
Conceptual	Changes in institutions, policies and the way organisations behave are often informed by conceptual and discursive innovation. Particularly important in recent years have been those associated with governance and organisational theory, conceptual approaches towards alternative development pathways, such as *Buen Vivir,* or social and solidarity economy, and new social policy concepts, such as the care policy approach.

Source: UNRISD, 2016: 5

3.33 Contained in Table 2 are a wider range of innovations that have accumulated in the preceding decades of experimental learning for national systems of innovation in practice. Schot and Steinmueller (2016: 21) have also suggested that it is now time to rethink innovation policy. They base their analysis on the economic history of Western Europe, and, by studying the evolution of innovation policy, identify three very distinct framings within a historical periodisation. Frame 1 (from the 1960s until the 1980s) focused on research and development (R&D) and regulation. Frame 2 (from the 1990s until the present) established national systems of innovation. Frame 3 is an emergent frame that Schot and Steinmueller ostensibly label transformative change (Schot and Steinmueller, 2016: 3-4). The NWPS&T would be enhanced by the utilisation of such a wider range of interpretations that transcend the narrower R&D-based linear paradigm that continues to haunt South Africa's application of the concept of innovation. More details of this persistence and even resistance to change are available in the performance analysis. This table also allows for the wider deployment of the concept to extend across ecological, economic, political and social domains.

3.34 The persistence of combined and uneven development on an international scale is the result of an apparent lack of initiative from multilateral (interstate) institutions to realise profound, radical and transformative change. Thus, while the Global Climate Legislation Database currently lists approximately 867 instances of national climate change laws that are in place, these remain territorial and their application is circumscribed by domestic capacities and capabilities (LSE, 2016). With respect to the intransigence to confront the fossil-fuel dependencies, the private sector has itself moved considerably in effecting game-changing strategies. According to Arabella Advisors and in the year since the UNFCCC's COP 22, "the value of assets represented by institutions and individuals committing to some sort of divestment from fossil fuel companies has reached $5 trillion. To date, 688 institutions and 58 399 individuals across 76 countries have committed to divest from fossil fuel companies, doubling the value of assets represented in the last 15 months. Pension funds and insurance companies now represent the largest sectors committing to divestment, reflecting increased financial and fiduciary risks of holding fossil fuels in a world committed to stay below 2° Celsius warming" (Arabella Advisors, 2016: 1).

The African Union and Science, Technology and Innovation Strategy for Africa

3.35 The 23rd session of the African Union (AU) Heads of State and Government Summit adopted a 10-year Science, Technology and Innovation Strategy for Africa (STISA-2024) in June 2014. STISA-20124 was the successor to the Consolidated Plan of Action, which was adopted by the Conference of Ministers in charge of Science and Technology, known as the African Ministerial Council on Science and Technology (AMCOST) in 2005. In its Agenda 2063, the AU had already recognised that science, technology and innovation represented multi-functional tools that would enable the achievement of continental development goals. The Department of Human Resources, Science and Technology constitutes one of the eight technical departments of the AU Commission (AUC). It is mandated to "advance education, science and technology, and human capital development in the continent". STISA-2014 is apparently "designed to respond to the need of transforming Africa into a knowledge-based and innovation-led society" (AU, 2014: 20). STISA-20124 has six priority areas: eradicate hunger and ensure food and nutrition security prevent and control diseases and ensure wellbeing, communication (physical and intellectual mobility), protect our space, live together, and create wealth (AU, 2014: 21-23). The AU's STISA-2024 is resonant with the NWPS&T insofar as it proclaims itself as "a cross-sectoral and multidisciplinary approach, which intends to strengthen the use of science, technology and innovation in addressing socio-economic challenges" (AU, 2014: 49).

The emergence of Brazil, Russia, India, China and South Africa (BRICS) and the possibilities of alternative geopolitical developmental perspectives

3.36 While acknowledging that the world is complex, interdependent and capable of generating a range of institutional forms, the Transnational Institute notes that only 31 of the 100 wealthiest entities in the world today are countries, while 69 are transnational corporations (TNCs) (TNI, 2016). Three of the TNCs (Apple, Shell and Walmart) each collect more revenue than the world's 180 poorest countries combined (including South Africa). Brazil, Russia, India, China and South Africa are countries that are individually and collectively undergoing rapid processes of structural transformation, institutional change and systemic transitions (Maharajh, 2015c). While heterogeneous in terms of histories and contemporary contexts, these four countries, together with South Africa, have been collectively bound in an emerging multilateral forum, BRICS, since 2009. In the context of world systems, all of the BRICS countries occupy the position of semi-peripheral countries. They are neither core capitalist economies, as is the case in the OECD, nor are they peripheral, such as the least developed countries (LDCs). Individually, Brazil contributed 3.15%, Russia generated 2.49%, India produced 2.74%, China occupied 13.9%, and South Africa was responsible for 0.46% of the global economy's total output in 2015. The BRICS countries are therefore emergent in the context of international and intranational inequalities and may be the ascension of a new geopolitical bloc of the semi-periphery of the contemporary world systems. The BRICS countries are constituted by 42% of the world's population and collectively contributed 22.74% of the world's GDP in 2015. This share is marginally lower than the hegemonic USA, which produced 23.32% of world output in 2015.

3.37 The founding statement of the BRICS bloc defined the grouping as a strategic geopolitical partnership that specifically aims to "advance cooperation among our countries in science and education with the aim, inter alia, to engage in fundamental research and development of advanced technologies" (BRICS, 2009: item 11). Subsequent engagements between these countries have built upon its initial, albeit narrower formulated sentiment, and expanded upon the scale and scope of intra-BRICS STI cooperation and collaborations[6]. Besides the annual summit meetings of the heads of states and the formal academic fora, line ministries from the five member countries have increased their engagements with each other. The first meeting of the ministries responsible for STI was hosted in Cape Town in 2014. That meeting discussed issues of mutual interest and identified future directions of institutionalising cooperation. The meeting stressed "the paramount importance of science, technology and innovation for human development. Indeed, while recognising the role and significance of competitiveness in the rapid technologically changing global environment, we agree that people-centred and public-good driven science, technology and innovation, supporting equitable growth and sustainable development, shall form the basis of our cooperation within the framework of BRICS" (BRICS, 2014a).

3.38 The second meeting of the ministers responsible for science, technology and innovation adopted a memorandum of understanding in science, technology and innovation cooperation, which established research fields that were identified as priorities for BRICS and allocated leadership responsibilities for each of these to Brazil for the prevention and mitigation of natural disasters, Russia for water resources and pollution treatment, India for geospatial technology and its applications, China for new and renewable energy, and energy efficiency, and South Africa for astronomy (BRICS, 2015a). The third meeting of

6 These meetings are: Cape Town Declaration: Outcomes of the first BRICS Science, Technology and Innovation Ministerial Meeting, Cape Town (BRICS, 2014a). Brasilia Declaration: Outcomes of the second BRICS Science, Technology and Innovation Ministerial Meeting, Brasilia (BRICS, 2015b). Moscow Declaration: Outcomes of the third BRICS Science, Technology and Innovation Ministerial Meeting, Moscow (BRICS.2015a).

the ministers responsible for science, technology and innovation agreed to create the BRICS Research and Innovation Networking Platform, and committed to supporting the BRICS Economic Partnership Strategy, which included STI as a priority (BRICS, 2015c). This meeting also declared that "long-term cooperation in [STI] will help bridge the scientific and technological gap between BRICS and developed economies and provide a new quality of growth based on economic complementarity" (ibid. Item 10). The meeting further endorsed the BRICS Science, Technology and Innovation Work Plan 2015-2018.

3.39 The benefits of innovation in BRICS would appear to address the explicit needs of the poor rarely because most their national systems of innovation are primarily orientated at achieving economic growth and competitiveness, and not at reducing poverty or inequalities (Soares et al., 2013). The coexistence of economic growth, substantial investments in STI and increasing inequality or the persistence of an important percentage of the population living in poverty remains a major challenge faced by the BRICS countries. The governments of the BRICS countries are increasingly concerned about this phenomenon, and their contemporary rhetoric resonates with framings such as inclusivity or 'harmonious' pathways to achieve improved conditions of existence for their people within the constraints of ecological sustainability. BRICS should encourage the increased participation of academia, enterprises, civil society and other relevant stakeholders for science, technology and innovation development among BRICS countries. BRICS must recognise the complex and dynamic interdependence between investment into education, capability formation and economic development.

3.40 With the establishment and operationalisation of the New Development Bank in 2016, BRICS has indeed consolidated itself as a political bloc of countries. It is within this emergent geopolitical alliance that there is a need to establish an agency function embedded within BRICS, which will create, collate, compile and consolidate STI data for the purposes of improving the quality of discourse, enabling the formation of STI analytical capabilities, and extending policy competences. In South Africa, both the Frascati-based R&D Survey and the Innovation Survey are conducted by the Centre for Science Technology and Innovation Indicators (CeSTII) at the Human Sciences Research Council (HSRC) on behalf of the DST. The agency responsible for maintaining national statistics, Statistics South Africa (Stats SA), has become increasingly more involved in the quality assurance of the process. The STI data that is published is considered part of the country's official national statistics. As the BRICS countries improve their capacities for the collection of data on R&D personnel and R&D expenditures in accordance with international standards, we can expect missing data to be relegated to a previous epoch. Working together, BRICS can build a better world for all. Improving the data management capacity of BRICS, improving data manipulation capabilities and ensuring sovereignty over data utilisation for STI will be crucial to realising the developmental potential of BRICS.

3.41 The current conjuncture of global capitalist expansion has been characterised as neo-liberalism. Ban argues that neo-liberalism should not be considered as either a purely economic doctrine (market fundamentalism) or a set of practices (policies, institutions, programmes), but that real-existing neo-liberalism is "a set of social facts that should not be conflated with either purist pro-market ideology or neoclassical economics, a much broader corpus of economic ideas" (Ban, 2016a). For Ban, neo-liberalism rather represents "a hybrid set of ideas and institutions that can coexist – albeit uneasily – with a range of very different political projects (from liberal-democracy to political Islam) and economic approaches (from Chinese planning to Scandinavian welfare state)" (Ban, 2016b). According to Brenner et al. (2010: 3) neo-liberalism has become "simultaneously, a terminological focal point for debates on

the trajectory of post-1980s regulatory transformations and an expression of the deep disagreements and confusions that characterise those debates".

3.42 Ban draws on the work of Hall (1993), among others, to determine that neo-liberalism has three main economic policy objectives: trade and financial openness, the benchmarking of economic and social relations by the standards of market competitiveness, and the evaluation of macroeconomic and social policies in terms of their credibility with financial markets" (Ban, 2016b). The intersection between these discrete characteristics and the totalising worldwide system is because "the new constitutionalism of the post-1980s period appears to entail a direct inversion of historically entrenched national/global relations. The 'global' is no longer seen as a derivative product of nationally steered institutionalisations. Instead, globally constituted forces and interests, institutionalised in the form of various multilateral apparatuses, impose strict market discipline on national states, regardless of their structural position in the world order" (Brenner et al., 2010: 13).

3.43 Under neo-liberalism, international inequalities have grown and expanded, while poverty and unemployment have become concentrated among the masses of the people. As argued by Hearse, neo-liberal deregulation and privatisation promoted the dominance of financial capital and the expense of industry and the state (2016). For Hearse, "financialisation and low capital gains taxes have turned big companies and utilities into cash cows, virtual banks with huge wealth, looking to maximise the interest on their money and minimise their tax. The shift to the right crashed 'socialist' command economies and undermined nationalist governments in the third world, replacing both them with corrupt and usually highly authoritarian neo-liberal regimes. Getting hold of the state apparatus has become a royal road to mega-wealth for dozens of dictators and their cronies through simple theft. Financialisation, neo-liberalism and corporate state capture are increasingly presenting themselves in a variety of territories as the core characteristics of contemporary capitalism." (2016).

3.44 As noted by Gramsci, "The crisis consists precisely in the fact that the old is dying and the new cannot be born; in this interregnum, a great variety of morbid symptoms appear" (Gramsci, 1971). With economic austerity sweeping across Europe and populist political conservatism having captured the USA, the time may be appropriate for the fast-emerging countries constituting the BRICS countries to expand their innovative competences further, improve their S&T capabilities, and increase their expenditures to widen their R&D capacities. Such a radical geopolitical shift would afford the global South the possibility of leading in this sixth techno-economic paradigm. It would, however, require significant attention to be focused on the socio-technical, local and innovative productive arrangements (LIPS)[7]. This potentially optimistic note provides the vantage point from which to shift our attention to appreciating the long transition in South Africa and its more recent experiences in reforming its NSI.

7 Local productive and innovative systems involve groups of economic, political and social agents localised in the same area, performing related economic activities, in which formal and informal interdependence and consistent linkages usually result in cooperation and learning processes, with a potential to generate the increase of productive and innovative capabilities. They generally include firms – designing, producing and commercialising final goods and services, suppliers of inputs and equipment, service providers, etc. – and their different forms of representation and association. They also include other public and private organisations specialised in educating and training human resources, R&D, engineering, promotion, financing, etc. Local productive arrangements refer to those less structured cases in which interaction, cooperation and learning processes are incipient (Lastres and Cassiolato, 2005).

4. Periodising South Africa's transitions and transformations

4.1 Our species, *Homo Sapiens Sapiens,* is the last surviving member of our hominid family and is estimated to have occupied the planet for at least 200 000 years as anatomically modern human beings. Genetic[8] and phenotypic[9] evidence estimates that our species originated in a wide territory, ranging across southern and eastern Africa, with some minor boundary variations, depending on whether we are considering the genetic or the phenotypic evidence (Manica et al., 2007). Other recent evidence suggests that complex cognition capacities emerged in our species between 164 000 and 75 000 years ago (Marean, 2010), together with the origins of hypothetic-deductive thought (Liebenberg, 1990). The study of phonemic language diversity is "consistent with the archaeological evidence suggesting that hominin behaviour became increasingly complex during the Middle Stone Age in Africa, sometime between 350 000 and 150 000 years ago" (Perreault and Mathew, 2012: 5). Thus, while noting that South Africa became one of the 'youngest' countries in contemporary world systems in 1994, and was an early adopter of the NSI policy reform agenda in 1996, it is also important to remember that the territory is a 'cradle of humankind' (United Nations Educational, Scientific and Cultural Organization(UNESCO), 2000). STI played a critical role across the millennia, albeit in a variety of institutionalised formats that conformed to the nature of the political economy, the ideology and cultural norms of those specific times, and the governance regimes that resulted within the different modes of production, exchange, distribution and consumption.

4.2 The accumulation of surplus value over approximately 363 years created a wealthy and racialised bourgeoisie that retained international linkages with global capitalism. An abhorrent history of colonial subjugation and the elaboration of a racialised capitalist mode of production was further consolidated through an acute period of 46 years during which apartheid was legislated and institutionalised within the machinery of the state. As noted by Wolpe (1972: 426-427), "What is necessary for an adequate explanation is a specification of the historical conjuncture between ideology, political practice and the mode of production". We, therefore, construct the narrative, paying attention to the relationship between ideology, politics and the mode of production in the following tables. Table 1 presents a general overview over the long durée of South Africa's historical evolution, and indicates some of the 'revolutionary' transitions induced to accelerate the processes of change over time.

8 Analysis of Y chromosome DNA.

9 Description of one's actual physical characteristics.

Table 3: The long durée of South Africa's science, technology and innovation

	Until 1652	Until 1867/1886	1910	1948	1970s
Political economy	Communal: hunter-gatherer, agrarian, mining, metallurgy, and trade	Mercantile capitalism: colonial occupation slavery, agrarian and capitalist articulation of modes of production	Racial capitalism: settler colonialism, capitalist agriculture, minerals-energy complex establishment	Racial capitalism	Racial capitalism
Dominant ideology	Communal/ feudal	Multiplicity co-existing and competing	Imperial	Grand apartheid	Grand apartheid
Governance framework	Traditional	Autonomous though increasingly engaged	Undemocratic imperial	Undemocratic conservative	Undemocratic increasingly autocratic
Macro-economic policies	Communal	Expropriation and acquisition through violence	Dependency	Affirmative action for non-English whites	Import substitution industrialisation
Micro-economic policies	Indigenous and traditional	Imperial/colonial rural/urban	Colonial mineral and commercialagriculture	State-aided development	Corporatism(government and private sector)

Source: Adapted from Maharajh, 2011.

Pre-colonial southern Africa

4.3 According to Chirikure and Dandara (2016), the earliest human use of tools dates back over 2.5 million years ago. Since this invention was made, tools were adapted and re-contextualised in a wide variety of ways to suit different situations. The Middle Stone Age (300 000 to 50 000 BP) stands out as an essential period of innovations in making complex stone tools, the use of fire as an engineering tool and the beginning of symbolic and abstract art forms. During the Late Stone Age, innovations associated with rock art and stone tool technology developed further and are attested to all over southern Africa. Not only were innovations made within the realm of stone tools, but they were also made in domains such as food and nutrition. There is evidence to suggest that certain trees with medicinal qualities were used at places such as Sibudu Cave over 100 000 years ago. Perhaps the most important demonstration of pharmacological knowledge is associated with the use of the hoodia plant by pastoral people and hunters and gatherers in several areas of southern Africa.

4.4 Chirikure (2016) shows how mining and metallurgy capabilities arose among the indigenous miners and metallurgists who also farmed and settled in permanent villages early in the first millennium CE. This capability also co-evolved with significant geochemical engineering in pre-colonial southern Africa. Studies by modern prospectors and mining geologists in the 20th century demonstrated that most of the ore bodies that are worked today had been previously worked in pre-colonial times. From the early first millennium CE, several innovations unfolded within the domain of ore extraction. Sophisticated methods of retrieving underground ore were developed, and these were supported by a good reading of structural geology and ways of introducing air into the belly of the earth. When extracted, the ore from the mines was smelted in very diverse and continually evolving furnace types, ranging from the bowl to the tall natural draught types. Apparently, different furnace types were designed to suit various ore grades, some too low to be smelted using modern techniques. The metal from the furnaces was

fabricated using a wide array of techniques, which are all indigenous. The finished objects were used in utilitarian and expressive tasks to support agriculture, the army and other functions such as royal investiture. For example, the iron gongs found at Great Zimbabwe, the golden rhino at Mapungubwe and the Venda musuku ingots are all ceremonial objects meant to demonstrate the power of the rulers. Chirikure (2016) also ventures that mining and metallurgy promoted cultural contact and interaction within southern Africa and between southern Africa, the east African coast and the Indian Ocean rim region.

4.5 Chirikure et al. (2016) argue that agriculture was one of the most important innovations that have ever developed in pre-colonial southern Africa. The mobility of people in the region afforded the introduction and cultivation of crops such as millets and sorghum, which were drought resistant and could be grown even in areas with low rainfall. It is believed that early farmers practised shifting cultivation or slash-and-burn agriculture, which gave the land an opportunity to regenerate. One of the earliest innovations related to the cultivation of multiple areas, some which are moist, while others require normal rainfall to thrive. This form of risk management sustained Mapungubwe, which is believed to have practised floodplain agriculture along the Limpopo River. As agriculture was strongly linked to the availability rainfall, cultural practices around rain-making emerged and were incorporated into the agricultural cycle (Chirikure et al., 2016).

4.6 While much of our collective pasts are only recently being uncovered and analysed, the economic history of the South Africa clearly indicates that the indigenous peoples of the territory were violently incorporated into the international circuit of mercantile capital by the mid-17th century. Bartolomeu Diaz, a Portuguese navigator, was the first European to travel around the extreme southern point of Africa in 1488. Vasco da Gama, another Portuguese navigator, followed and landed in St. Helena's Bay in 1497. The local indigenous Khoi-speaking peoples apparently chased the 'foreigners' away and even wounded Da Gama. On entering the Indian Ocean, these Europeans found themselves "on the threshold of a long-established network of maritime commerce, in which Arabic, Indian, Malayan and even Chinese traders had been active for hundreds of years" (Crump, 2006). A subsequent Portuguese expedition landed in Table Bay in 1503, but the indigenous Khoi-speaking peoples killed Francisco d' Almeida (a Portuguese 'Viceroy' of India) and 64 other sailors in 1510. Portugal did not establish a permanent presence on the mainland of South Africa, although the Portuguese Empire monopolised the trade routes around Africa to the Indian Ocean.

Colonisation

4.7 In 1580, Francis Drake, an English sea captain, pirate, navigator and slaver travelled around the Cape on a return trip to Plymouth after successfully circumnavigating the planet. Cornelis de Houtman was the first Dutch person to circumvent the South African coastline in 1583 and spent a week in Mossel Bay in 1595. After this, several merchant companies were established in Holland with the objective of exploiting trade between the East and Europe. The Vereenigde Oost-Indische Compagnie (VoC) was established in 1602 as a monopoly enterprise for shipping and trading. The VoC would establish an initial settlement in South Africa to act as a refreshment facility in 1652 and thereby unleash systemic processes of primitive accumulation as the colonisation of southern Africa proceeded. Besides the material effects, the engagement between Africa and Europe was also mediated by the latter being involved in a scientific revolution now termed the Enlightenment Movement. According to Macamo,

"This is marked by the assumption that scientific knowledge is by definition universally valid because it applies objective concepts. By extension, what we know about Europe is consistent with what we can know about the world. Within the context of the social sciences, which rely on empirical generalisations, it is easy to assume that the conceptual apparatus that developed at this very crucial moment in Europe's history provides an adequate framework to render other parts of the world intelligible" (2016).

4.8 The peoples and societies that occupied the southern-most territories of Africa were fundamentally impacted on by the arrival of the mercantile representatives of European corporations (Dutch and English East Indies Companies respectively in succession) in 1652. This rupture would result in the Cape, and subsequently the wider southern Africa, being violently incorporated as colonial possessions held by corporate interests with the support of their respective governments. Again, science and technology played a contributory part in both the occupation of the space and in enabling resistance to dispossession. Pogue and Scerri identify three distinct eras of colonial innovation systems(2016). The first is the era corresponding to that of Dutch colonisation, running from the mid-17th until the early 19th century. Southern Africa, more accurately the Cape Peninsula, was a provisioning station of the Dutch East Indian Company during this era. Although free settlers made some inroads into the southern African interior, settlement, commerce and associated innovation were largely centred around the Cape Peninsula during this era. Analysis of the colonial system of innovation in this era will focus on reviewing developments in agricultural science, health sciences and natural sciences (Pogue and Scerri, 2016).

4.9 The second distinct era corresponds with the initial British colonisation in the early 19th century until the mineral discoveries and mining rushes of the mid-19th century. Colonial settlement and expansion characterised this era, with the associated development of the colonial system of innovation. This era also saw the emergence of independent Afrikaner-led colonial states across the southern African interior, as well as associated conflict and interaction with existing African political communities. As commerce and the colonial system of innovation were predominated by the British colonies, the focus will be on those colonies. In addition to reviewing developments in agricultural science, health sciences and natural sciences, this era will include an analysis of the initial development of colonial higher education systems and scientific institutions such as the South African Library, the Royal Observatory in the Cape and the South African Museum (Pogue and Scerri, 2016).

4.10 The third era marks a distinct transformation of the colonial system of innovation. It is associated with the mineral discoveries made across southern African in the mid-19th century, which drove a rapid modernisation of the economy. Pogue and Scerri (2016) argue that the focus of that era was on the innovation system that was associated with the mineral deposits. These resources transformed global markets, as well as the southern African economy, but critical innovations to existing technologies were fundamental to their economic extraction. Thus, the late 19th century saw the emergence of racial capitalism as the dominant mode of production in South Africa, incorporating settler-based, commercialised agriculture, mining and limited secondary industries being developed and expanded (Bundy, 1979; Davies, 1979; Freund, 1984; Johnstone, 1976; Legassick, 2007; Magubane, 1979; Mbeki, 1964; Simons and Alexander, 1969; Terreblanche, 2002; Wolpe, 1972; Yudelman, 1983, among others). Central to this phase was the establishment of the Union of South Africa in 1910.

4.11 The elaboration of combined and uneven development would be strongly advanced through the imposition of apartheid following the ascendancy of Afrikaner nationalism in 1948 (Bunting, 1969; Tabata, 1974). Such processes of expropriation, exploitation and oppression framed the evolution of a

political economy that was mainly constructed around commercial agriculture, the mining of minerals, the generation of energy, and a limited number of relatively sophisticated secondary industries and services. In 1961, the Union of South Africa officially shifted to a decimal currency, and withdrew from the Commonwealth Association as its racialised policies were untenable among an increasing number of nationally liberated territories. As reflected upon, and in a critique of Wolpe, Fine (1990) argued that humans had "to live as if race [was] not merely a phantasma – the ideological expression of social relations of alienation and exploitation – but [was] real. The state demands that people behave as if race is whatever they actually believe in their heart of hearts. Because of this, life in the apartheid system is permeated with hypocrisy and lies. Whenever individuals reproduce the lie as reality – declaring that race is real rather than that the illusion of race has been turned into the reality of power – they become not just oppressed by apartheid, but reproduce apartheid in the texture of their everyday lives" (Fine, 1990: 93). Under the apartheid regime, precariousness, poverty, under-employment and inequality would characterise the lives of the majority of South Africans and determine both their life opportunities and even constrain their very life expectancies.

Post-colonial period and/or colonialism of a special type

4.12 South Africa began a process of metrication in 1967 and had largely completed the transition from an imperial scale of measurements in the early 1970s. The means of the transition was state-led and included that the "sale of measuring devices that were calibrated in imperial units whether on their own or in conjunction with metric units was prohibited and the media was forbidden to use imperial units" (Ball, 2016). While a major accomplishment for metrology, the political economy of apartheid had also generated sufficient contradictions to realise an organic crisis, which bedevilled its capacity to reproduce itself (Saul and Gelb, 1981, among others). After various unsatisfactory reforms, which sought to retain the hegemony of those designated as 'white', apartheid entered successive states of emergency in the 1980s. International sanctions, domestic mobilisation and armed propaganda by the national liberation movements eventually forced the regime into a negotiated settlement with the majority of South Africans, thus paving the way for the enactment of a constitutional democracy in 1994.

Table 4 presents a stylised representation of the transition period, from the demise of apartheid, the negotiated interregnum, and the six subsequent elected governments of post-apartheid South Africa.

Table 4: Recent periodisation of South Africa's science, technology and innovation

	-1989	~1990	~1994	~1997	~2001	~2007	2012+
Political economy	Racial capitalism	Siege economy	Mixed	Mixed market-led	Mixed market-led	Mixed state-led	Mixed market-led
Dominant ideology	Apartheid	Dual power	Post-Keynesian	Structural adjustment	Neo-liberal	Second radical phase of the national democratic revolution	Neo-liberal
Governance framework	Authoritarian: military	Negotiations	Democratic developmental	New public management	NPM	NPM	NPM
Macro-economic policies	Normative Economic Model	Normative Economic Model	Reconstruction and Development Programme	Growth, Employment and Redistribution Strategy	Accelerated and Shared Growth Initiative for South Africa	New Growth Plan	National Development Plan
Micro-economic policies	Subregional industrialisation	Deregulation and GATT	WTO	Privatisation and structural adjustment	Reducing costs of doing business	Industrial Policy Action Plans	Infrastructure and sector strategies
Science, technology and innovation	Science and technology discrete and stratified	International Mission review and contestation	Green Paper on Science and Technology	White Paper on Science and Technology (NSI-perspective)	The National Research and Development Strategy and the DST (2004)	The 10-year Innovation Plan	Ministerial Review of the Science, Technology and Innovation Landscape
Higher education and training	National Education Crisis Committee	Post-secondary Education Report of the National Education Policy Investigation	Policy Framework for Education and Training (ANC) and National Commission on Higher Education	White Paper on Higher Education Transformation and a new Higher Education Act	Towards a New Higher Education Landscape (Council for Higher Education)	Department of Higher Education and Training (2009)	Green Paper on Post-school Education and Training (2012) and White Paper (2014)

Source: Adapted from Maharajh, 2011

Post-apartheid South Africa

4.13 The WPS&T introduced the national systems of innovation as a normative model to transform the science and technology institutional landscape that was inherited from the apartheid regime, and to mobilise its resources for the purposes of enabling all South Africans to "enjoy an improved and sustainable quality of life, participate in a competitive economy by means of satisfying employment, and share in a democratic culture" (RSA, 1996b: 3). The interceding two decades have witnessed the generation of more detailed strategies and plans, which ostensibly sought to reform the science and technology system into an appropriate, relevant and functional NSI. South Africa has thus generated significant lessons, accumulated through the implementation of the NSI policy framework and the reform of the science and technology institutional landscape within rapidly changing global and domestic contexts. It is important to locate the efforts made by South Africa in seeking to induce transformative change within a national project of consolidating a constitutional democracy, engendering social cohesion,

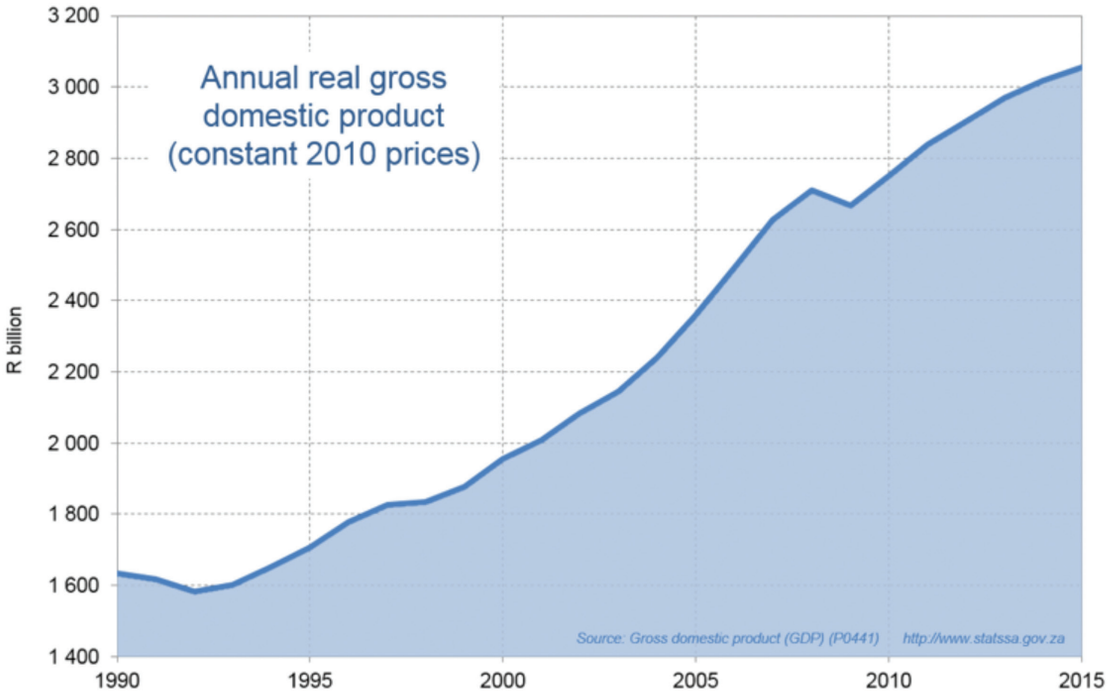
and redressing the inequitable distribution of economic wealth and incomes. Adding to the complexity of the situation is the heightened awareness and consciousness that the strategies and tactics of reconstruction and development would have to be pursued within ecologically determined constraints and a rapidly changing balance of forces in the international political economy.

4.14 The work of Mazzucato is particularly relevant to the contemporary conjuncture in South Africa, as she exposes the populist neoclassical myth framed as 'Market Failure Theory' that argues that "government should take a back seat and simply create the 'conditions' for innovation - establishing a playing field, but allowing the playing itself to be done by the dynamic business community" (Mazzucato, 2015: 3). This foundational misconception had driven an essentially conservative approach to policymaking in the first democratic government of national unity in 1994 and was further embedded in the architecture of the political economy when it adopted the Growth, Employment and Redistribution (GEAR) strategy as its macroeconomic strategy for the country (Maharajh, 2016). Besides rendering the more expansionist expressions of the Reconstruction and Development Programme (RDP) unattainable, the impact of GEAR was to significantly reduce government expenditures as resources were shifted to repaying the odious debts of the apartheid regime.

4.15 An increasingly sophisticated and complex NSI has continued to evolve in South Africa. The transition to post-apartheid South Africa has ensured the continuance of the country as one of the most diversified economies on the continent, the leading financial hub, a major resource for higher education, and the leader in research and innovation. Even the OECD noted that this status did not come easily: "the most striking achievement of South Africa has simply been to defy the extremely poor framework conditions facing the innovation system in the early 1990s" (OECD, 2007: 4). While institutional reforms have largely proceeded within a more conservative (neo-liberal) macro-economic framework, transformation of the STI apparatus of the state remains mired in legacies. As noted by Abrahams and Pogue in reference to the period between 1994 and 2010, "Policy and institutional choices over the past 15 years have skewed the innovation system towards science, engineering and technology for the middle-class and upper middle-class parts of the economy and society" (Abrahams and Pogue, 2013: 292). They argue further that the "cross linkages between inequality and the evolution of the innovation system create a tension which must be broken" (ibid.: 292). This narrative is in accordance with recent observations by Daniels argues that "Evidence also indicates that the present-day science and technology and R&D-led innovation has contributed to exacerbating poverty, inequality and social exclusion, and thus may be reinforcing these societal challenges rather than addressing them" (Daniels, 2016: 2).

4.16 South Africa is estimated to currently host a population of approximately 55 million people (Stats SA, 2016a). The size in market prices of the South African economy in 2015 was estimated at R3,055.2 billion and measured in constant 2010 prices, seasonally adjusted and annualised (Stats SA, 2016b). Figure 5 shows how the GDP of the country has nearly doubled since the transition from apartheid in 1994 to its current institutional form as a constitutional democracy.

Figure 5. South African GDP (1990-2015) in constant 2010 prices



4.17 In the context of world systems, South Africa contributes only 0.46% of the global economy's total output. Emergent in the context of international and intranational inequalities is the ascension of Brazil (3.15% of total world output), Russia (2.49% of total world output), India (2.74% of total world output), China (13.9% of total world output) and South Africa (BRICS) as a new geopolitical bloc of the semi-periphery of the world systems. The BRICS countries are constituted by 42% of the world's population and collectively contributed 22.74% of the world's GDP in 2015. This share is only marginally lower than the USA, which generated 23.32% of world output.

4.18 Even though the direct share of GDP of the minerals-energy-chemicals complex has fallen, its indirect contribution is massive, and this shapes economic structure, livelihoods and lived experiences. Unprocessed commodities remain the leading exports and source of foreign exchange, and the share of manufacturing in GDP has declined. Correspondingly, the services sector has been the main contributor to economic growth since the 1980s, contributing 66% of GDP. Mineral dependence comes with significant environmental and health costs: South Africa's carbon footprint is 13th in the world; nitrogen oxide emissions stand at 30th, a measure that is somewhat misleading since these emissions, the highest in the southern hemisphere, are concentrated on the Highveld. Even as environmental degradation remains problematic, the opening of the market to renewable energy providers has mitigated the electricity supply crisis and inadvertently somewhat reduced the carbon footprint.

4.19 According to Stats SA, South Africa employed 9.2 million people in the second quarter of 2016, which represented a decrease of 67 000 jobs since the first quarter of the year (Stats SA, 2016c). The jobs lost were in the community services, finance, manufacturing, mining, trade and transport sectors (ibid.). Government shed 55 000 jobs, of which 48 000 were temporary employment opportunities at the Independent Electoral Commission, and 7 000 were directly linked with national government

departments' reduced expenditures (ibid.). A further concern generated by such empirical data is the challenge of young people in South Africa who are neither in employment, nor in education and training. The UN Development Programme (UNDP) Human Development Report argues that "work can enhance human development when policies expand productive, remunerative and satisfying work opportunities, enhance workers' skills and potential, and ensure their rights, safety and wellbeing" (UNDP, 2015: 1).

4.20 According to the UNDP, South Africa achieved an Inequality-adjusted Human Development Index (IHDI) score of 0.428, which represented a loss in its Human Development Index (HDI) of 35.7%, resulting in it sliding 15 places lower in the international rankings (UNDP, 2015). According to Bhorat (2015), South Africa is "one of the most consistently unequal countries in the world". South Africa is home to the most unequal distribution of incomes and wealth, which is consistent with its history and the persistence of market-orientated fundamentalisms, which continues to exclude the majority of the country's population from access to economic resources. The following figures provide details of South Africa's Gini[10] and Palma[11] indices.

Figure 6. Income and consumption Gini scores for South Africa

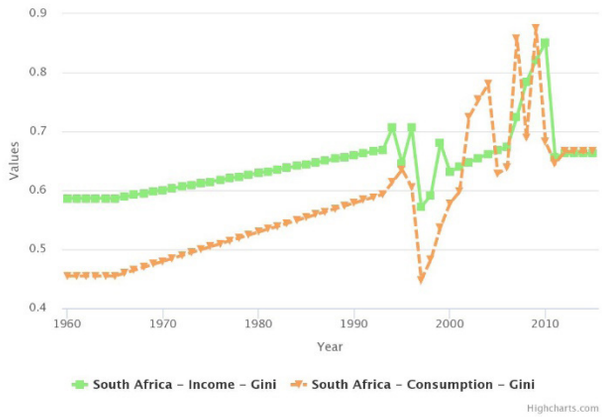
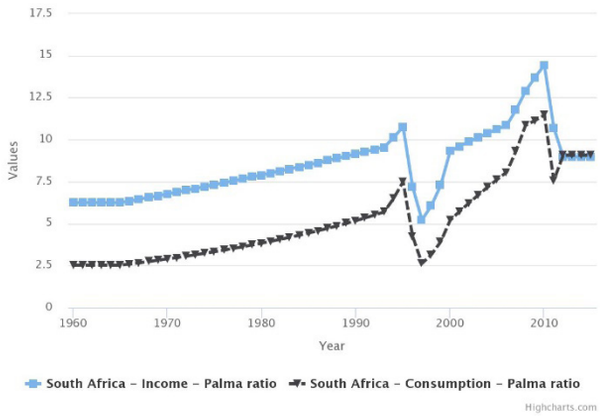


Figure 7. Income and consumption ratios for South Africa



Source:

4.21 The analysis by Orthofer (2016b) of the Personal Income Tax (PIT) assessment for the 2010-2011 tax year recognises the exclusion of nearly 80% of the population due to their incomes being assessed at below the threshold for filing returns. She, therefore, correlates the information with that derived from the National Income Dynamics Study (NIDS). In describing the circumstances of the 20% of the country's population that earned sufficient incomes to file tax submissions, she notes that "The wealthiest 10% of the population own at least 90 to 95% of all wealth, whereas the highest-earning 10% receive ('only') 55 to 60% of income; (t)he next 40% of the population - the group that is often considered to be the middle class - earn about 30 to 35% of all income, but only own 5 to 10 % of all wealth; and (t)he poorest 50% of the population, who earn about 10% of all income, own no measurable wealth" (Orthofer, 2016b: 4). This data has significant implications for class formation in the new South Africa. According to Orthofer (2016b: 6), "While there may be a growing middle class with regards to income (the middle 40% of the income distribution come close to owning a 'fair' share of 30 to 35% of all income), there is no middle class with regard to wealth: the middle 40% of the wealth distribution is almost as asset-poor as the

10 The Gini Index is a measure of the deviation of the distribution of income among individuals or households within a country from a perfectly equal distribution. A value of 0 represents absolute equality, a value of 100 absolute inequality.

11 The Palma ratio is defined as the ratio of the richest 10% of the population's share of gross national income divided by the share of the poorest 40%.

bottom 50%".

4.22 A recent study by the Centre for Social Development in Africa of the University of Johannesburg suggests that over a third of people aged between 15 and 24 are not in employment, education or training, despite interventions from the state, such as the Expanded Public Works Programme and the Employment Tax Incentive, popularly known as the youth wage subsidy. Of particular worry is the recognition by Lauren (in Musgrave, 2016) that "A key human development assumption is that investment in education can break the cycle of poverty. However, youth in this study have higher levels of education, and many have completed some form of post-secondary education or have a training qualification. Yet, they still face unemployment and poverty. This not only points to wider economic challenges that underlie structural unemployment and systemic failures in education, but also to other barriers that keep talented young people locked out of work opportunities". As argued by Kay (2015), "It is a mistake to focus basic education on job-specific skills that a changing world will render redundant in a few years. The objective should be to equip students to enjoy rewarding employment and fulfilling lives in a future environment whose demands we can neither anticipate nor predict. In 20 years, we will probably not be using the Black Scholes Model, or be referring to the case of Bloggs v Bloggs. But the capacities to think critically, judge numbers, compose prose and observe carefully - the capacities that education can and should develop - will be as useful then as they are today".

4.23 Our current conjuncture reflects our historical past and contemporary challenges, and obscures progressive possibilities in our emergent futures. Contemporised with the rise in environmental degradation is the expansion of world systems that largely represent a variety of capitalist formats through which globalisation has engendered an integrated, interdependent and hierarchical international economic order. Poverty, underdevelopment, unemployment and inequality constitute major inherited and embedded structural legacies. The minerals-energy complex, which underpinned apartheid, was being unbundled and de-concentrated, but its impacts included increased ecological constraints and environmental degradation. State capacities and capabilities are displaying evidence of being 'hollowed-out' through the local variation of new public management (NPM) also known as *Batho Pele* (RSA, 1995). This has perversely allowed continuities with the corruption of apartheid (Van Vuuren, 2006).

National Development Plan and Vision 2030

4.24 The NDP reminds South Africa of its original RDP by quoting from that seminal document that "No political democracy can survive and flourish if the mass of our people remain in poverty, without land, without tangible prospects for a better life. Attacking poverty and deprivation must, therefore, be the first priority of a democratic government" (RSA, 2012). While the achievement of the objectives of the NDP requires progress on a broad front, three priorities stand out: raising employment through faster economic growth, improving the quality of education, skills development and innovation, and building the capability of the state to play a developmental, transformative role. The NDP is premised on a recognition that science and technology "continue to revolutionise the way goods and services are produced and traded" (RSA, 2012). The NDP further asserts that "As a middle-income country, South Africa needs to use its knowledge and innovative products to compete" (RSA, 2012). For the NDP, innovation is necessary for a middle-income country to develop, because "On its own, a more competitive cost of production will not be sufficient to expand the global presence of South African industry. This applies to both new industries and traditional sectors, such as mining" (RSA, 2012).

4.25 In advising the Senate of the USA how to avoid 'secular stagnation', Mazzucato argued that "What is needed to both fuel innovation and limit inequality is a change in the narrative about the role of the state in the innovation-driven, wealth-creation process: a narrative that doesn't just describe the state as regulating and re-distributing the pie, but gives tax payers the credit for having co-created the pie in the first place, through strategic public investments of the kind that led to the technology behind the iPhone. Alongside, of course, an active innovative business sector that invests in both basic and applied research. Then, perhaps, we can have the courage to debate the really big questions about how to get public and private actors in the US to build together the future foundations of growth, through long-run investments aimed at new missions – whether they be around climate change, ageing, or even the mission to Mars – galvanising innovation in many different sectors" (Mazzucato, 2015b: 6). Herein lies a major challenge for South Africa's NSI. Whereas the USA is a much more advanced and mature capitalist country, the tasks of engendering working together on medium- to long-term planning horizons seems particularly difficult.

4.26 The NDP recognises that science and technology can also be leveraged to solve some of the biggest challenges in education and health. The NDP identifies the high domestic cost of broadband internet connectivity as a major hindrance. All South Africans should be able to acquire and use knowledge effectively. To this end, the institutional arrangements to manage the information, communications and technology (ICT) environment need to be better structured to ensure that South Africa does not fall victim to a 'digital divide'. Besides bridging the digital divide, the NDP also specifies that the country "needs to sharpen its innovative edge and continue contributing to global scientific and technological advancement" (RSA, 2012). This requires greater investment in research and development, better use of existing resources, and more nimble institutions that facilitate innovation and enhanced cooperation between public science and technology institutions, and the private sector.

4.27 The NDP advocates that a "simultaneous focus on R&D and on the calibre of teaching would improve the quality of higher education, but without attention, inadequate human capacity will constrain knowledge production and innovation. Universities need to become centres of excellence at the cutting edge of technology. By attracting students from abroad, universities can generate revenue and increase the skills pool. Students from abroad who graduate from South African universities should qualify for a seven-year work permit to encourage them to stay and work here. While South Africa needs to spend more on R&D in general, the institutional setup also needs to improve the link between innovation and business requirements. Government should partner with the private sector to raise the level of R&D, with resources targeted towards building the research infrastructure required by a modern economy" (RSA, 2012).

4.28 The NDP also seeks greater synergies between R&D and the higher education and training system. The NDP, therefore, argues that "The performance of existing institutions ranges from world-class to mediocre. Continuous quality improvement is needed as the system expands at a moderate pace. A major challenge is that poor school education increases the cost of producing graduates, and a relatively small number of black students graduate from universities. Increasing participation and graduation rates, with the option of a four-year university degree, combined with bridging courses and more support for universities to help black students from disadvantaged backgrounds, is likely to yield higher returns" (RSA, 2012).

Multilateral climate change agreements and constraints on policy sovereignty

4.29 South Africa acceded to the Copenhagen Accord on 29 January 2010 and declared its intention to ensure that greenhouse gas emissions peak in 2020 to 2025 at 34 and 42% respectively below a business-as-usual baseline, plateau to 2035 and begin declining in absolute terms from 2036 onwards (RSA, 2011). The emission level derived from South Africa's pledge suggests that the country's emissions should peak between 2020 and 2025, plateau for approximately a decade, and then decline in absolute terms thereafter. This characterises a peak-plateau-decline trajectory that is conditional on a fair, ambitious and effective agreement in the international climate change negotiations under the Climate Change Convention and the Kyoto Protocol and the provision of support from the international community (RSA, 2016). South Africa viewed adaptation as a global responsibility in light of Article 2 of the Convention, as further codified in the UNFCCC as a temperature goal. It further understood that climate impacts were being driven by global inaction/action on mitigation. The adaptation burden is, therefore, a global responsibility. It is in that light that South Africa considered its investments in adaptation as a contribution to the global effort, which should be recognised as such.

4.30 On 1 November 2016, South Africa lodged its intended nationally determined contribution to reduce its contribution to climate change (RSA, 2016). The adaptation objectives and planning for implementation were to be undertaken over the period 2020-2030 and comprised six goals:
Develop a National Adaptation Plan (NAP), and begin operationalisation as part of implementing the National Climate Change Response Policy (NCCRP) for the periods 2020-2025 and 2025-2030.
Take into account climate considerations in national development, subnational and sector policy frameworks for the period 2020-2030.
Build the necessary institutional capacity for climate change response planning and implementation for the period 2020-2030.
Develop an early warning, vulnerability and adaptation monitoring system for key climate-vulnerable sectors and geographic areas for the period 2020-2030, and reporting in terms of the National Adaptation Plan with rolling five-year implementation periods.
Develop a vulnerability assessment, and adaptation needs framework by 2020 to support a continuous presentation of adaptation needs.
Communicate past investments in adaptation for education and awareness, as well as for international recognition (RSA, 2016).

4.31 South Africa estimated that the adaptation investment required for the period 2020-2030 would amount to approximately US$0.17 billion per annum.[12] Goal 5 would require the institutionalisation of a biennial study of climate-related impacts and responses through the early warning, vulnerability and adaptation monitoring system, with a view to determine the cost-effectiveness of responses and recommend improved or alternative responses. Damage costs associated with severe climate-related events (wildfires, storms, droughts and floods), including both direct and downstream costs, were estimated for the present-day climate and for the near future under low and moderate-high mitigation scenarios.

4.32 South Africa assumed that its NDP Vision 2030, sector plans and any future variants thereof would constitute the underpinning foundation for sustainable development planning in South Africa. The NCCRP provides guiding principles and will form the basis for the integrative NAP, focused on vulnerable sectors and geographic vulnerabilities. South Africa also sought to integrate flexible adaptation sector

12 The INDC utilised a currency exchange rate of 10 SA rand to 1 US dollar.

policies and measures into national and subnational policy frameworks to enable the implementation of climate change adaptation programmes and projects. Sector adaptation plans will be integrated into broader sector plans that are consistent with the relevant sector planning or regulatory legislation. South Africa also assumed that national and subnational policy and legislation development and budget reprioritisation would enable the institutional capability to plan and implement catalytic adaptation programmes and projects. The comprehensive adaptation-related training of development planners, regulators and practitioners was foreseen, and South Africa argued that specific adaptation planning at subnational level, taking into account specific or unique geographical circumstances, will be integrated into subnational development frameworks, land use schemes and the planning authorisation system in terms of the provisions of and standards set in the Spatial Land Use Management Act (SPLUMA). South Africa promised that its development of a national framework for early warning, vulnerability and needs assessment would be undertaken well before 2020. It was also stressed that South Africa would develop and support a climate change early warning and vulnerability network with the involvement of relevant stakeholders, such as the South African Weather Service and the South African Earth Observation Network, as well as the downscaling, modelling and adaptation academic community (RSA, 2016).

4.33 In keeping with South Africa's commitment to progress its contribution to the global effort to mitigate climate change in line with the principle of common, but differentiated responsibilities and respective capabilities, South Africa's mitigation component of its INDC moves from a "deviation from business-as-usual" form of commitment and takes the form of a peak, plateau and decline greenhouse gas (GHG) emissions trajectory range. South Africa's emissions by 2025 and 2030 will be in a range between 398 and 614 Mt CO_2-eq, as defined in national policy. South Africa specified this benchmark against which the efficacy of its mitigation actions would be measured. South Africa also identified the following technologies that could help the country to reduce emissions further: energy-efficient lighting, variable-speed drives and efficient motors, energy-efficient appliances, solar water heaters, electric and hybrid electric vehicles, solar photovoltaic (PV) cells, wind power, carbon capture and sequestration, and advanced bio-energy. The INDCs are, however, not the only global commitment that encumbers South Africa's planning of its NWPS&T. Another major multilateral obligation arises from the UN SDGs and, as discussed in more detail in sections 3.28 to 3.30.

4.34 In accessing the creditworthiness of South African debt, Standard and Poors found that "South Africa's pace of economic growth remains a ratings weakness. It continues to be negative on a per capita GDP basis. While the government has identified important reforms and supply bottlenecks in South Africa's highly concentrated economy, delivery has been piecemeal, in our opinion. The country's longstanding skills shortage and adverse terms of trade also explain poor growth outcomes, as does the corporate sector's current preference to delay private investment, despite high margins and large cash positions" (Standard and Poors, 2016: 3). Our advance, as a species, into the 21st century, has, however, been neither common nor even. Globalisation has reconnected humanity and has also laid bare our combined and uneven development. Thus, our contemporary conjuncture reflects the persistent injustices that continue to be reproduced through systems and structures of our global political economy and its international division of labour. Marginalisation, exclusion and, ultimately, underdevelopment are recognised features of our contemporary conjuncture. STI has played a role in maintaining such features, while also contributing to redressing some of them through 'creative destruction'. It is imperative that the South African state acts in the public good to redress the anomalous 'investment strike' by the local private sector and advance STI. On this note, we turn our attention to the emerging opportunities and threats posed by new developments in science and technology.

5. STI Megatrends Foresight Report

5.1 All scientific and technological fields exhibit dynamic characteristics. The internal dynamic of science and technology ensures that fields continuously develop. It is generally accepted that it is impossible to accurately predict all the future developments in all science and technology fields. However, by developing trends, it becomes possible to identify certain trajectories into various possible futures. This renders the STI Megatrends Foresight Report an invaluable supportive policy-determining tool in the NSI.

5.2 On 28 November 2016, the International Union of Pure and Applied Chemistry approved the names and symbols for four elements: nihonium (Nh), moscovium (Mc), tennessine (Ts) and oganesson (Og), respectively, for elements 113, 115, 117 and 118 (IUPAC, 2016). Besides including new elements into the periodical table, metrologists are also busy with changes to the practical system of units of measurement that constitute the International System of Units (SI). This process was initiated in 2014 through a resolution of the 25th General Conference on Weights and Measures, which sought to redefine the four base SI units, the kilogram, ampere, kelvin and mole, in terms of constants. The new definitions will be based on fixed numerical values of the Planck constant (h), the elementary charge (e), the Boltzmann constant (kB) and the Avogadro constant (NA) respectively. This will result in the definitions of all seven base units of the SI being subsequently uniformly expressed using the explicit-constant formulation, and specific *mises en pratique*[13] will be drawn up to explain the realisation of the definitions of each of the base units in a practical way. It is expected that this process will be completed in 2018.

5.3 Besides measurement and material sciences, huge advances in how we construct futures, or prospective studies have unlocked specific ways in which we can generate memories of the future today. The following subsections outline key changes that are expected in the following domains of science and technology: bio-economy and food security, climate change and energy, social cohesion, safety and security, space sciences, engineering and services (looking up and looking down), and water resources and sustainability. Full texts of these reports are submitted as a separate compilation to this situational analysis.

Bio-economy and food security

5.4 New possibilities for agriculture are identified in the urban, saltwater/saline and fishery sectors which emerge from the demands of food sustainability through enhanced local and global food security. A shift from 'grey tech' to 'green tech' emerges from the transition from established technologies to newer technologies with greater benefits for health, the environment and the bio-economy. Ultimately, building and maintaining resilient ecosystems and communities providing opportunities for enhancing biodiversity conservation, and reducing ecosystem degradation are critical.

Climate change and energy

5.5 It is well recognised that ongoing climate change is generating adverse effects on human and energy security. Concurrently, we are also experiencing increasing demands for primary energy, driven by population and economic growth. New technologies and opportunities for energy and the environment are increasingly becoming viable and available. The convergence affords increased opportunities for

13 A set of instructions that allow the definition to be realised in practice at the highest level.

a new energy mix. While urbanisation and megacity expansion also requires a move towards smarter and more sustainable cities, we also need to assess the energy infrastructure and its capacity for being improved and decentralised.

Social cohesion, safety and security

5.6 Demographic change and other challenges are driving a phenomenal growth in international migration. Geopolitical instability and the changing nature of warfare are further reasons that contribute to growing social inequality and instability. These trends are encouraging developments that support a move towards more holistic health, which privileges the prevention and treatment of diseases and pandemics. With an increasing digitally connected world, more attention is required in the field of cybersecurity.

Space sciences, engineering and services (looking up and looking down)

5.7 While it remains an eternal quest for humanity in 'looking up' at space, advances in STI are affording increased possibilities and opportunities to explore wider and deeper space. From earth-based infrastructures, rapid improvements in observation, positioning, navigation and communication now allow for improved 'looking down' capacities. A massive growth of micro and nano satellites is also evident in the increased deployment of equipment in space. As the resource base of the planet decreases, the capacity and capability to access resources from space becomes more necessary. Possibilities such as mining the moon, asteroid mining, and space-based solar panels for energy generation are shifting the location of the primary sector (Department 1) and require responses domestically. Within such opportunities lurks the hegemony of the USA and its military-industrial complex. Building competencies in space technology require attention to be paid to global/national security issues.

Water resources and sustainability

5.8 While the consumption of water grows, climate change and human activity are impacting on water resources. Consequently, transboundary aspects of water are increasing in importance. New technologies for sustainable water use are emerging, and the shift towards a circular economy must also concentrate on water.

6. Towards the Next-generation White Paper on Science and Technology

6.1 On 8 November 2016, Oxford University Press (OUP) announced its choice for Word of the Year as the adjective 'post-truth', which was defined as "relating to or denoting circumstances in which objective facts are less influential in shaping public opinion than appeals to emotion and personal belief" (OUP, 2016). According to OUP, "Post-truth has gone from being a peripheral term to being a mainstay in political commentary, now often being used by major publications without the need for clarification or definition in their headlines" (OUP, 2016). Until 2016, the date 9 November had been notable as the day on which the erstwhile government of the German Democratic Republic opened the wall segregating the city of Berlin into an epitomic caricature of the 'Cold War', thereby heralding "the apex of the neo-liberal counter-revolution in economics that began with the collapse of the Bretton Woods system in the early 1970s" (Ban, 2016b). With the announcement that Donald Trump had won the 58th presidential elections in the USA, and was poised to assume the role of the 45th President of the most advanced and mature capitalist economy in the world, 9 November has gained a newer and more relevant significance. Brought together, these facts confirm the choice of Word of the Year by OUP (which self-acknowledges its Dictionary as the "foremost single volume authority on the English language") as an apt descriptor of the current world situation and an important introduction to our analysis of the contemporary conjuncture. Echoes of 'post-truth' reverberate across international boundaries and find resonance in continental, regional and domestic discourses.

6.2 The year 2016 is also the 20th anniversary of the adoption of South Africa's White Paper on Science and Technology: Preparing for the 21st century by the Government of National Unity (RSA, 1996b). The post-apartheid Republic of South Africa was inaugurated in 1994 and heralded a rupture with centuries of mercantilism, colonialism, racial capitalism and decades of internal colonialism (segregation and apartheid). The passage of 22 years since the adoption of the WPS&T provides the vantage point whereupon this situational analysis is premised. The world is indeed a different place to what it was at the emergence of the new South Africa. It is thus necessary to revisit the epistemological influences on the WPS&T and update the empirically determined contextual factors that shaped its orientation and form. In shaping an NWPS&T, we should recognise that "Scientists and philosophers should be shocked by the idea of post-truth, and they should speak up when scientific findings are ignored by those in power or treated as mere matters of faith" (Higgins, 2016: 9). Slovo had argued a long time ago that people have "not yet succeeded in discovering everything there is to know about our material universe in wresting all the secrets of nature. But, ultimately there are no unknowable mysteries, and with each new advance in science, we advance closer to our goal of the conquest of objective truth" (Slovo, 1964: 74). For Higgins, "Scientists must keep reminding society of the importance of the social mission of science – to provide the best information possible as the basis for public policy. And they should publicly affirm the intellectual virtues that they so effectively model: critical thinking, sustained inquiry and revision of beliefs on the basis of evidence" (Higgins, 2016).

6.3 This situational analysis is cognisant of the profound impacts generated by the combination of individual cognitive capacities for social learning, our scientific and technological capabilities for transforming our ideas into methods and tools, and our innovative competencies in sharing our knowledge across society and generations. At an abstract and generic level, our learning capacities in R&D, our science and technology capabilities, and our innovation competencies constitute fundamental attributes that have

afforded us the opportunities to construct a globalised system of production, distribution, consumption and waste management that underpins the provisioning of our material requirements for reproduction. This system, while combined, also reflects increasing unevenness. The consequences of being enjoined within unequal relations generate contradictions, conflicts and crises. Such global challenges also become manifest in domestic matters. Thus, ecological catastrophes, social dissonance, political disquiet and economic paradoxes all find local embodiments in climate change, inequality, poverty and unemployment.

6.4 As noted by Brody, "A country without science is like a car without an engine: it's not going anywhere" (Brody, 2016: S1). South Africa requires such an innovative dynamic engine if it were to seriously seek to ensure that it does, indeed, redress the legacies of apartheid, decolonise its STI institutional landscape, and ensure a better life for all. In considering the periodisation of South Africa's evolution, it is important to acknowledge that STI did not begin with colonisation in 1652. Rather, the territories that would eventually coalesce into South Africa have a long history of innovation, tied to indigenous and traditional knowledge systems. The imposition of Eurocentric models largely eschewed the contributions of the local peoples and, therefore, demands redress in the subsequent epistemic hegemony currently in practice. This has a huge import in the context of increasing calls by students and academics for the decolonisation of higher education and training. The NWPS&T would be remiss were it not to speak to this challenge.

6.5 In the transition from apartheid to the constitutional democratic society established in 1994, much attention had been paid to the reform of the inherited STI apparatus. While significant progress has afforded institutions the ability to adapt organisationally to the new context, a more intense examination of the relevance and appropriateness of the STI institutional landscape needs to be conducted to identify the gaps in coverage and the levels of interlinkages and societal participation, especially in determining investment priorities. Also necessary are the requirements of expanding the NSI to be more inclusive and demographically representative. The challenges of social innovation and entrepreneurship require attention, especially in the context of faltering domestic economic growth prospects and socio-political unrest.

6.6 The NDP argues for two major transformations of the NSI in South Africa. Firstly, it clearly articulates the requirement of a larger, more effective innovation system, closely aligned with firms that operate in sectors consistent with the growth strategy. Secondly, the NDP demands that consideration be given to widening the system of innovation to ensure greater linkages between universities, science councils and other R&D role players in priority areas of the economy. The NWPS&T should seize these aspects of the NDP and advance them in a rigorous manner in order to expand the NSI with the objective of driving innovation for inclusive development.

6.7 The enormity of ecological challenges does indeed pose problems associated with maintaining our survival as a species on the planet. Various multilateral and international regimes, which all derive from science and technology competencies, are in the process of emerging. The NWPS&T would need to pay attention to the ways in which local policy sovereignty is curbed and constrained by such instruments. On the positive side, these accords also offer the possibility of progressive responses to the challenges of sustainability and of reconstructing society in general. Towards this end, it would be useful to consider the presidential address of Lubchenco (1998) at the annual meeting of the American

Association of the Advancement of Science in 1997, where she argued that "As the magnitude of human impacts on the ecological systems of the planet becomes apparent, there is increased realisation of the intimate connections between these systems and human health, the economy, social justice and national security. The concept of what constitutes 'the environment' is changing rapidly. Urgent and unprecedented environmental and social changes challenge scientists to define a new social contract. This contract represents a commitment on the part of all scientists to devote their energies and talents to the most pressing problems of the day, in proportion to their importance, in exchange for public funding. The new and unmet needs of society include more comprehensive information, understanding and technologies for society to move towards a more sustainable biosphere – one that is ecologically sound, economically feasible and socially just. New fundamental research, faster and more effective transmission of new and existing knowledge to policy- and decision-makers, and better communication of this knowledge to the public will all be required to meet this challenge" (Lubchenco, 1998: 491).

6.8 Nearly two decades later, it is now necessary to consider the establishment of a new social accord for STI between the citizens of South Africa and the role-players that constitute the country's NSI. In considering the application of such a device, it should also be noted that "Innovation is key to prosperity. But corruption is inimical to innovation. If firms and individuals are to be creative, and if their societies are to make the best use of that, competition and hard work must be more strongly valued than reliance on connections" (Mungiu-Pippidi, 2015: 295). Mungiu-Pippidi has also suggested that "for science and technology to fulfil their potential for growth, they must be empowered by a combination of funding and good governance" (ibid: 297). Ensuring the participation and inclusion of both 'domestic civil societies and science communities' allows for democratic national governments to be more accountable. Enabling such an initiative requires the construction of such a new social contract, which would be further enhanced through the elaboration of institutional compacts between the agencies of the NSI and policymakers. This will ensure that the public sector generates high-quality public goods that contribute towards expanding the global knowledge commons. Such an instrument will also make transparent the prioritisation by NSI agencies of relevant and appropriate expenditures of the resources invested within them. It will allow for better reporting and the possibility of wider participation in ensuring that science and technology deliver innovation as an outcome and thereby enables the socio-economic and political impacts required by the society they serve. This would also lay the basis for a monitoring, evaluation and learning system that works towards innovation outcomes and impacts rather than primarily focusing on inputs and processes.

6.9 According to IBM, "Every day, we create 2.5 quintillion[14] bytes of data – so much that 90% of the data in the world today has been created in the last two years alone. This data comes from everywhere: sensors used to gather climate information, posts to social media sites, digital pictures and videos, purchase transaction records, and cell phone GPS signals to name a few" (IBM, 2016). The brief presentation of some selected STI mega-trends shows the proliferation of new and emerging opportunities over the medium- to long-term planning horizons. It also supports the idea of embedding a permanent science and technology foresight competency within the NSI. Just keeping pace with developments requires robust capabilities and dedicated capacities. The NWPS&T would be remiss to neglect this crucial function from its objectives of improving the performance of the NSI, engendering transformative change, ensuring an orientation towards inclusive development, and improving the quality of living for all those in South Africa.

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14 A thousand raised to the power of six (10^{18})

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