Investigating cyberinfrastructure strategy, higher education policy and digital transformation in public South African universities

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Abstract

In 1996 the principle of the National System of Innovation (NSI) was introduced as a vehicle to eradicate South Africa's socio-economic challenges. In support, the government introduced a research and development strategy and a ten-year innovation plan, collectively addressing funding and priority research projects. The policy framework acknowledged the importance of elevating higher education through improved, development of human resources, knowledge creation, and collaboration on research and innovation.

The research investigated the impact of investment and policies in cyberinfrastructure on digital transformation at public universities, concerning teaching and learning, and research practices. The study adopted a qualitative single case-study methodology to understand the underlying concepts of the subject. Data was collected through in-depth interviews with senior managers specialising in higher education, science and technology, telecommunications, and through documentary analysis.

The findings of the research indicate that the historic investment and policies consideration in cyberinfrastructure has a positive impact on teaching and learning, and research at public universities. The effect varies according to the following, amongst other things: 1) financial standing of the public university; 2) geographic location of the public university; 3) historical background of the public university, and; 4) density of commercial ICT infrastructure.

The investment enabled public universities to access cyberinfrastructure and effectively collaborated with other research institutions. Investment in competency programmes empowered increased usage of cyberinfrastructure thereby growing research outputs, improved research quality, introduced technology transfer, human development, expanded the scope of research at public universities, enabled public universities to collaborate and host sections of international projects.

Declaration

I declare that this report is my own, unaided work. It is submitted in partial fulfilment of the requirements of the degree of Master of Arts in the field of ICT Policy and Regulation in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

Thato Toko

24 January 2020

Dedication

To the beautiful people of the African continent and diaspora, let altruism be the measure for our collective unbiased upliftment.

Acknowledgements

I am grateful to my supervisor, Dr Kirubagaran Jagathesan Pillay for their guidance and dedication throughout the research process; Ms Susisizungu Thandeka Ncube for their assistance with proofreading my research and being my soundboard; the generosity of the interview respondents. Without their support, this research would not have been possible.

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List of Acronyms

3D	Three Dimensional
AI	Artificial Intelligence
CHE	Council of Higher Education
CHPC	Centre for High-Performance Computing
CPS	Cyber-Physical Systems
CSIR	Council for Scientific and Industrial Research
DHET	Department of Higher Education and Training
DDF	Digital Development Fund
DIRISA	Data-Intensive Research Initiative of South Africa
DPME	The Department of Planning, Monitoring and Evaluation
DST	Department of Science and Technology
DTPS	Department of Telecommunications and Postal Services
EDD	Economic Development Department
FRD	Foundation of Research Development
FLOPS	Floating Point Operations Per Second
GDP	Gross Domestic Product
GDS	Growth and Development Strategy
HESA	Higher Education South Africa
ICASA	Independent Communications Authority of South Africa
ICT	Information and Communications Technology
IoS	Internet of Services
IoT	Internet of Things
ITU	International Telecommunications Union
MOHE	Department of Higher Education Malaysia
NACI	National Advisory Council on Innovation
NDP	National Development Plan

NICIS	National Integrated Cyber Infrastructure System
NPC	National Planning Commission Department
NREN	National Research and Education Network
NRF	National Research Foundation
NSI	National System of Innovation
PFLOPS	PetaFloating Point Operations Per Second
PICC	Presidential Infrastructure Coordinating Commission
R&D	Research and Development
RCCP	Rural Campuses Connectivity Projects
REN	Research and Education Network
SADC	Southern African Development Community
SANReN	South African National Research Network
SDG	Sustainable Development Goals
SIP	Strategic Integrated Project
SKA	Square Kilometer Array
STEM	Science, Technology, Engineering and Mathematics
STI	Science, Technology and Innovation
TENET	Tertiary Education and Research Network of South Africa
TFLOPS	TeraFloating Point Operations Per Second
USAf	Universities of South Africa
USAF	Universal Service Access Fund
VO	Virtual Organisation
WEF	World Economic Forum

Chapter One: Framing the context of South Africa's academic research network

This study examines the role of national policy, and higher education institutions' strategies have played in creating an enabling environment for digital transformation at public universities using cyberinfrastructure. This study will interrogate the impact of policy and investment in cyberinfrastructure in a situation where the mandate for supporting the use of ICTs for research, teaching and learning is not limited to a single department. Lastly, this study will describe the limitations and provide recommendations.

A qualitative single case-study methodology is used to understand the underlying concepts of the dissertation. The researcher collected data through in-depth interviews with senior managers at the Department of Higher Education and Training (DHET), Department of Science and Technology (DST), Department of Telecommunications and Postal Services (DTPS), Independent Communications Authority of South Africa (ICASA), and University of Witwatersrand, as well as documentary analysis.

1.1 Research problem statement

Through technological innovation, universities are proponents of a prosperous and inclusive growth-driven economy by producing skills and knowledge relevant to present and future economic and societal requirements, through a fair-minded education system. The challenge with the South African higher education system is that rural and remote institutions historically lacked appropriate ICT infrastructure for research, teaching and learning purposes. There are also concerns regarding the inconsistencies in the quality of graduates and high university dropout rates for both undergraduates and post-graduates.

The research seeks to understand the effect of the strategy for and investment in cyberinfrastructure on research, teaching and learning at public universities, as this has not been studied and reported on in depth. The investigation concerns the provisioning of access to bandwidth and strategy emphasis, and campus level access and usage. The research seeks to understand how cyberinfrastructure usage at public universities is encouraged and the value of cyberinfrastructure to research, teaching and learning.

1.2 Research purpose statement

The purpose of the research is to determine what role national policies and investment and organizational strategies have played in creating an enabling environment for effective digital transformation through the deployment of cyberinfrastructure, which can promote improved research, teaching and learning at public universities. Through a qualitative case study of a single university, this study strives to understand how public investment in cyberinfrastructure, and ICT policy in higher education–contribute to digital transformation in public higher education, by enabling improved research, teaching and learning.

The study is interpretivist, with the researcher adopting an exploratory-qualitative research method, using the case study method. The researcher will undertake data collection through interviews and document analysis: policy, regulatory, and university operational strategies.

1.3 Choice of case study

The researcher's option of selecting the University of the Witwatersrand for exploratory case study purposes considered proximity and research convenience of the institution. The University of Witwatersrand is one of the public institutions that make use of TENET as a service provider for network connectivity. DST's strategy on SANReN and the DHET's policies on higher education influences this public university's cyberinfrastructure environment.

1.4 Research Questions

1.4.1 Main Research Question:

What has been the effect of policy and investment in cyberinfrastructure on digital transformation at public universities, concerning teaching and learning, and knowledge creation, and why?

1.4.1.1 *Research sub-questions: With respect to the case study university*

1. How has the cyberinfrastructure funded through DST influenced the university's research capacity?
2. How does the cyberinfrastructure strategy effect on the university's teaching and learning?
3. How were the challenges on the use of cyberinfrastructure addressed?

1.5 South Africa National Research Network (SANReN)

The formation of the South African academic research network was a collaboration between the public higher education institution and the National Research Foundation (NRF), previously Foundation for Research Development (FRD). The collaboration resulted in the formation of Uninet in 1989, the South African academic and research network. Due to financial constraints, majority of the financial and equipment requirements including hosting facilities came from NRF with higher education institution contribution consisting of membership fees and paying for capacity usage (Shaw, 1991; Knoch,1997).

Uninet developed and implemented research infrastructure, including promoting the usage of the academic and research network within the Southern African Development Community (SADC) region (Shaw, 1991). Uninet enabled academia access to email, file transfer services, local and international information sharing through mailing lists, etc. (Shaw, 1991). Uninet was South Africa's first Internet Service Provider (ISP) and central to academia's efforts that led to South Africa is connected to the Internet (Balliah, 2001). Rhodes University pioneered the first international link to the Internet (Balliah, 2001). The introduction of the Internet in South Africa was for academic and research purposes (Shaw, 1991; Knoch,1997; Balliah, 2001).

The early foundation of the South African National Research Network (SANReN) was built on a collaboration between the public higher education institutions and the Foundation for Research Development (FRD), now the National Research Foundation (NRF). The collaboration resulted in the formation of Uninet in 1989, a cyberinfrastructure network to support South African academic and scientific research. Due to financial constraints, the majority of the financial and equipment requirements, including hosting facilities, were provided by the FRD, with the higher education institution contribution consisting of membership fees and paying for network usage (Shaw, 1991; Knoch,1997).

Uninet established the early cyberinfrastructure to support research and promoted the its usage within the Southern African Development Community (SADC) region (Shaw, 1991; Knoch,1997; Balliah, 2001). The network enabled access to email, file transfer services, local and international information sharing through mailing lists, etc. (Shaw, 1991). Uninet was South Africa's first Internet Service Provider (ISP) and was central to academia's efforts to be connected to the Internet (Balliah,

2001). Rhodes University pioneered the first international link to the Internet (Balliah, 2001). The South African National Research Network (SANReN) was established in 2007.

1.6 Framing Cyberinfrastructure

Of the various definitions encountered, the EDUCAUSE Campus Cyberinfrastructure Working Group and Coalition for Academic Scientific Computation's characterisation is relatively comprehensive: "Cyberinfrastructure consists of computational systems, data and information management, advanced instruments, visualization environments, and people, all linked together by software and advanced networks to improve scholarly productivity and enable knowledge breakthroughs and discoveries not otherwise possible" (Steward, Simms, Plale, Link, Hancock & Fox, 2010, p. 2).

This definition highlights the interoperability between technologies, as well as coordination between processes, systems, and human resources (competency) to enable increased productivity for teaching and learning; and innovation through knowledge creation. The elements of cyberinfrastructure directly link to key challenges for universities, such as access barriers (Peixoto, Martinazzo and Weber, 2017). Figure 1.1 illustrates the elements of cyberinfrastructure.

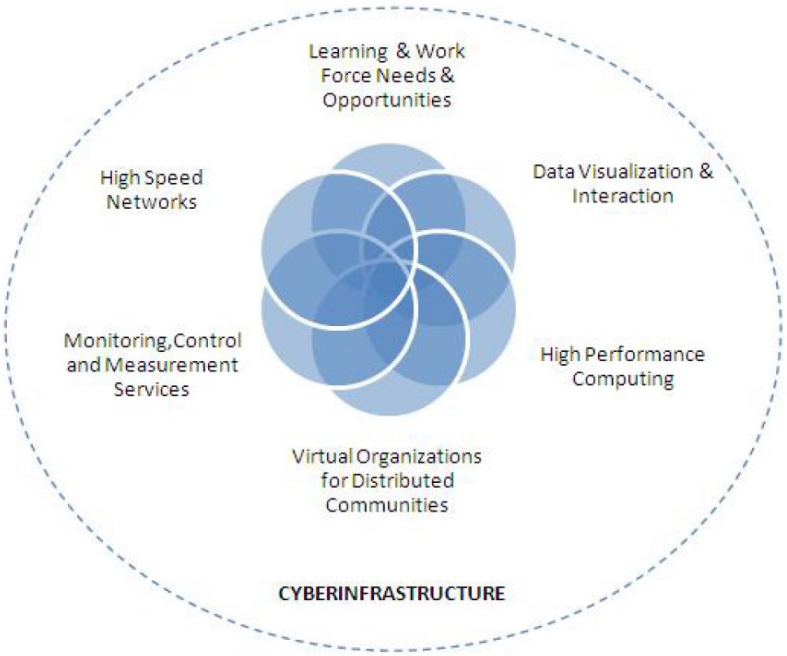


Figure 1.1: Schematic representation of cyberinfrastructure (Source: Ursuleanu, Graur, and Dimian (2010))

Figure 1.2 illustrates a cohesive and symbiotic end-to-end technological and human-based system which holistically makeup cyberinfrastructure (Steward et al., 2010). For example, a researcher may require subject-specific and multi/cross-disciplinary application software to access and analyse specific remotely stored data. The application software, in turn, will interface and collaborate with system software from remote but connected infrastructure (research groups/communities/education institutions) to source, process, visualise and store the resultant data.

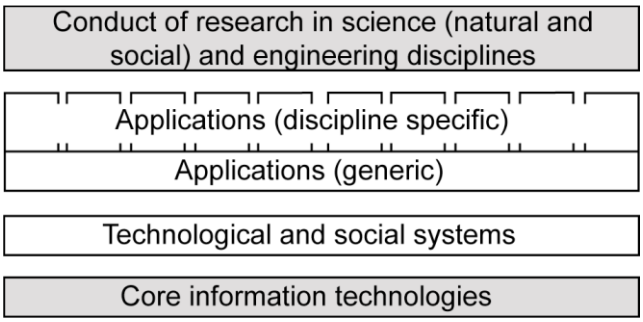


Figure 1.2: Relationship between components making up Cyberinfrastructure (Source: Steward et al., 2010)

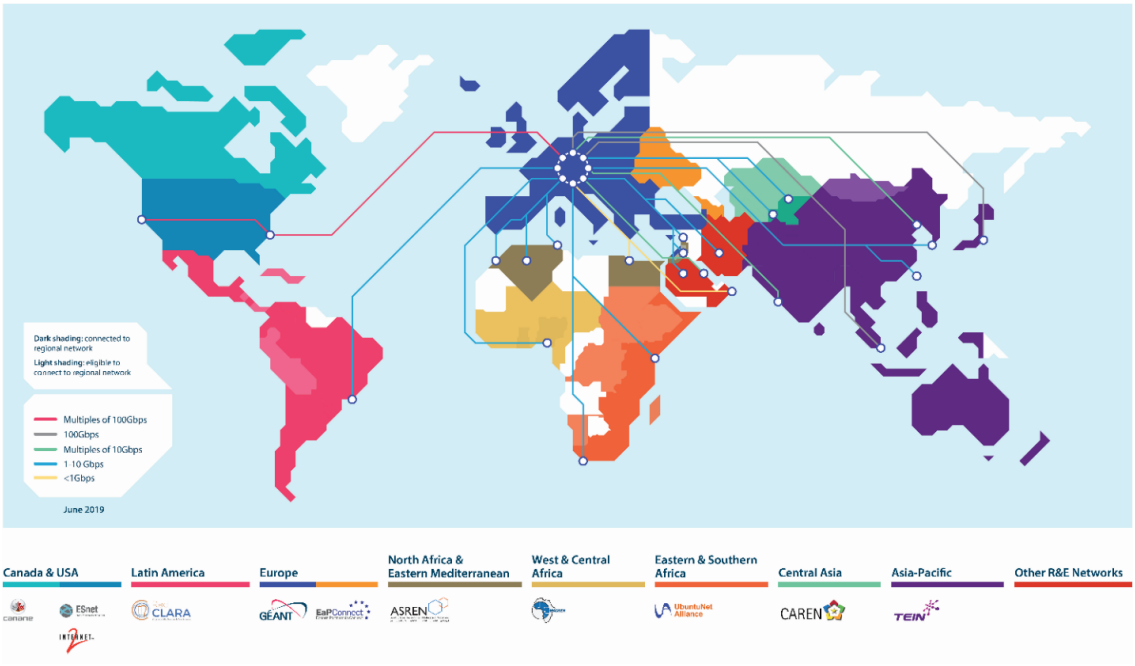
1.7 Characteristics of National Research and Education Networks (NRENs)

Cho (2015) characterises cyberinfrastructure as a system made up of three core infrastructures that are geographically dispersed and connected through the Internet by high network speeds: virtual organisations, grid computing, and scientific data. The term virtual organisation (VO) represents the cooperation between research communities, universities, and scientists through resource sharing for a common goal, or interest in research projects (Cho, 2015).

To facilitate the collaboration, coordination, and resource sharing, a private network made up of high-performance backbone links is built to nationally interconnect research communities and universities (Adams, 2016). The independent institution managing and operating the network is the national research and education network (NREN) operator. The research communities and universities take part in the governance structure of the NREN (Foley, 2016).

Countries each have organisations responsible for their NRENs for example, TENET in South Africa; Internet2 in the US; RENATOR in France; RNP in Brazil; CERNET in China; etc. Regions also have high-performance backbone links to interconnect country NRENs (Foley, 2016). These include GÉANT (Europe),

RedCLARA (Latin America), UbuntuNet Alliance (Eastern and Southern Africa), WACREN (Western and Central Africa). Figure 1.3 illustrates the interconnection



of the regional NRENs.

Figure 1.3. The Global Research and Education Network (Source: GÉANT (no date))

To ensure benefit of its members (including but not limited to research institutions and universities) NREN responsibilities include providing RENs regional and global connectivity; dedicated excess bandwidth between RENs; secure connectivity and network management; technical support; training; services specific to members' needs; authentication; etc. (Foley, 2016; Kashefi, Taylor, Abbott, Anagnostou, Tessa, Oaiya, Barry & Alline, 2018).

1.8 The National Integrated Cyberinfrastructure Systems for South Africa

1.8.1 The layers of the National Integrated Cyberinfrastructure Systems

In acknowledging the importance of appropriate and modern cyberinfrastructure as a driver for R&D and innovation, the Minister of Science and Technology commissioned the committee on infrastructure to "determine the appropriate model for the optimal integration of the components" (DST, 2013, p. 15) of the country's cyberinfrastructure. The committee report, titled National Integrated Cyberinfrastructure Systems: A framework for the establishment and maintenance of a sustainable NICIS, argued that South Africa's cyberinfrastructure is a two-tier

system (DST, 2013). Tier-1 consists of the following national components financed by DST devoted to science, research, education, and innovation -

1) Centre for High-Performance Computing (CHPC) is responsible for providing computational resources for educational, research and industrial usage;
2) The South African National Research Network (SANReN) is responsible for providing national and international connectivity to universities and research institutions, with TENET tasked to operate the network;
3) The Data-Intensive Research Initiative of South Africa (DIRISA) is responsible for data storage, "curation, provenance, trust, digital preservation, and analysis" matters; and
4) The South African Grid Initiative (SAGrid) is responsible for providing infrastructure to enable "sharing decentralised, autonomous computing facilities" (DST, 2013, p. 24)

Figure 1.4 illustrates the structure of the NICIS.

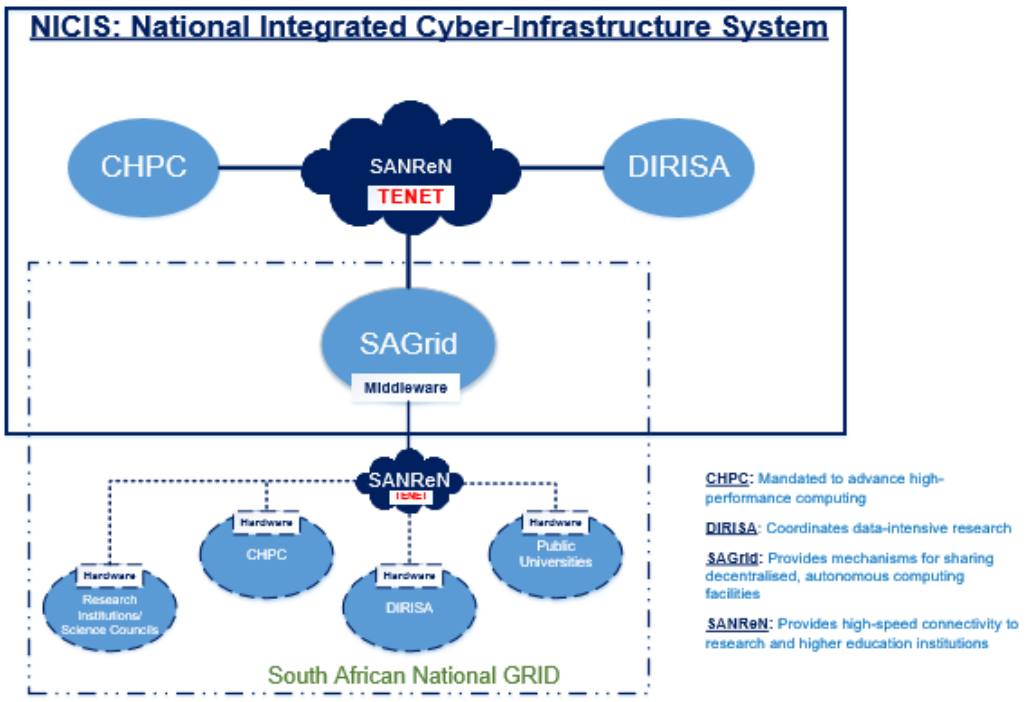


Figure 1.4. The Components of the NICIS, Source (Author)

Meraka Institute, a unit of the Council for Scientific and Industrial Research (CSIR) under the portfolio of DST, managed SANReN for many years though mandated and funded by the DST (DST, 2013). The Tertiary Education and Research

Network of South Africa (TENET), an organisation created by public universities, operates the SANReN network (DST, 2013). TENET also operates the tier-2 systems consisting of regional network infrastructure financed by the South African universities, research organisations and science councils.

The Department of Higher Education and Training (DHET) does not directly fund TENET, but instead funds state-initiated projects (DST, 2013; DHET, 2015b) such as the Rural Campuses Connectivity Projects (RCCP I & II) implemented in partnership with SANReN, Universities South Africa (USAf) and TENET (DHET, 2015b).

1.8.1.1 *The Centre for High-Performance Computing*

The Centre for High-Performance Computing (CHPC) was established in 2007 by DST as an intervention to strengthen South Africa's national cyberinfrastructure (DST, 2013). The government-funded institution seeks to make South Africa globally competitive by commissioning and providing massive parallel processing competences and services to empower industry and academic researchers. Universities are the primary users and upgrade drivers of the CHPC infrastructure (DST, 2013). To ensure effective utilisation of the technology platform, the CHPC provides human capital development through initiatives, which include flagship projects financially supporting research programmes for graduate students; training events and workshops for graduate students, e.g. CHPC winter school; and an annual Centre for High-Performance Computing Student Cluster Competition (DST, 2013).

1.8.1.2 *The South African National Research Network (SANReN)*

The SANREN is made up of the Tertiary Education and Research Network (TENET) and the South African National Research Network Competency Area (SANReN CA) and is responsible for ensuring authorised global access to South Africa's recognised tiered cyberinfrastructure systems (SANReN, "n.d."). The collaboration between SANReN CA and TENET includes the building and supporting of the national network for research, education, and innovation purposes (SANReN, "n.d."). The cooperation empowers and ensures that the network will benefit its targeted users, including safeguarding the fulfilment of R&D national development objectives. Figure 1.5 illustrates the entities making up the South African NREN.

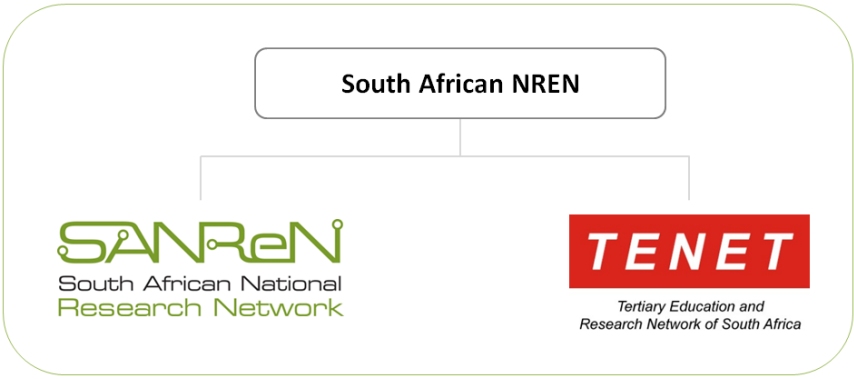


Figure 1.5. South African NREN (Source: SANReN (no date))

1.8.1.2.1 The South African National Research Network Competency Area

The SANReN CA falls within the portfolio of the Council for Scientific and Industrial Research (CSIR), which is tasked with implementing South Africa's science and technology R&D strategy by researching, developing, localising and diffusing technologies that will empower accelerated socio-economic prosperity for the country (CSIR, n.d.). The DST through CSIR has tasked SANReN with the responsibility to design, acquire and roll-out the national and international capacity for South African research communities and academia. SANReN CA develops and incubates advanced services applicable for research, teaching and learning purposes, e.g. network security, etc. (SANReN, n.d.). Figure 1.6 illustrates the SANReN backbone map indicating international capacity.

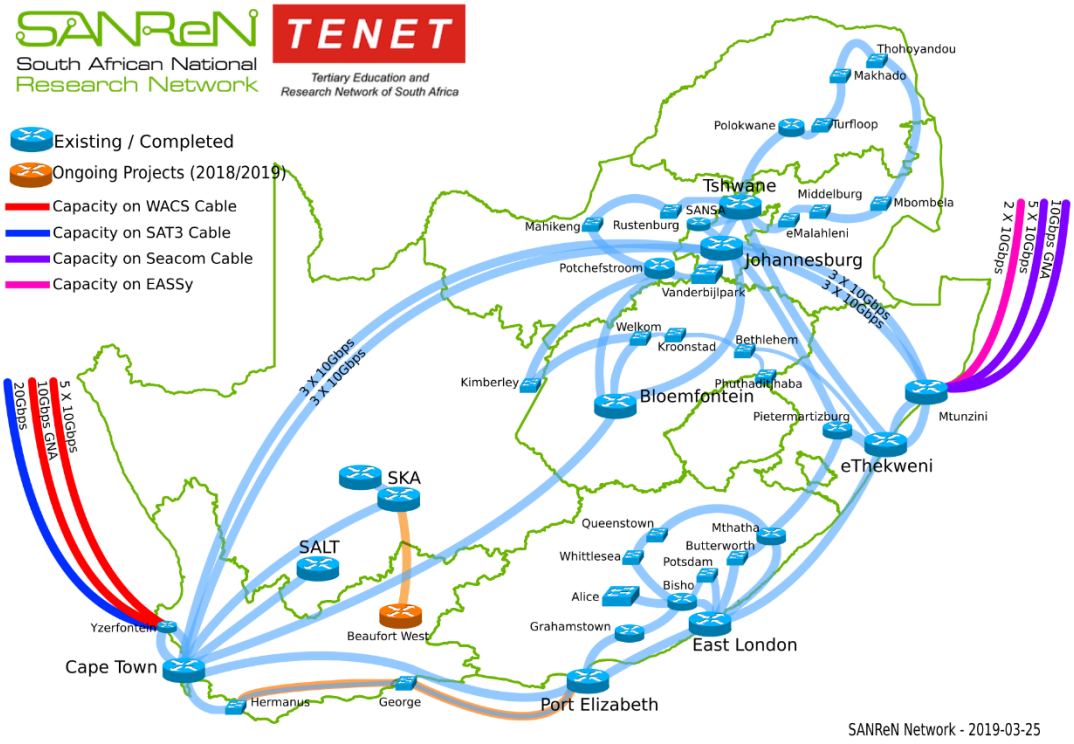


Figure 1.6. SA NREN Backbone Map indicating International Capacity (Source: SANReN (2019))

1.8.1.2.2 The Tertiary Education and Research Network of South Africa

The Tertiary Education and Research Network of South Africa (TENET) is a non-profit organisation managed and funded by South African universities, research organisation and science councils, tasked with providing connectivity to universities (DST, 2013). TENET collaborates with SANReN to provide technical expertise enabling the institution to operate the SANReN Network (TENET, “n.d.”). Over the years TENET has evolved, offering more than just connectivity to universities, research organisation and science councils. The institution has become more pro-active and started developing and sourcing more advanced services specifically tailored to the needs of the higher education and research communities, e.g. global roaming access service for academia (TENET, “n.d.”). This include access to seamless internet connectivity enabling researchers and registered mobile across campuses and another research and education institution (eduroam, 2018). Figure 1.7 illustrates the number and position of eduroam access points in South Africa.

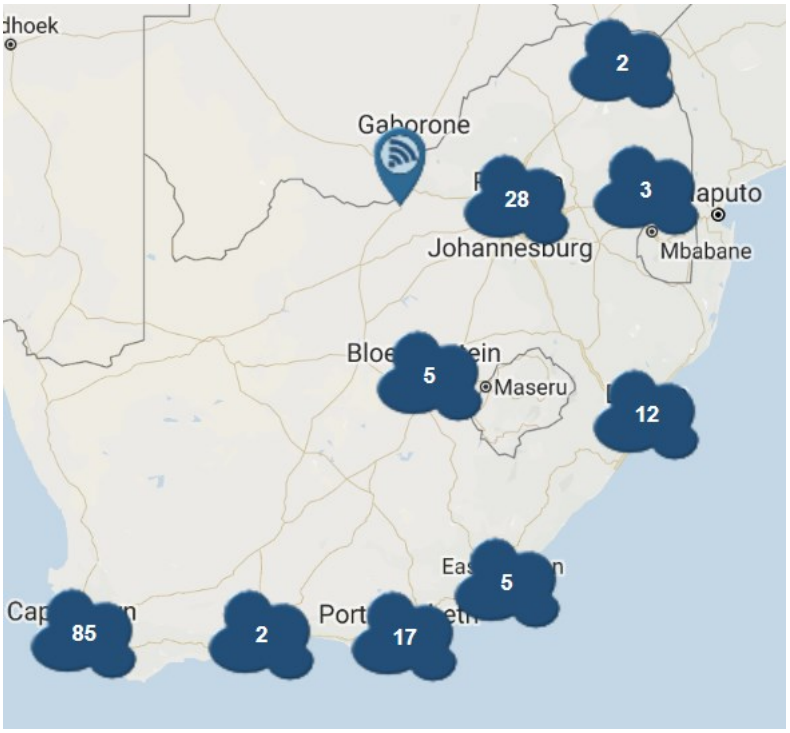


Figure 1.7. Number and position of eduroam access points in South Africa (Source: eduroam (no date))

The Department of Higher Education and Training (DHET) does not directly support TENET but instead funds state-initiated projects (DST, 2013; DHET, 2015b) such as the Rural Campuses Connectivity Projects (RCCP) I & I I implemented in partnership with SANReN, USAf, and TENET (DHET, 2015b).

1.8.1.3 *The Data-Intensive Research Initiative of South Africa*

The creation of the Data-Intensive Research Initiative of South Africa (DIRISA) is as a result of the realisation that CHPC created massive data capacity linked with initiatives born out of the commissioning and provisioning of massively parallel processing competences and services targeting industry and academic researchers (CSIR, n.d.; DST, 2013). DIRISA has the responsibility of ensuring the integrity of data linked with CHPC initiatives by coordinating and supporting the South African data-intensive research ecosystem that includes universities, research organisation and science councils.

DIRISA receives public funding to ensure: competencies in data management and the data sciences; implementing infrastructure for data storage; provisioning for curation, trust, data management, provenance, data sharing, digital preservation, data analysis; providing significant data usage guidelines; advising on policy issues

relating to data-intensive research; and other responsibilities(CSIR, n.d.; DST, 2013).

DIRISA collaborates with USAf to encourage the efficient usage of its infrastructure as an indication of the acknowledgement that across all academic disciplines, data-intensive research has produced innovative outcomes (CSIR, “n.d.”). This collaboration has encouraged the expansion of the infrastructure to enable the integration of the national e-science postgraduate training and teaching platform, and the accommodation of the regional research data centre hosted by a consortium of academic institutions (CSIR, n.d.; DST, 2013). Figure 1.8 illustrates DIRISA's value proposition.

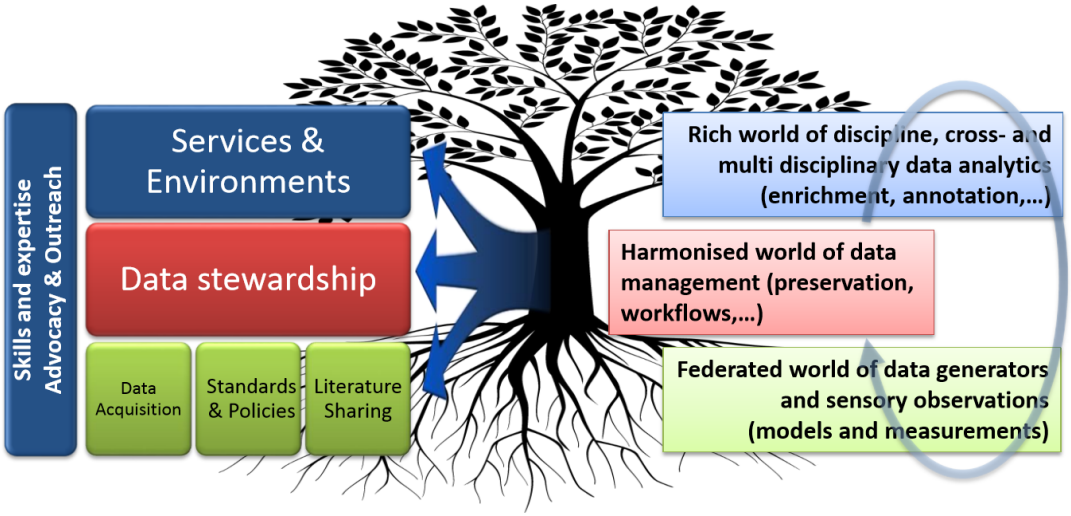


Figure 1.8. DIRISA value proposition (Source: DIRISA (no date))

1.8.1.4 *The South African Grid Initiative*

The investments made by the DST in CHPC and SANReN encouraged a consortium of universities and research laboratories to consider a collaboration framework that will improve (quality and speed) the productivity of research, that was not possible with the use of each institution's infrastructure used separately (Ardizzone, Becker, Gazendam, Eck, Vaux, Murray, Ballestrero, Ives, Barbera, Giorgio & Ricciardi, 2009). The collaboration framework resulted in the birth of the South African National Computing Grid (SA Grid) in 2008 (Ardizzone et al., 2009).

The pooled resources empowered researchers to complete tasks they previously could not enabled by the coordination and interconnection of each institutions' computing infrastructure via SANReN links (high-bandwidth and low-latency) which created a supercomputer. The SA Grid was coordinated through the Meraka

Institute (CSIR) and seeks to enable improved research outputs for multidisciplinary data-intensive projects through the coordinated sharing of decentralised autonomous facilities owned by a consortium of universities and research laboratories (DST, 2013). Figure 1.9 demonstrates the SAGrid with functional sites and site personnel, superimposed on the backbone of the South African NREN.

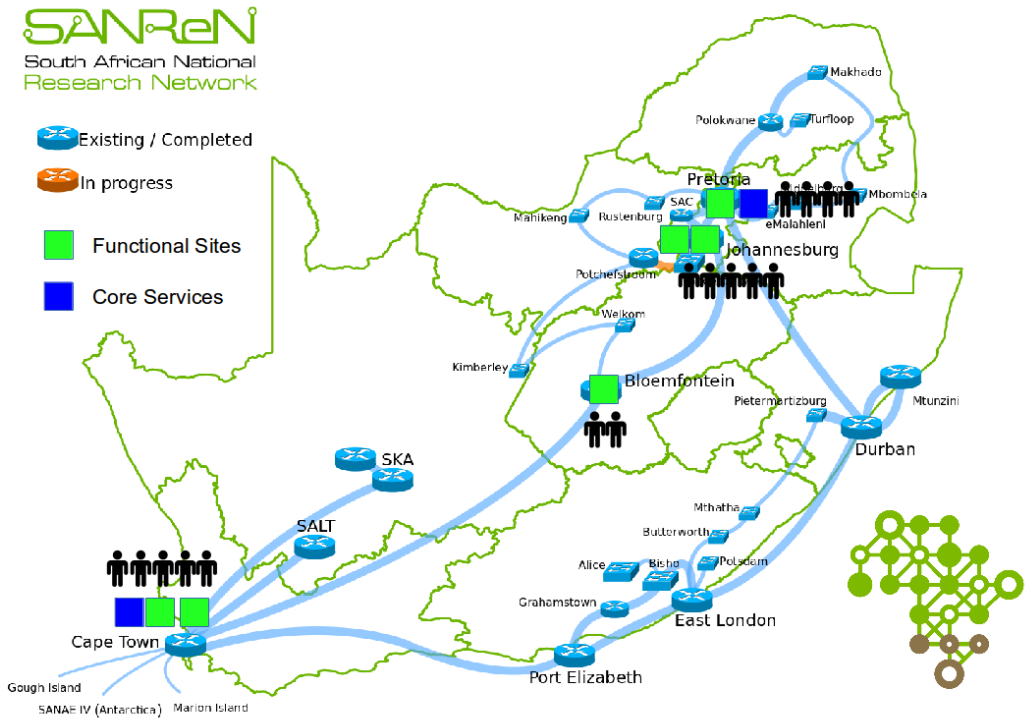


Figure 1.9. The SAGrid functional sites and site personnel superimposed on the backbone of the South African NREN (Source: africa-grid (no date))

1.8.1.5 *The Rural Campuses Connectivity Projects*

The purpose of the Rural Campuses Connectivity Projects (RCCP) is to connect rural higher education institutions to the SANReN network to ensure that all institutions are connected and have access to appropriately fast bandwidth (DHET, 2015b). The envisioned improvement of broadband connectivity at rural and remote campuses was expected to have a positive impact on research, teaching and learning and effectively decrease the digital divide between urban and rural campuses. The DHET undertook to do a needs analysis of universities with the purpose of ensuring "that the internal ICT infrastructure across all university campuses is updated and able to support new teaching and learning technologies,

the effective utilisation of e-resources, ICT administration systems" (DHET, 2015b, p. 3) by the year 2020.

1.8.1.5.1 The Birth of Rural Campuses Connectivity Projects I

The Universities South Africa (USAf), then Higher Education South Africa (HESA), together with TENET had concerns that the government-funded backbone network to connect universities was likely going to first benefit urban-based institutions due to historic technical reasons, e.g. lack of telecommunication infrastructure (HESA, 2015). The two institutions successfully lobbied the DHET to approve a grant allocation that would focus on ensuring the connectivity of rural campuses to the SANReN network thereby limiting the extent of the digital divide between urban and rural universities (Greaves, 2019). The RCCP I ran between 2011 and 2014 on an allocation of R28 million, despite the initial budget request being R127 million, to connect 22 sites (Greaves, 2016).

1.8.1.5.2 The Continuation of the Rural Campuses Connectivity Projects

The shortfall in the initial allocated budget implied that several rural campuses could not be connected. For the financial year beginning April 2015, USAf and TENET managed to successfully lobby the DHET to allocate funding to the RCCP again. The DHET approved a grant allocation of R71 million over four years for the connectivity of an additional 57 rural or remote campuses (Greaves, 2019). With RCCP II, USAf and TENET wanted to correct the challenges and gaps experienced during the implementation of RCCP I (USAf, 2017).

RCCP II accommodated institutions that could not afford operational and maintenance costs; sought consensus on the term rural; planned and executed for connectivity, as well as for capacity training for the use of the connectivity (Greaves, 2019).

1.9 Policy Framework

1.9.1 The Science and Technology Policy Framework

The 1996 White Paper on Science and Technology outlines the Department of Science and Technology's policy mandate (DST, 2018). The White Paper states that science and technology is "central to the success of the Growth and Development Strategy (GDS) of the Government as it seeks to address the needs of all South Africans" (DST, 1996). The White Paper introduced the concept National System of Innovation (NSI) as a vehicle under which science and

technology developments and applications would be used to address the country's socioeconomic issues (DST, 1996). The NSI represents a framework constituting collaboration between state-funded institutions and policies, with the sole purpose of creating, acquiring, diffusing and putting "into practice new knowledge to help achieve individual and collective goals" (DST, 2018, pp. 13).

Amongst the issues highlighted in the White Paper the following, among other things, elevate the importance of the role of higher education: development of human resources, knowledge creation, and collaboration on research and development (DST, 1996). Taking into consideration the impact of pre-democracy policies and the need for South Africa to become globally competitive, the White Paper proposes the review of the higher education systems that includes expanding to multi-disciplinary, innovative curricula and training programmes particularly for researchers (DST, 1996). The contribution to "national per capita income" (DST, 1996) of research activities illustrates the crucial roles higher education institutions play in national socio-economic progress. Lastly, the White Paper highlights the importance of R&D collaboration between higher education institutions, the research community and the private sector (DST, 1996).

The introduction of the 2002 National Research and Development Strategy and the 2008 Ten-year Innovation Plan for South Africa (2008 – 2018) were further policy effort to support the NSI (DST, 2018).

1.9.1.1 *South Africa's National Research and Development Strategy*

The South African government published the National Research and Development Strategy document (R&D Strategy) in 2002 to encourage improvement in the quality of life and generation of wealth through science and technology (DST, 2002). The purpose of the R&D Strategy is to realign the country's policy: 1) R&D funding as a factor of gross domestic product (GDP); 2) reprioritisation of research programmes; 3) addressing issues of ageing and decreasing R&D personnel; 4) all-inclusive R&D programmes; 5) coordinating intergovernmental strategies; 6) support for innovation as an output of the higher education system, (DST, 2002). For the country to achieve its goals on increased quality of life and inclusive economic growth, "South Africa has much more to do in the development of human capital and needs to stimulate higher levels of R&D and innovation spending" (DST, 2002, p. 29).

Figure 1.10 illustrates the strategy framework proposed and identified indicators determined as the "reliable way of measuring the progress of short, medium and long-term plans within an agreed strategy" (DST, 2002, p. 28). These "indicators allow long-term planning and tracking of the progress of the system as well as benchmarking against the performance of other countries" "(DST, 2002, p. 29). An effective strategy framework needs to fulfil the government mandate of ensuring a high quality of life and wealth creation (DST, 2002). An environment of leading in knowledge creation, innovation, increased productivity, and increase in relevant and current capacity enables the government to achieve its imperatives (DST, 2002).

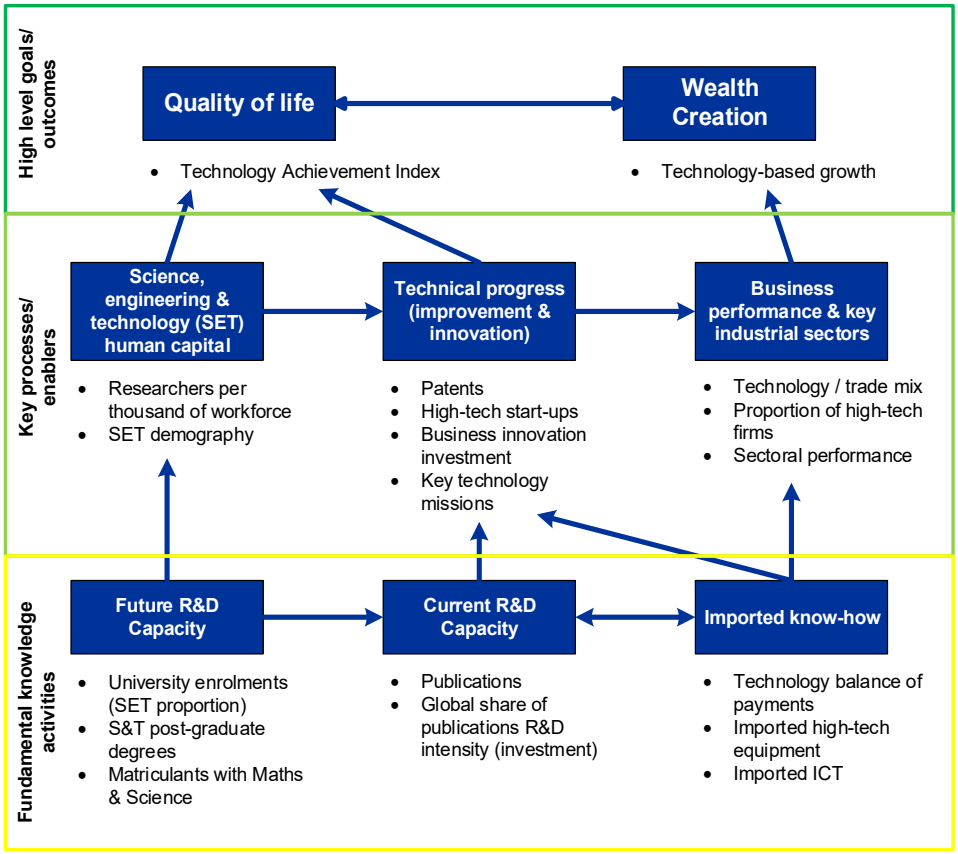


Figure 1.10. Revised strategy framework diagram (Source: DST (2002))

1.9.1.2 *Ten-year Innovation Plan for South Africa (2008 – 2018)*

The ten-year plan supports the NSI by outlining the strategic scientific research priorities that have been identified to have the potential to transform the country into a knowledge-based economy by the year 2018 (DST, 2008; DST, 2018). The plan seeks to create an environment that will encourage a conducive and beneficial environment for the transition process from research and innovation to

commercialisation (DST, 2008). The following have been identified, among others , as research priority areas: biotechnology, space, energy; climate change and research on human and social issues (DST, 2008). The strategic research priorities will be supported through "technology development and innovation, human capital and knowledge infrastructure" (DST, 2008, pp. 9) as illustrated in Figure 1.11.

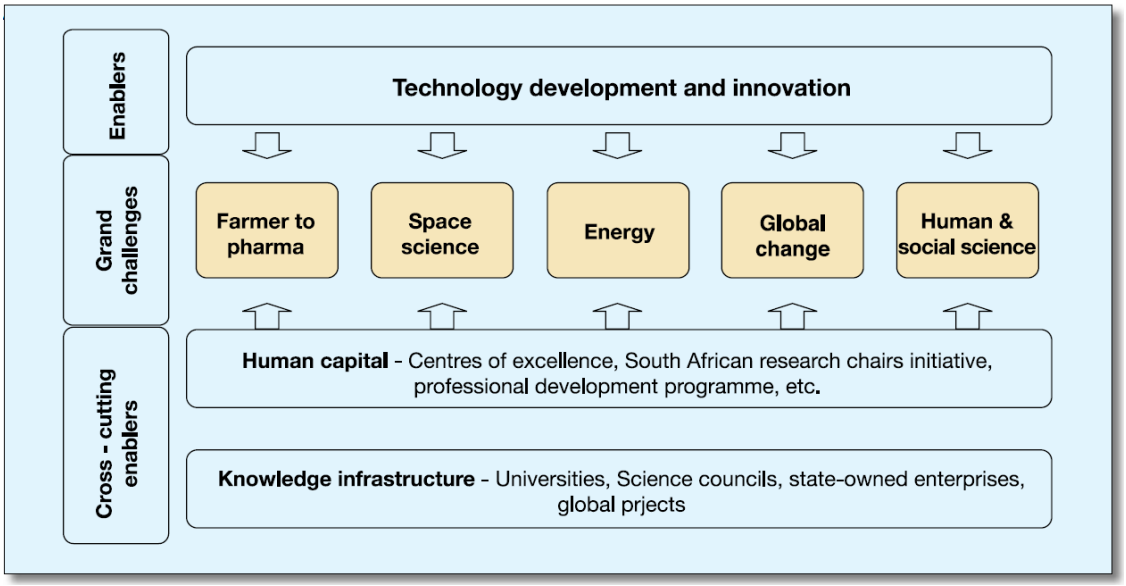


Figure 1.11. Strategic priorities and enablers of the ten-year plan (Source: (DST (2008))

South Africa seeks to be competitive in areas of biotechnology and the commercialisation of research and innovation undertaken by higher education, research communities and industry in collaboration with the "pharmaceutical, nutraceutical, flavour, fragrance, and bio-pesticide industries" (DST, 2008, p. 11). South Africa has elevated the importance of space science issues and has illustrated its intentions by hosting a large portion of the global project, the Square Kilometre Array radio-telescope (SKA) (DST, 2008). The SKA project addresses matters relating to the country's space research competencies and the manufacturing of space monitoring systems (DST, 2008). South African interests include satellite ownership and launch for services, which include earth observation, communication, navigation, engineering services and expertise development (DST, 2008).

South Africa's economy is dependent on sustainable and reliable energy sources. To ensure energy security, South Africa has prioritised energy research and production with respect to diverse sources of energy generation, a combination of

different energy generation technologies and types of energy sources used by users (DST, 2008). Higher education research has been identified as necessary in the following areas of energy sources, namely clean coal and gas, safe nuclear, and renewable energy (DST, 2008). South Africa's positioning and proximity to the "Antarctic, the Southern Ocean, and the Agulhas and the Benguela currents" (DST, 2008, pp. 19) enables the country to make a crucial contribution to global issues on climate change. The agricultural and health industries are generally first to experience the impact of climate change. Therefore, research into climate change will assist South Africa to create mitigation measures to strive to preserve the economy (DST, 2008). Lastly, the plan seeks to elevate the importance of research for "evidence-based support for interventions in learning processes and education, indigenous knowledge systems and heritage literacy" (DST, 2008, pp. 20). All these areas of research and innovation require contributions from universities, who need enabling cyberinfrastructure to access, host and share data and engage in research collaboration online.

1.9.2 The National Development Plan 2030

The National Development Plan (NDP) developed by the Department of Planning, Monitoring, and Evaluation (DPME), is South Africa's national unified strategy for development. It proposes a "vision, discusses challenges, and presents proposals" (DPME, 2011a, p. 296) in respect of all sectors, including the post-school education ecosystem. Concerning universities, the NDP (DPME, 2011a) identified targets to be met by the year 2030 if the higher education institutions are to succeed in addressing their mandate. With respect to the post-school education system, through "[i]mproving education, training and innovation" (DPME, 2011a, p. 295), the NDP (DPME, 2011a) seeks to address, inter alia 1) creation of employment opportunities relevant to the country's current and future needs; 2) drastic increase in "participation of black people, women and people with disabilities" (DPME, 2011a, p. 296); 3) encourage continuous learning; 4) empower innovation and research through increased participation rates at masters and doctorate levels; 4) increased higher education and industry collaboration; 5) ensuring consistency in quality of education in the post-school education system; and 6) encouraging higher education institutions to be globally competitive.

Amongst other sectors, the NDP recognises that "[e]ducation has intrinsic and instrumental value in creating societies that are better able to respond to the

challenges of the 21st century" (DMPE, 2011a, p. 296). The NDP (DPME, 2011a) further frames post-schooling systems as quality-based, well-coordinated, collaborative, interdependent and infrastructure-sharing, sufficiently funded and governed, an ecosystem to accommodate all educational needs of South Africans (DPME, 2011a).

1.9.2.1 *Challenges identified by the NDP*

The NDP (DPME, 2011a) raises issues of inconsistency in the quality and relevance of universities in South Africa. The consequence of the apartheid policies resulted in anomalies within the higher education systems where Universities deemed competitive were historically white, and institutions identified as mediocre were historically black (DPME, 2011a). This historical anomaly accounts for the current situation where too many universities are inadequately capacitated, lack enough funding, and are subsequently not efficient. The lack of funding also contributes to high attrition and impacts teaching and learning quality (DPME, 2011a). Also raised by the NDP (DPME, 2011a) are issues of lack of leadership and governance processes that have led to some institutions taken under administration.

The NDP (DPME, 2011a) also raises the issue of the high graduate unemployment rate, while industry is facing challenges of skills shortages. The situation of high graduate unemployment rates "is an indication that universities produce graduates who do not meet the needs of industry and society" (DPME, 2011a, p. 317). Universities are under pressure with respect to improving teaching and learning in an environment where funding has consistently lagged demand (DPME, 2011a). Figure 1.12 below illustrates how universities are increasingly dependent on student fees due to the decrease in both government and third-party funding (DHET, 2018). University annual fees increases are generally above inflation and therefore add to challenges of teaching and learning (DPME, 2011a). The NDP (DPME, 2011a) acknowledges inefficiencies in the current higher education system that have skewed demand for post-school education towards universities resulting in insufficient development of a range of skills for the economy.

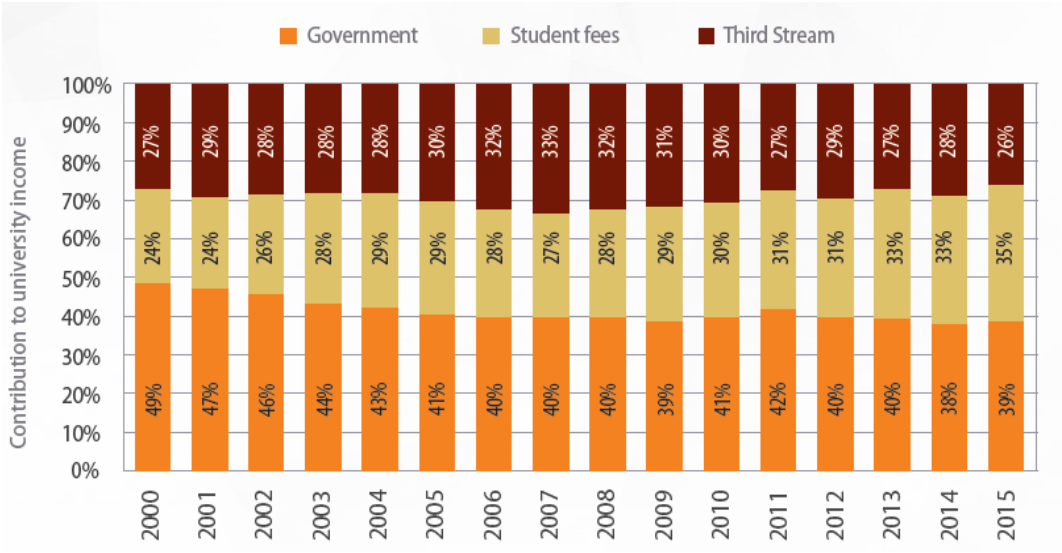


Figure 1.12. The main source of income for public universities (Source: DHET (2018))

Many, but not all these identified challenges, can be addressed through the effective and innovative use of cyberinfrastructure.

1.9.2.2 *NDP proposed targets for universities*

Specific to universities, the NDP proposes the targets to be achieved by the year 2030, *inter alia*: 1) university enrolment rate of at least 1,62 million per year; 2) at least 28% of university enrolment must be "towards maths and science-based degrees" (DPME, 2011b, p. 59); 3) 75% of annual university enrolment must obtain a bachelor's degree; 4) 25% of students enrolled at universities must be at masters and PhD levels; 5) at least 75% of higher education staff must have obtained a PhD; 6) universities must produce at least 5 000 PhD graduates per year; and 7) create an environment supporting the increase of "African and women postgraduates" (DPME, 2011a, p. 319).

To nurture knowledge creation and improvements in innovation, "[u]niversities need to become centres of excellence at the cutting edge of technology" (DPME, 2011a, p. 40). The NDP also calls for the expansion of "infrastructure of existing institutions and allow all universities [the] use of distance education to reach more learners" (DPME, 2011b, p. 61).

1.9.3 Infrastructure development Act of 2014

In 2012, Cabinet decided to create the Presidential Infrastructure Coordinating Council (PICC) to empower the South African government to implement priority

projects in line with the objectives of the NDP and to arrest negative consequences of the global economic decline due to subprime mortgage crisis (PICC, 2012). The PICC is mandated with integrating, coordinating, and accelerating the long-term priority projects and transforming the socio-economic landscape. Cabinet identified 18 Strategic Integrated Projects (SIPs) for the PICC to address a unified National Infrastructure Plan (PICC, 2012).

In June 2014 the Infrastructure Development Act came into effect and established the PICC in statute (RSA, 2014). The preamble to the Act states (RSA, 2014, p.2):

> To provide for the facilitation and coordination of public infrastructure development which is of significant economic or social importance to the Republic; to ensure that infrastructure development in the Republic is given priority in planning, approval, and implementation; to ensure that the development goals of the state are promoted through infrastructure development; to improve the management of such infrastructure during all life-cycle phases

Of the 18 SIPs, the two more relevant to the research are SIP 14 (Higher education infrastructure) under the responsibility of the DHET, and SIP 15 (Expanding access to communication technology) with the DTPS. The Treasury 2018 Budget Review under SIP14 indicated continued construction of the University of Mpumalanga and Sol Plaatje University as on-going major infrastructure projects (National Treasury, 2018). Table 1.1 below illustrates Treasury allocation under SIP 15, as stated in the Budget Review 2018. Under SIP 15, there is no mention of funding allocations for connectivity programmes linked to public universities.

R million	**2014/15**	**2015/16**	**2016/17**	**2017/18**	**2018/19**	**2019/20**	**2020/21**
SIP category	**Audited outcome**			**Preliminary outcome**	**Forecast**		
SIP 14: Higher education infrastructure	2 700	3 301	3 397	3 520	3 689	3 883	4 082

Table 1.1. SIP 14 allocation from the fiscus (Source: Treasury (2018))

1.9.4 Higher education policy

This section will only highlight the DHET draft open learning policy framework for post-school education and training (DHET, 2017). The researcher acknowledges

that several important policies affect the public universities, such as the policy framework for the realisation of social inclusion in the post-school education and training system. But to ensure focus, and to reduce the level of complexity of the multifaceted topic on public universities, the stated policy will suffice for this research.

1.9.4.1 *Draft Open Learning Policy Framework for Post-School Education and Training (2017)*

Leading from chapter 7 of the White Paper for Post-School Education and Training (DHET, 2014), the DHET gazetted Open Learning Policy Framework for Post-School Education and Training (2017) for public comment. In the draft, DHET strives to create a policy framework that will make open learning one of the complementary methods for attaining education at universities. Open learning is not expected to be secondary to, nor substitute traditional methods of education provisioning (DHET, 2017). The DHET advances the argument that a unified open learning system that is not only conscious of learners' background, but also integrates ICT applications can enhance teaching and learning including increased and diversified industry-relevant qualifications, at undergraduate through to doctoral level.

To ensure a unified understanding and adoption of open learning principles, the DHET (2017) draft framework seeks to create an integrated, interdependent and collaborative PSET ecosystem adopting open learning principles and "distance education methodologies" (DHET, 2017, p. 2) with a coordinated and systematic approach. To address issues of quality teaching and learning processes, the DHET proposes that the framework must determine tools and means to guide the phased adoption of open learning principles including "appropriate monitoring, evaluation, and quality assurance" (DHET, 2017, p. 2).

The framework envisions the following outcomes at all institutions under the supervision of the DHET: 1) open learning principles effectively and increasingly used; 2) supported pedagogy enabled by the use and integration of ICTs; 3) Open Education Resource (OER) forming the foundation of "high quality, shared teaching and learning resources" (DHET, 2017, p. 18); and 4) applicable education opportunities provided through competent open learning structures (DHET, 2017).

This proposed policy seeks to advance and champion open learning principles to complement but not substitute established traditional methods of education provisioning (DHET, 2017).

1.10 Structure of the Research

Chapter One introduces the NREN concept and its relevance to public universities, the framework for cyberinfrastructure and the some of the policies related to cyberinfrastructure and public universities.

Chapter Two explains the relevance of the analytical framework chosen for this study. It discusses available literature on digital transformation at public universities, the significance of cyberinfrastructure for public universities, policy consideration, and the effects of the data-driven revolution on digital transformation at public universities.

Chapter Three describes and justifies the appropriateness of the research methodology chosen for the study, the justification for the preferred methods for data collection and analysis, and the case study approach. Furthermore, this chapter describes the ethics requirements to ensure the reliability and integrity of the study.

Chapter Four presents insights obtained from the data collected. The elements of the analytical framework discussed in Chapter Two will be used to present the data thematically.

Chapter Five presents and discusses the meaning of the analysis of the data in relation to the body of knowledge reviewed in Chapter Two.

Chapter Six presents summation, conclusions, recommendations, limitations of the study, and suggestions for further research. This chapter also details the importance of this study.

1.11 Conclusion

This chapter provided a brief overview and history of South Africa's academic research network and evolution of cyberinfrastructure relevant to public universities, as background data to the research problem statement.

Chapter 2: A literature review: The implication of cyberinfrastructure, digital transformation and the fourth industrial revolution on higher education

The researcher acknowledges that the existing body of knowledge consistently refers to aspects of open learning principles when addressing issues of democratisation and massification of higher education in an environment where country economies faced with several challenges competing for governmental resources. This review explores the key concepts and challenges raised in the existing body of knowledge on the influence of national policy, cyberinfrastructure and digital transformation on public universities.

The acknowledgement of the role of the data-driven revolution is due to the transforming impact of big data, particularly the disruptiveness when integrating existing, emerging and new technologies with current policies and operational models the higher education institutions. The chapter concludes by discussing a conceptual framework relevant to addressing the identified research problem, as the outcome of the review of the existing body of knowledge and aligned theoretical framework.

2.1 Re-invention of higher education through digital transformation

As stated earlier, the purpose of this research is to strive to determine whether public investment already deployed for R&D and research infrastructure and ICT higher education policy have empowered digital transformation in public universities. This section mainly deals with some of the key principles of digital transformation; several success factors; and what a digitally transformed higher education ecosystem should enable. With respect to this latter point on enablement, it is noted that

> In the pursuit of growth and equity, no country can afford to ignore higher education. Through higher education, a country forms skilled labor and builds the capacity to generate knowledge and innovation, which boosts productivity and economic growth" (Ferreyra, Avitabile, Álvarez, Haimovich Paz & Urzúa, 2017).

2.1.1 Digital transformation concept

Digital transformation relates to the ability of institutions to speedily adapt and succeed in the fulfilment of core competencies in a rapidly changing environment, despite any challenges experienced (Manda & Backhouse, 2017). Another view

presented is that of digital transformation is a process enabling the integration of disruptive technologies into revised operational models to create and offer a variety of flexible and individualised programmes more efficiently, effectively and economically while improving quality of service/experience (Sharma, 2015; Seufert & Meier, 2016). The view is important when taking into consideration that the pervasiveness of technology has been integral and crucial to all aspects of life, to the extent that the impact has fundamentally changed how society expects to achieve education (Wilms, Meske, Stieglitz, Decker, Fröhlich, Jendrosch, Schaulies, Vogl & Rudolph, 2017).

At a national level, digital transformation is seen as the successful implementation of national strategy and policy reforms intended on creating an enabling environment for inclusive socio-economic growth in a “connected and smart society” (Manda & Backhouse, 2017, pp. 1). This enabling environment must equitably and non-discriminately expose citizenry to opportunities created, including sharing of financial and non-financial surplus because of leveraging the changes prescribed by the data-driven revolution technology drivers (Manda and Backhouse, 2017; Wilms, *et al.,* 2017).

From the above definitions it is clear that digital transformation is affected by not only the innovation of processes and people’s expectations but also by the environment including 1) enabling government policies, 2) digital needs and contributions of the private sector and state-owned companies,, 3) digital needs and contributions from higher education, and 4) a country’s technology status (Manda and Backhouse, 2017; Petrova & Kostadinova, 2017; Wilms, *et al.,* 2017). Beyond understanding and identifying key themes in digital transformation, it is also as crucial to highlight several elements that are central to the successful implementation of the innovative processes in higher education institutions, including the contributions from government and other public institutions.

2.1.2 Success factors for digital transformation

At the national level, Schwab (2016) Manda and Backhouse (2017) present the need for agile policy frameworks. The authors posit that agile policy will empower governments to adapt to the drivers of the data-driven revolution with the purposes of not only reaping the benefits brought about by the paradigm but also successfully mitigating against negative socio-economic impact accompanying the revolution.

For governments to successfully leapfrog some of the missed targets of the first three industrial revolutions, the adoption of the following digital readiness strategic pillars is recommended, *inter alia*: 1) agile and creative policy and legislative frameworks; 2) innovative economies; 3) future proof intellectual competencies; and 4) universal adoption, diffusion and usage of ICT tools/services & infrastructure (Schwab, 2016; Manda & Backhouse, 2017).

At the institutional level, the essential elements are people and processes, even though the accelerated technology developments and adoption are the foremost reasons for the revolution (Sharma, 2015; i-scoop, n.d). Digital transformation is about how people and processes can be efficiently and purposefully integrated through technology adoption, with the rationale of tackling identified present and future challenges (i-scoop, n.d; Seufert & Meier, 2016; Wilms, *et al.,* 2017).

The following elements at institutional level are also considered to be central to the successful digital transformation processes namely, 1) innovative psyche; 2) reinventing operational practices; 3) destroying departmental silos; 4) competency development; 5) value creation; 6) resource optimisation; and 7) accommodating people subtleties (Sharma, 2015; i-scoop, n.d; Wilms *et al.,* 2017). Organisational wide innovative psyche is important to how higher education institutions collectively approach changes introduced through digital transformation, as the process is a comprehensive approach demanding leadership support and participation (Salmon, 2014; Sharma, 2015; Seufert & Meier, 2016; Manda & Backhouse, 2017;). Innovative operational models should also empower the identification of new opportunities and initiatives seeking to empower institutions to timeously respond to varying and individualised student expectations (Sharma, 2015).

2.1.3 Digitally transforming higher education

The focus of the study is higher education. It is, therefore, necessary to highlight how higher education institutions are affected by technological developments and the change in societal expectations. The institutions are faced with challenges such as how technological disruptions have affected the culture of knowledge acquisition and institutional pedagogy delivery strategies, as witnessed through the increased adoption of blended learning, online institutions, mobile learning, etc. (Seufert & Meier, 2016; Petrova & Kostadinova, 2017). When harvesting the benefits of these disruptions, institutions must take cognisance of the challenges created when students from diverse demographical backgrounds find themselves

obligated to contribute, collaborate and interact in the quest for collective knowledge acquisition and creation (dos Santos, Punie & Castaño-Muñoz; 2016; Wilms *et al.,* 2017).

It is generally accepted that for digital transformation to be effective at higher education institutions, the implementation of collaborative and communications technologies must cater for all levels of student experience based on, *inter alia*: 1) diversity of background; and 2) phase within higher education lifecycle (e.g. undergraduate, post-graduate, Masters and PhD) (dos Santos *et al.,* 2016; Wilms *et al.,* 2017;). dos Santos *et al.* (2016) add that the higher education ecosystem needs to take into consideration the economic challenges of students when striving to enable the democratisation, massification and customisation of higher education.

In a digitally transformed environment, the industry benefits from innovative pedagogical processes and practices, while higher education makes use of industry subject matter specialists to create value for education (Petrova & Kostadinova, 2017). Two (2) ways higher education institutions and industry can collaborate are 1) industry specialists used as mentors during the training of lecturers; and 2) industry specialists used to provide practical skills to enhance theoretical concepts (Petrova & Kostadinova, 2017).

Additionally, quality of education can be guaranteed through the integration of technology into management strategy and through the inclusion of “appropriate, well-supported and focused human intervention, good learning design or pedagogical input and the sensitive handling” (Salmon, 2014, p. 221) of the cyclic transformational processes. Salmon (2014, p. 223) advises the inclusion of administrative staff, “academics and their departments” in the design of the transformation to ensure long term sustainability of change and to take note of the “cultural, historical, institutional and power-constructed contexts” of the university.

2.2 Value creation by NRENs

Policy and investment in cyberinfrastructure within the scope of NREN, research and higher education institutions empowers universities to be globally competitive and leverage innovative pedagogical processes and practices for research, teaching and learning. Globally, higher education and research institutions connect via dedicated, interconnected research networks managed through agreed protocols (Foley, 2016; Suresh, 2016). The interconnected networks are meant to

share resources (computing power, storage, raw data, instrumentation, course material, etc.) empowering innovation; discoveries; collaborative research; increased access to higher education; among other things (Cho, 2015; Foley, 2016; Pacheco, Nascimento & Weber, 2018). Each participating country or region generally manages its own National Research and Education Network (NREN). Figure 2.1 illustrates groups of NREN users.

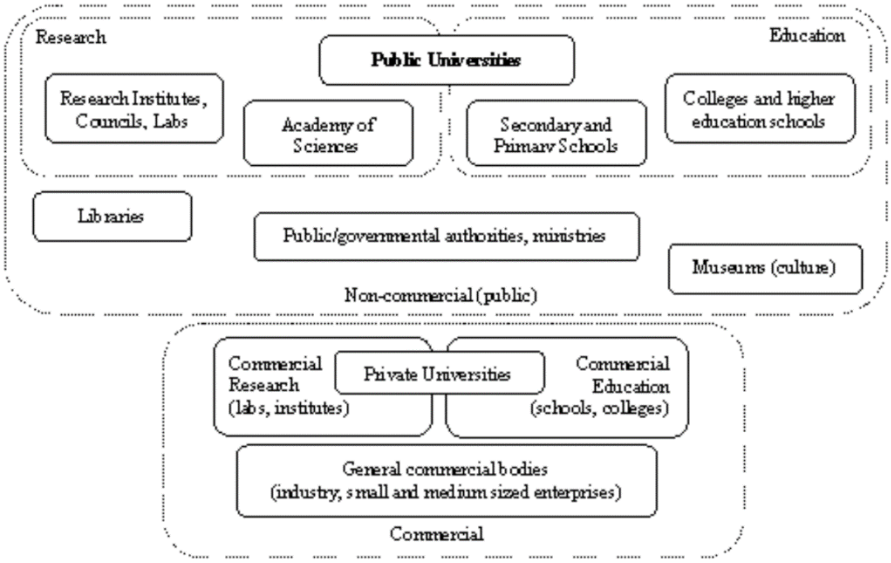


Figure 2.1: Classification of NREN users (Source: Galagan and Looijen (2009))

2.2.1 Importance of NRENs for Africa

In the last 10 years there has been urgency and concerted effort to encourage the formation of African RENs and RRENs connecting universities, enabling them to participate in collaborative local/regional/global research projects and access education resources (Foley, 2016; Kashefi, Taylor, Abbott, Anagnostou, Tessa, Oaiya, Barry & Alline, 2018). Foley (2016) raises the concern that Africa's economic development and global competitiveness is harmed by the situation where the majority of countries do not have established NRENs. Robust NRENs enable positive socioeconomic and inclusive development nationally, regionally and globally (Bankole & Assefa, 2017; Kashefi et al., 2016). Figure 2.2 illustrates the status of NREN on the African continent.

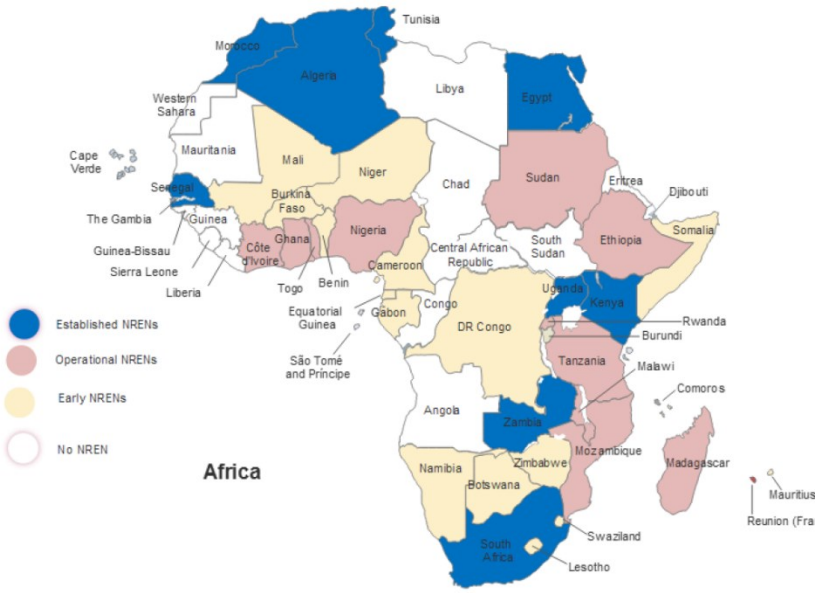


Figure 2.2: The status of NREN on the African continent (Source: Adams (2016))

The data-driven revolution requires African research communities and universities to highly dependent on RENs and NRENs to be globally competitive and to deal with localised challenges (Foley, 2016; Yaver, Sánchez-Torres, Amórtegui & Giraldo-Ríos, 2016; Kashefi et al., 2018; Smith & Veldsman, 2018;). Best practice requires RENs and NRENs to build and manage robust research infrastructure to ensure a conducive environment empowering provisioning of quality research, teaching and learning outcomes for socioeconomic growth and innovation (Kashefi et al., 2016; Yaver et al, 2016).

2.2.2 Universities exploiting the benefits of RENs and NRENs

Carabine (2016) argues that African universities that are already engaged in some form of digital transformation are in the best position to maximise the benefits of RRENs and NRENs. The author justifies this view by pointing out that the proliferation of smart devices is not by itself an indication of technology-savvy universities. A digitally transformed university enhances research, teaching and learning processes by making use of elements of the REN/NREN (Carabine, 2016; Foley, 2016). Carabine's (2016) justification includes academic peering, networking and knowledge sharing through guest lecturing via video conferencing services. Peering is an economically reasonable and sustainable solution for universities with funding challenges, as this allows collaborating institutions to exchange programmes via video downloads or video conferencing, and other

digitally-enabled activities (Carabine, 2016). Katz and Proctor (2014) posit that research infrastructure must support collaborative initiatives between a large number (quantity and variety of disciplines) of research communities exposed to big data.

Foley (2016) supports Carabine (2016) that the proliferation of smart devices and the exploitation of REN and NREN elements empower transformed universities to be innovative. The high penetration of smart and mobile devices has enabled universities to introduce bring-your-own-device policies and therefore empowering the institutions to improve research, teaching and learning by investing more into ubiquitous campus connectivity (Foley, 2016). Universities are also empowered to make use of applications, such as Google Apps, to enhance education (Carabine, 2016; Foley, 2016). These developments have changed how universities view learning space and pedagogy methods through the creation of learning spaces outside lecturer rooms and libraries for research, learning and collaborating purposes (Foley, 2016).

Universities are increasingly making use of pervasive campus connectivity and elements of REN and NREN to deal with large classes by incorporating on-campus, blended learning with revised pedagogy methodologies to enhance teaching and learning (Foley, 2016; Bankole & Assefa, 2017). The combination of global Internet connectivity, affordable cost to communication, high penetration of smart and mobile devices enables research, teaching and learning to occur away from campus as university students can access open educational resources through NRENs from any connected institution or space in the world (Foley, 2016; Kashefi et al., 2018). The NREN services supporting this is *eduroam*, by enabling students to connect via any participation university with the authentication only done once through a student's registered institution (Kashefi et al., 2018).

2.3 The importance of cyberinfrastructure for higher education institutions

As stated earlier, digitally transformed universities are empowered to speedily adapt and succeed in fulfilling their core competencies with the aid of research infrastructure managed by NRENs. The adoption of a definition for cyberinfrastructure, previously referred to as research infrastructure, by any administration, speaks to policy consideration and investment requirements relating to the scope of the definition.

2.3.1 Defining Cyberinfrastructure

From the number of articles reviewed as part of undertaking a literature review, it has emerged that different regions use different terms for cyber-based research infrastructure. The pattern identified is that some North American and African countries mainly make use of the term cyberinfrastructure while the European Commission and some Asian countries make use of the term e-infrastructure. For this research, the researcher adopts the term cyberinfrastructure.

The researcher also took the decision not to review the various definitions of cyberinfrastructure, but to accept the explanation as adopted by the Department of Science and Technology. The Minister of Science and Technology commissioned a committee on infrastructure to ascertain the appropriate model to enable an integrated national cyberinfrastructure system (DST, 2013). The committee's report, *National Integrated Cyberinfrastructure Systems: A framework for the establishment and maintenance of a sustainable NICIS*, defined cyberinfrastructure as follows:

> [R]esearch environments that support advanced data acquisition, data storage, data management, data integration, data mining, data visualisation, and other computing and information processing services distributed over the internet beyond the scope of a single institution. In scientific usage, cyberinfrastructure is a technological and sociological solution to the problem of efficiently connecting laboratories, data, computers, and people with the goal of enabling derivation of novel scientific theories and knowledge (DST, 2013, p. 83)

2.3.2 Collaborative and collective usage of cyberinfrastructure

From the definition adopted above, there is an inference that individual institutions are not necessarily required to own all or most elements of the cyberinfrastructure to benefit from the use of the systems. Sekgobela (2015) points to the University of the Witwatersrand's use of SANReN infrastructure to provide e-services to staff and students through the institution's eLearning, Support and Innovation (eLSI) platform. The author also refers to how the institution consistently makes use of the DST funded research infrastructure as a research-intensive public university.

It is therefore important to note that high speed, uninterrupted connectivity is crucial for global participation and collaboration, including enabling the use of local infrastructure to support local scientific needs (Cho, 2015; Spyridonis, Taylor, Abbott, Barbera, Nungu, Gustafsson, Pehrson, Oaiya & Banda, 2015).

Collaboration between regional and/or global NRENs, and between local institutions (higher education and research) highlights the importance of cyberinfrastructure in respect of the use of technology to enable activities such as "online learning, virtual labs, global research networks and worldwide sharing of computer facilities" (Pacheco, Nascimento & Weber, 2018, p. 4).

Cyberinfrastructure enables collaborative research on a large scale and innovative projects, including empowering remote institutions to access advanced research infrastructure and services (Peixoto, Martinazzo & Weber, 2017; Spyridonis *et al.,* 2015). It is further intimated that infrastructure that accommodates big data, high-performance computing, connectivity and knowledge creation, when empowering initiatives to produce innovative solutions to "complex social problems such as poverty, pollution, and sustainability" (Peixoto *et al.,* 2017, PP. 3) is crucial to a knowledge economy. The reference of cyberinfrastructure as "infrastructure of knowledge" (Steward, Simms, Plale, Link, Hancock & Fox, 2010) epitomises the importance of the systems to the education, research and innovation.

Cyberinfrastructure is also important in simplifying traditional processes linked to the function of the public university's library (Sekgobela, 2015). The author refers to the digitisation of the library resources, institution's subscription to internal journals/books and the introduction of the Wits Institutional Repository on DSpace (WIREDSpace) enabling students and academia to expediently and effortlessly access resources for ease of learning and teaching and research purposes (Sekgobela, 2015).

2.3.3 Epistemological changes to research: the impact of big data and cyberinfrastructure

Kitchin (2014) argue that big data forces us to review research processes at epistemological and ethical levels. Smith and Veldsman (2018) posit that this is likely how technological developments have enabled and reduced the "costs and difficulties of generating, processing, analyzing and storing data sets" (Kitchin, 2014, pp. 2). These developments, combined with training for the use of cyberinfrastructure has increased the exposure of researchers and scholars to opportunities and challenges brought about by big data (Agarwal & Dhar, 2014; Cho, 2015).

The technology developments have also resulted in data management becoming a lot more manageable and flexible, resulting in a continuous collection of data

sets (Kitchin, 2014). Cyberinfrastructure has enabled applications of artificial intelligence for the use of innovative forms of data analytics capable of managing big data (Agarwal & Dhar, 2014; Kitchin, 2014). The author, supported by Agarwal and Dhar (2014), further states that the "new techniques are rooted in research concerning…expert systems that have sought to produce machine learning that can computationally and automatically mine and detect patterns and build predictive models and optimize outcomes" (Kitchin, 2014, pp. 2).

The use of artificial intelligence applications for data analysis has epistemological and ethical paradigm consequences because different models induced from the data without the need to test any hypothesis (Agarwal & Dhar, 2014; Kitchin, 2014). The implication is that knowledge of theories is no longer the foundation for data analysis. The author argues that the epistemological paradigm changes advocates for a research process with multidisciplinary inputs. Kitchin (2014) agrees with Jim Gray that science has increasingly become data-driven and has consequently entered the fourth paradigm: "[d]ata-intensive; statistical exploration and data mining" (Kitchin, 2014, pp. 3). The fourth paradigm enables the use of "hybrid combination of abductive, inductive and deductive approaches to advance the understanding of a phenomenon" (Kitchin, 2014, pp. 5). Cho (2015) posits that the "[d]ata-intensive science (fourth paradigm)" is reliant on cyberinfrastructure.

2.3.4 Katz and Proctor's Cyberinfrastructure Sustainability Model: Technical, social and political contexts

Katz and Proctor (2014) argue that the consequence and sustainability of cyberinfrastructure (e-research infrastructure) are dependent upon intent/purpose and effort. It is on this basis that the authors' intimate discussions on cyberinfrastructure according to the following contexts, *among other things*: 1) technical; 2) social; and 3) political. They argue that the technical elements of the cyberinfrastructure relate to fit and interoperability with existing research systems. For example, fit and interoperability between government-funded infrastructure and, university and research community funded infrastructure, *among other things*.

The social context links the human resources and institutional involvement with the function of the cyberinfrastructure in terms of development, usage and intent (Katz & Proctor, 2014). Government funding takes into consideration country imperatives concerning research and higher education. University and research community funding depends on institutional goals and objectives. It is, therefore, reasonable

to conclude that effective and improved usage of cyberinfrastructure depends on the intent and user training on how to exploit the elements.

Katz and Proctor (2014) link the political context with funders of the creation and upkeep of the cyberinfrastructure. The authors posit that this context determines the scope of the REN and measures the impact of the cyberinfrastructure. Funding and intent will determine whether the scope of the research infrastructure will be for “local, regional, national, or international” (Katz & Proctor, 2014, PP. 1) initiatives. One of the funding models highlighted by the authors speaks to government funding based on public good for tier 1 network, with universities and research community making use of their resources for tier 2 and 3 networks. This funding model allows universities to make use of the tier 1 cyberinfrastructure network for free, while the government can sell spare capacity to industry (Katz & Proctor, 2014).

Taking into consideration the contexts discussed above, the authors created a cyberinfrastructure sustainability model, *figure 1*, based on three-dimensional axis consisting of temporal duration, spatial extent and purpose as inputs (Katza & Proctor, 2014). For output, the authors’ model measures the impact on cost and usage based on at least one of the dimensions. The temporal duration axis illustrated in *figure 1* relates to the perceived lifespan of each component, making up research infrastructure (Katz & Proctor, 2014). Katz & Proctor (2014) advance the view that the spatial extent relates to the scope of the infrastructure in terms of funding and intent. The purpose axis addresses the problems the cyberinfrastructure is meant to solve (Katz & Proctor, 2014). Katz and Proctor (2014) believe that the scale axis resembles a scenario where an increase in scope (local, regional, national, etc.) linked with high perceived lifespan and broader purpose for the cyberinfrastructure must result in a higher number of users and greater costs for the infrastructure to serve its purpose. Katz and Proctor (2014) argue that the creation and sustainability of cyberinfrastructure need consideration of all elements in Figure 2.3.

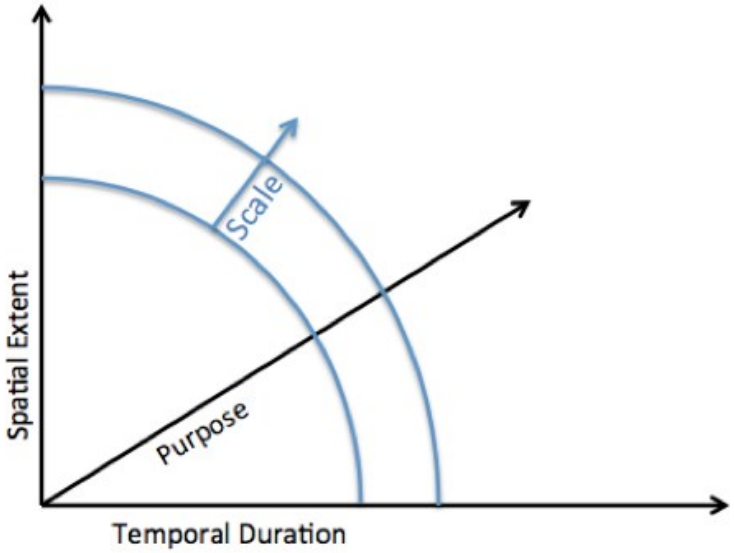


Figure 2.3: The Space of e-Research Infrastructure Elements (Source: Katz and Proctor (2014))

2.4 How cyberinfrastructure and digital transformation empowers universities in a data-driven revolution

It is important to acknowledge that policy and investment in cyberinfrastructure, and the outputs envisioned through digital transformation empower universities to exploit changes brought about by the data-driven revolution. Several authors such as Prisecaru (2016), Schwab (2016), Pereira and Romero (2017), Xing and Marwala (2017) address the extent of the impact of this paradigm shift, *among other things*. It is therefore realistic, prudent and imperative to understand and appraise how this paradigm shift is accommodated through policy and investment on cyberinfrastructure, thereby resulting in quality research, teaching and learning outcomes.

2.4.1 Exploiting data-driven revolution through cyberinfrastructure

The main pillars of the NICIS are the CHPC (computing services), DIRISA (data services) and SANReN (networking services), which are collectively meant to service academia, industry and research communities. The data-driven technologies influence the NICIS because of the collaboration and integration enabled by the paradigm's technology drivers, such as IoT, IoS, hyper-connectivity, artificial intelligence, quantum computer processing, autonomous

machines, robotics and nanotechnology. (Bahrin, Othman, Azli & Talib, 2016; Prisecaru, 2016; Schwab, 2016; Pereira & Romero, 2017; Xing & Marwala, 2017).

The effect refers to the transformation encompassing exponential technology developments in computer processing, data storage, connectivity and analytics. It is further argued that the impact begets further developments and increased up-take of disruptive technologies such as AI, 3D printing, etc. (Prisecaru, 2016). These developments are crucial, for example, to the smartness of manufacturing and service offering (Bahrin *et al.,* 2016; Prisecaru, 2016; Pereira & Romero, 2017;).

The data-driven revolution also impacts the academia, industry and research communities due to the paradigm's technology drivers empowering more accurate research outputs through shared data, visualisation, high-performance computing, simulations, etc. amongst other influences (Xing & Marwala, 2017). It is difficult to comprehend a scenario where there are aspects of society that are not going to be impacted by the data-driven revolution. Concepts such as e-government, e-education, smart cities/villages, smart factories, etc. exemplify the extent to which all spheres of society are being affected by the developments of the data-driven revolution (Duc, 2017).

2.4.2 Effects of the data-driven revolution on digital transformation at public universities

Several authors, such as Benešová & Tupa (2017); Elci, Vural & Elci (2017); Pereira & Romero (2017); Xing & Marwala (2017); amongst others, have detailed several issues that must be addressed through cyberinfrastructure because of the impact of data-driven revolution technology drivers on higher education. It is important to acknowledge that though there may exist similar country challenges, the extent and speed at which higher education is affected depends on the context of the country's challenges.

2.4.2.1 Cyberinfrastructure as a tool to build human capital

One of the common challenges raised is the possibility of job losses and the need for new skills to empower economies to survive (Prisecaru, 2016; Schwab, 2016; Benešova & Tupa, 2017; Duc, 2017; Elci, Vural & Elci, 2017; Pereira & Romero, 2017; WEF, 2017; Xing & Marwala, 2017; MOHE, 2018). WEF (2017) raises the concern that Sub-Saharan Africa's current education and skills development

systems and the limited collaboration between academia and business do not empower human capital, nor ensure preparedness for the transformational changes.

Benešová and Tupa (2017) highlights the importance of collaboration between academia and business to ensure a successful transformation. Schwab (2016) argues that no country or region can single-handedly address the challenges brought about by the data-driven revolution. These challenges require developed, developing and emerging markets to have a unified, collaborative and consistent agenda and implementation strategies, argued Schwab (2016). It is, therefore, reasonable to understand the notable urgency to ensure the establishment of Africa's NRENs.

Duc's (2017) bases an argument on the need for emerging and developing economies to transition towards characteristics defining developed countries (Figure 2.4). The author further states that highly ranked universities also characterise these economies (includes research outcomes, *among other things*), appropriate investment and performance in R&D sectors and high young population attending universities to obtain skills required for the data-driven revolution.

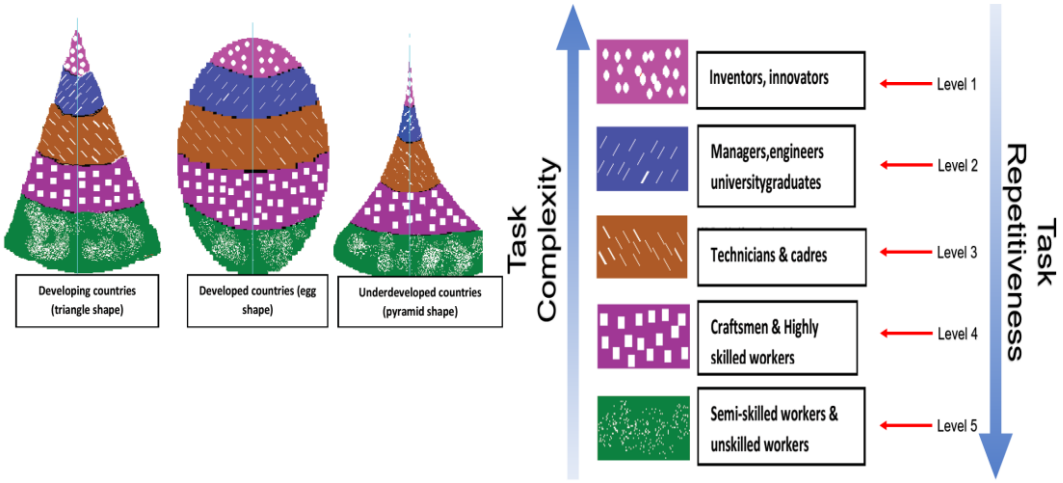


Figure 2.4. Division of labour per country categorisation. Adapted from (Duc 2017)

2.4.2.2 Changing the education ecosystem

Existing challenges of quality, teaching and learning, competency development, knowledge creation, etc. at public universities institutions cannot be addressed without systematically changing the current operational models (Benešová & Tupa,

2017; Elci, Vural & Elci, 2017; Pereira and Romero, 2017; Xing & Marwala, 2017; MOHE, 2018). Xing and Marwala (2017) argue that higher education must embrace and adopt emerging and disruptive technologies to enhance pedagogy, including ensuring competencies relevant to the data-driven revolution. Embracing and adopting these technologies will ensure that public universities are empowered to fulfil their mandates while the institutions remain globally relevant and competitive (Xing & Marwala, 2017).

South Africa's context requires addressing issues of broad participation and the cost to access quality public universities. There are arguments that e-learning (technology influenced learning) can likely address some of the important challenges of teaching and learning (Benešová & Tupa, 2017; Xing & Marwala, 2017; MOHE, 2018). Benešová and Tupa (2017) and, Xing and Marwala (2017) also expressed their support for technologies that will also be sensitive to the cost of education, especially when massification of public education is one of the main requirements for South Africa. MOHE (2018, p. 32) supports a need for "creating values-based society" through a public universities ecosystem that will ensure equitable access to education regardless of an individual's background and/or circumstances "in the age of cyber-physical connectedness" (MOHE, 2018, p. 55).

2.4.2.3 Why universities should be innovative in a data-driven revolution

As stated earlier, one of the common challenges raised is the possibility of job losses and the need for new skills to empower economies to survive (Xing & Marwala, 2017). What has become clear are the different reasons for likely job losses. Pereira and Romero (2017) posit that public universities are central to reskilling and development of new competencies, therefore enabling an environment where there is restriction of job losses through the creation of new employment opportunities through innovation (research outcomes). There is also the argument that gradual increase in job losses is unavoidable especially in scenarios where the inability to reskill employees is because of the speciality of newly required professions (Benešová & Tupa, 2017; MOHE, 2018).

MOHE (2018) argues that some jobs will be displaced while there will be an elevation of importance in other current skills' levels. In support, Schwab (2016), Priscecaru (2016) and, Pereira and Romero (2017) argue that there will be the loss of more jobs than those created, the fiscusl will be impacted because of technological unemployment, there will be dependency on government grants and

decrease on GDP. Bahrin et al., (2016) describe a more despairing picture for manufacturing by stating that smart factories will be not only autonomous and digitised but also so intelligent that they will be self-optimising, self-regulating and self-correcting while delivering huge cost efficiencies, better quality and vast product range.

2.4.2.4 Characteristics of a student needed for a data-driven revolution

The impact of the data-driven revolution on public universities raises the issue of what kind of characteristics will make a student relevant and effective. The data-driven revolution is still in its infancy; therefore, the long-term impact and competency requirements are still unknown (Schwab, 2016; MOHE, 2018). MOHE (2018) further posits that the current rate of technological developments imply that public universities are required to be agile and "consistently anticipate and prepare for the changing skills and new knowledge" (MOHE, 2018, p. 50). These developments, combined with training for the use of cyberinfrastructure, has increased the experience of researchers and scholars to opportunities and challenges brought about by big data (Agarwal & Dhar, 2014).

The digital world will require a high proficiency in digital literacy (Xing & Marwala, 2017), because of the high diffusion of technology and its integration into everyday activities. Students are also required to acquire a set of skills that allow for cross, multi and inter-disciplinary competencies enhanced through critical thinking, emotional intelligence, collaborative and creative qualities. (Schwab, 2016; Pereira & Romero, 2017; Xing & Marwala, 2017; MOHE, 2018;). Xing and Marwala (2017) and, MOHE (2018) also advocate for humanity and humility-based skills. Virtues associated with basic ethics of altruism, social awareness, empathy, accountability, considerateness, etc. differentiate humans from robots and AI (Xing & Marwala, 2017; MOHE, 2018). These traits must be taught at every learning stage to ensure the survival of humanity (MOHE, 2018).

2.5 National policy and investment consideration for cyberinfrastructure

The researcher has noted that there is insufficient peer-reviewed-literature on national policy and investment in cyberinfrastructure for research, teaching and learning purposes. The impact of national policy and investment in cyberinfrastructure on digital transformation for research, teaching and learning is presented more in reports attached to regional networks. Taking into consideration, the limited peered reviewed literature. This section will briefly

highlight from these reports policy issues impacting NRENs and investment considerations affecting campus networks/infrastructure.

Figure 2.5 illustrates the building blocks of connected NRENs, and as stated earlier, the discussions will be limited to the bottom two (2) blocks. That is policy and investment considerations in cyberinfrastructure required to enable digital transformation concerning research, teaching and learning.

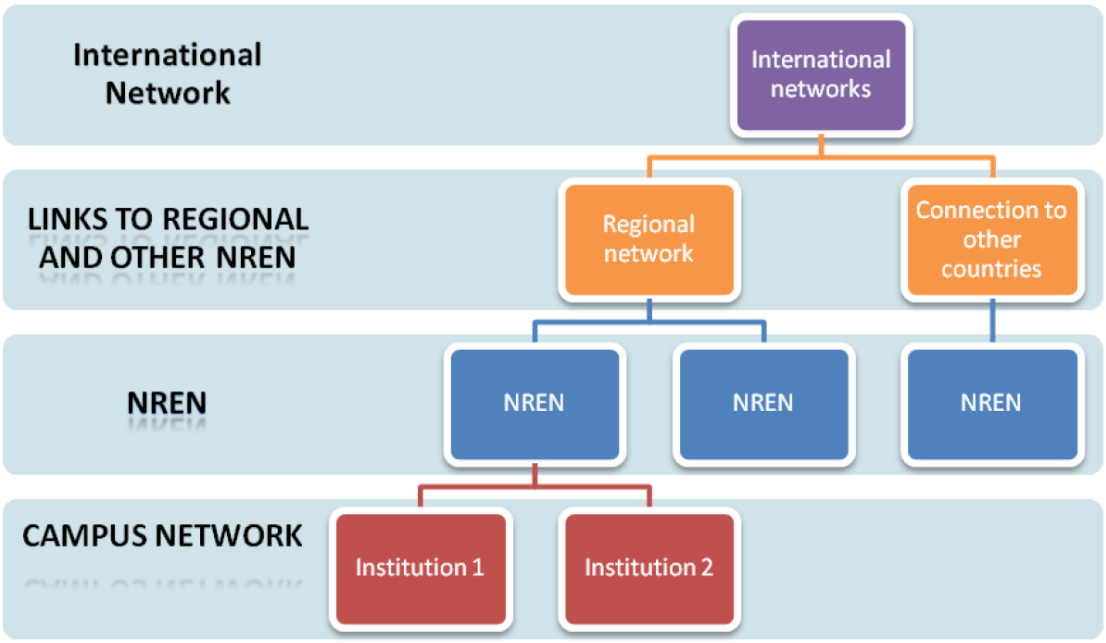


Figure 2.5: Building blocks for NRENs (Source: Adams (2016))

2.5.1 NREN formation for research, teaching and learning

Policy needs to acknowledge the importance of defining cyberinfrastructure and how the continuously evolving underpinning technologies impact on funding requirements for NRENs (Cho, 2015). The formation, governance, oversight and funding structure of an NREN depends on national policy (Foley, 2016). Best practice requires NRENs to have preferential tax consideration while being an independent governance structure with a funding matrix involving government, donors, higher education and research institutions (Foley, 2016). Higher education and research institutions are responsible for the operational requirements of the NRENs, while government and donor funding targets initial setup capital expenditures or required upgrades or additions (Adams, 2016; Foley, 2016). The success for NRENs for research, teaching and learning is dependent upon government and higher education institution leadership's awareness of the benefits of dedicated research infrastructure and stable sponsorship (Adams,

2016; Foley, 2016). Yaver et al. (2016) also highlight the importance of policy in determining the beneficiaries of government-funded NRENs projects and infrastructure.

An NREN deemed a 'public good' through policy is exposed to preferential consideration, such as acquiring access to telecommunications operators' backbone infrastructure at discounted rates (Foley, 2016). There is also the possibility of policy enabling NRENs to access partial funding through the "Universal Service Funds or Universal Access Funds" (Foley, 2016, pp. 9). Smith and Veldsman (2018) argue that a well-resourced REN is central to research-intensive universities and to meeting the 2030 SDGs objectives. Carabine (2016) further argue that well-funded RENs enable financially struggling universities to offer quality education through peering and collaboration. In a data-driven multidisciplinary research paradigm, well-funded connected NRENs are the drivers of intra-Continental and global research collaboration (Smith and Veldsman, 2018).

Foley (2016) presents the view that developed nations are illustrating better efficiency in the use of NREN due to issues such as cost to communication, fibre penetration and the ubiquitousness of the Internet. Kashefi et al. (2018) importantly provide a likely justification that implies that some developed region such as the European Union have better funded and more mature NRENs, therefore, have more specialised components. For example, concerning cyberinfrastructure (e-infrastructure) in a "European context evokes images of high-speed networks linking high-performance computers, concerning Africa this infrastructure is "one of the most significant forces and challenges of modernization" (Kashefi et al., 2018, pp. 4).

2.5.2 Enabling the sustainability of NRENs

Adams (2016) argues that the creation and sustainability of NRENs require synergy between the following principles: commitment; coordination; connectivity; capability; content and services; and financial requirements. The principles of coordination, content and services depend largely on investment requirements from universities and research communities. The policy, universities and the research community's investment strategies address competency and financial requirements. The cultural and socioeconomic considerations, particularly

concerning technologies deployment, are important for policy deliberation when it comes to user-centric cyberinfrastructure design (Kashefi et al., 2018).

The creation and sustainability of NREN require a policy to elevate the value of the infrastructure as a 'public good' (Adams, 2016; Foley, 2016). This argument recognises the impact of NREN concerning positive socioeconomic developments as a result of the outcomes of research, teaching and learning. Government policy concerning budget formulation through the treasury department empowers the state to ensure awareness and measure the impact of funding for NRENs (Adams, 2016). Governments need to acknowledge that national policy impacting on NRENs requires multi and cross-departmental mandate consideration (Adams, 2016; Lopes, Simoes, Coury, Rbeiro, Caetano, Machado, Pereira, Meireles, Brito, Messina, Pisa, Haddad & Al-Shorbaji, 2013). The acknowledgement will also impact regulatory consideration, particularly on the licensing and partial funding of NRENs (Adams, 2016; Foley, 2016; Khunga & Kunda, 2017).

The communications regulatory framework impacts NRENs concerning cost to communicate; licensing; the scope of universal services access; spectrum licensing considerations and fees; and licensing conditions for commercial telecommunications operators (Adams, 2016; Foley, 2016). The regulatory framework with the support of policy consideration must ensure that regulations do not financially burden the formation and operations of NRENs and that the research and education infrastructure regulated as a 'public good' (Adams, 2016; Foley, 2016). The consideration implies that NRENs must receive limited preferential consideration concerning licensing, spectrum fees and cost of accessing commercial infrastructure (connectivity) (Adams, 2016; Foley, 2016). The policy framework should enable NRENs to receive partial funding from the universal access fund contributions (Adams, 2016; Foley, 2016; Khunga & Kunda, 2017).

To ensure their sustainability the national government funding framework for NRENs must also take into consideration that the agencies managing the infrastructure must have independent governing structures, constituting of research entities and higher education institutions (Adams, 2016; Foley 2016; Yaver et al., 2016). Adams (2016) intimates that funding should ensure that competent staff are responsible for the daily operations of NRENs. There is an

expectation that the cost of creating and sustaining NRENs are the largest at the initial stages (Adams, 2016; Foley, 2016).

Therefore, as the NRENs operations mature, membership must be increased to enable the agency to seek funding for operations by leasing infrastructure to industry seeking the use of elements of the network (Adams, 2016; Foley, 2016; Yaver et al., 2016). Government funding is still crucial for infrastructure upgrades for mature NRENs (Foley, 2016). Yaver et al. (2016) warn against the over-reliance on government funding. But Adams (2016) posits that the maturity of NRENs determines government funding dependency. Taking into consideration Duncan Greaves NREN Maturity Model (Figure 2.6), NRENs at level 0 are highly likely to be dependent on access to government funding whilst level 4 translates to a funding model incorporating government and donor (national and/or international) funding, including revenue from industry (Adams, 2016; Foley, 2016).

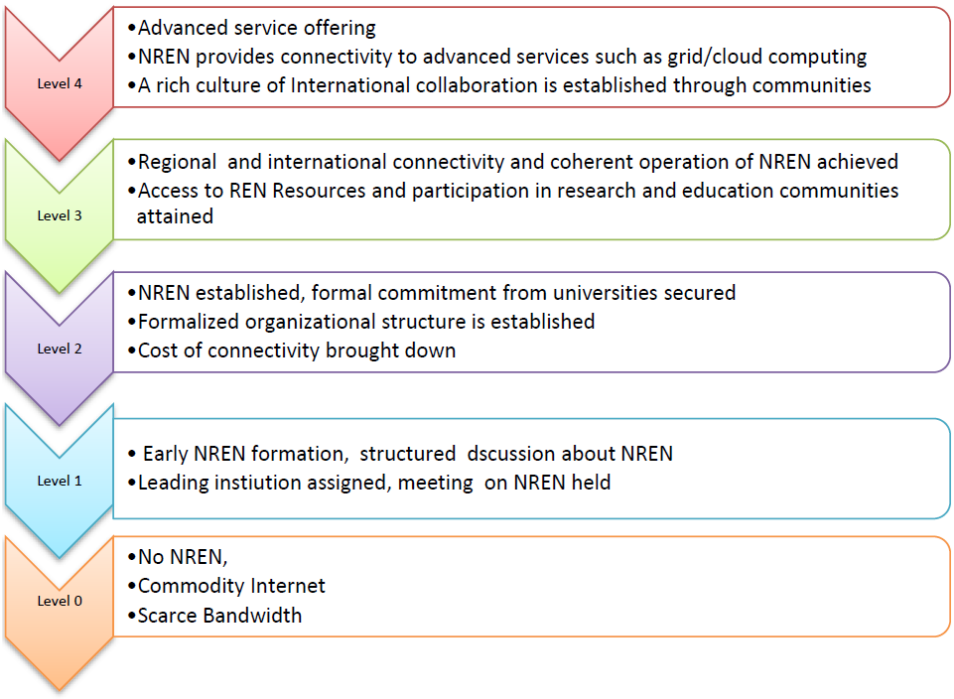


Figure 2.6: Duncan Greaves NREN Maturity Model (Source: Adams (2016)

2.5.3 Importance of a coordinated strategy by the research community and higher education institutions

The research community and higher education institutions should leverage the NREN services by coordinating infrastructure resource sharing (Adams, 2016; Kashefi et al., 2018; Songu, Powell, Barry and Brar, 2016; Carabine, 2016). The cost-efficiencies through the usage of NREN infrastructure requires that all national

research communities and higher education institutions interconnect with the national network, NREN (Adams, 2016; Kashefi et al., 2018; Songu et al., 2016). The efficient usage of the NREN infrastructure is dependent upon research communities and higher education institutions having competent support human resources (Adams, 2016; Foley, 2016; Kashefi et al., 2018).

The institutions are required to invest in training, upgrade of equipment, relevant content and services (Adams, 2016; Foley, 2016; Cho, 2016). Adams (2016) and Foley (2016) argue that the presence of trained staff, relevant equipment, access to content and services ensures that research communities and higher education institutions efficiently and correctly use the NREN infrastructure. If the campus network is not fit for purpose, “then service[s] to the campus users will be poor even if an advanced NREN is funded and built” (Foley, 2016, pp. 47).

2.6 Analytical framework: Effect of policy on cyberinfrastructure and its value

The conceptual framework adopted for this research posits that policy and investment in cyberinfrastructure managed by an NREN should produce measurable or notable outputs concerning South Africa’s research and, higher education teaching and learning outcomes. The cyberinfrastructure should empower digital transformation at universities especially when the data-driven revolution has resulted in epistemological paradigm changes that advocates for new competencies and a research process with multidisciplinary inputs (Agarwal & Dhar, 2014; Kitchin, 2014).

The conceptual framework, Figure 2.7, illustrates the three (3) key concepts crucial to measuring the impact of cyberinfrastructure at South Africa’s universities and research communities. The conceptual framework is an interpretation of Katz and Proctor’s (2014) model. Policy and investment address issues of cyberinfrastructure technical requirements, institutional goals and objectives, including development and intent. Additionally, the policy addresses issues of scope of cyberinfrastructure. The effective and improved usage links with intent and user training on how to exploit the elements of the cyberinfrastructure.

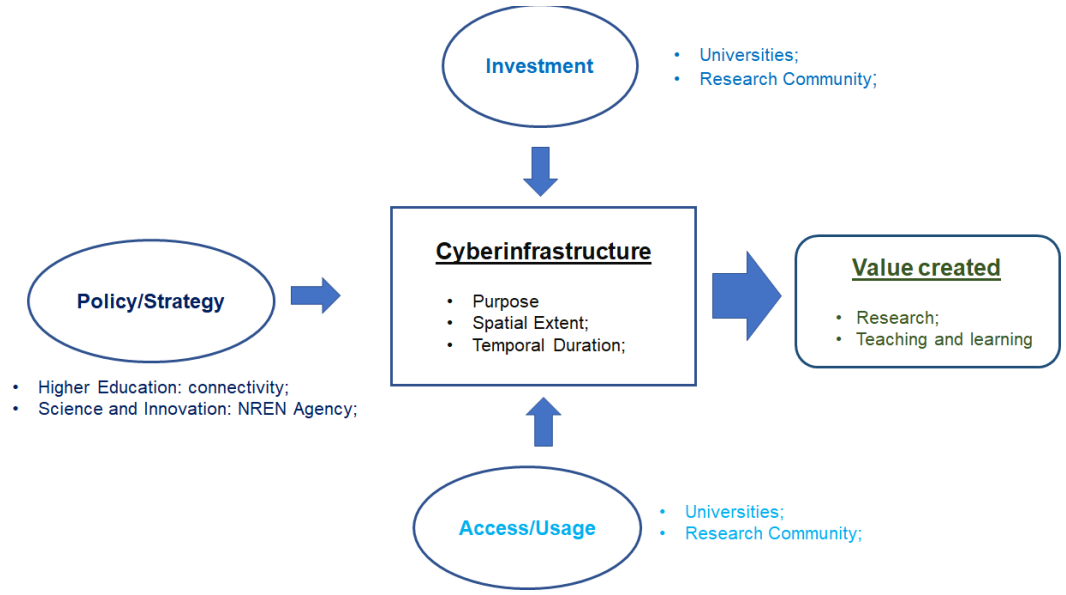


Figure 2.7: Analytical Framework

2.7 Conclusion

This chapter reviewed the existing body of knowledge on NRENs and explored the key concepts and challenges raised with regards to the influence of national policy, cyberinfrastructure and digital transformation on public universities. The role of the data-driven revolution was also reviewed and contextualised concerning its impact on public universities. To better understand the impact of the interaction between the concepts of this study, the conceptual framework adopted recognises that policy, investment in cyberinfrastructure and usage is crucial to measuring the impact at South Africa's universities and research communities.

Chapter 3: Research Methodology and Data Collection Process

Figure 3.1 illustrates the phases in the development of the study's operative research methodology (Saunders, Lewis, & Thornhill,2007).

This research approach adopted for the study included:

- qualitative social constructionism as a research philosophy;
- case study and document analysis to answer the research questions
- adoption of a multi-method;
- cross-sectional time horizon applies to the research as all data is collected simultaneously (Saunders et al., 2007); and
- for the exploratory-qualitative research, data collection is done through in-depth interviews and documentary analysis.

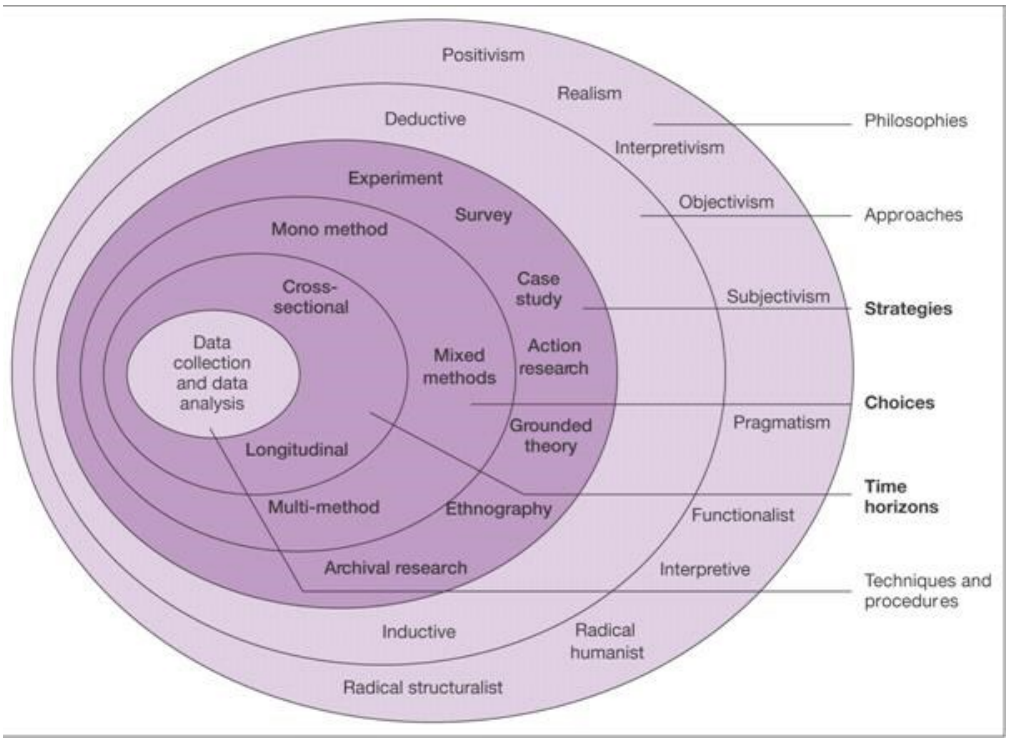


Figure 3.1. Research onion (Source: Saunders et al., 2007, p. 102)

3.1 Research Methodology

Saunders et al., (2007, p. 602) define research methodology as inclusive of "theoretical and philosophical assumptions upon which research is based and the implications of these for the method or methods adopted". This research examines the impact of cyberinfrastructure policy and investment, through the National

Integrated Cyber Infrastructure System (NICIS) on research and participation rates at South African public universities.

3.1.1 Main Research Question:

What has been the effect of policy and investment in cyberinfrastructure on digital transformation at public universities, concerning teaching and learning, and knowledge creation, and why?

3.1.1.1 Research sub-questions:

- How has the cyberinfrastructure funded through DST influenced the university's research capacity?
- How do the cyberinfrastructure strategy impact on the university's teaching and learning?
- How were the challenges on the use of cyberinfrastructure addressed?

The “knowledge and meaning” (Wisker, 2008, p.69) obtained through research comes from the experiences gained from public universities, related government institutions and government departments responsible for policy and legislation in the higher education sector, and the interactions between events informed by the legislative framework that guide universities and their operational strategies. The study employed a social constructionist view as its methodological anchor, which informed the “subjective meanings motivating the actions of social actors” with the view to contextualising the response and unspoken language of the participants (Saunders et al., 2007, p.108).

The constructionist framework for the study was based on the dependence of the study mainly on the data collected from participants (Creswell, 2014).

The questions posed were open-ended to enable participants to create their meaning, within their context, of the subject being studied (Creswell, 2014). The research, in turn, sought to make sense of the responses and meaning attached to the subject by the respondents (Creswell, 2014).

Taking into consideration the ontological and epistemological framework adopted, the research is considered an exploratory study based on magnitude or extent of a phenomenon, problem, or behaviour and on the intent of the study which was to

generate some initial ideas (or “hunches”) about that phenomenon (Bhattacherjee, 2012, p. 6).

Exploratory research in this context implies the need to acquire an understanding regarding the phenomena, through presenting pre-determined questions, therefore, enabling the assessment of the phenomena from a contextualised perspective (Saunders et al., 2007). The emphasis was on studying the presented problem by exploring and explaining relationships between key concepts and the phenomena (Saunders et al., 2007). It is with this understanding that the researcher interpreted the exploratory study as part of the broader qualitative research paradigm (Saunders et al., 2007).

To acquire a greater understanding of the phenomena within the operations of public university institutions, the researcher will also implement a case study research method at the University of Witwatersrand (Saunders et al., 2007; Petty, Thomson and Stew, 2012; Wisker, 2008).

In summary, the research was broadly exploratory and adopted a qualitative research approach. The choice of a qualitative research approach is because the researcher requires a more in-depth understanding of the phenomenon being studied (Bryman, 2012). The purpose of the research is to explore the meaning of how the participates view the issues studies (Bryman, 2012). This type of data is inherently qualitative and not conducive to a quantitative study, which produces quantitative data (Bryman, 2012). *Figure 3.2* illustrative the main steps of qualitative research.

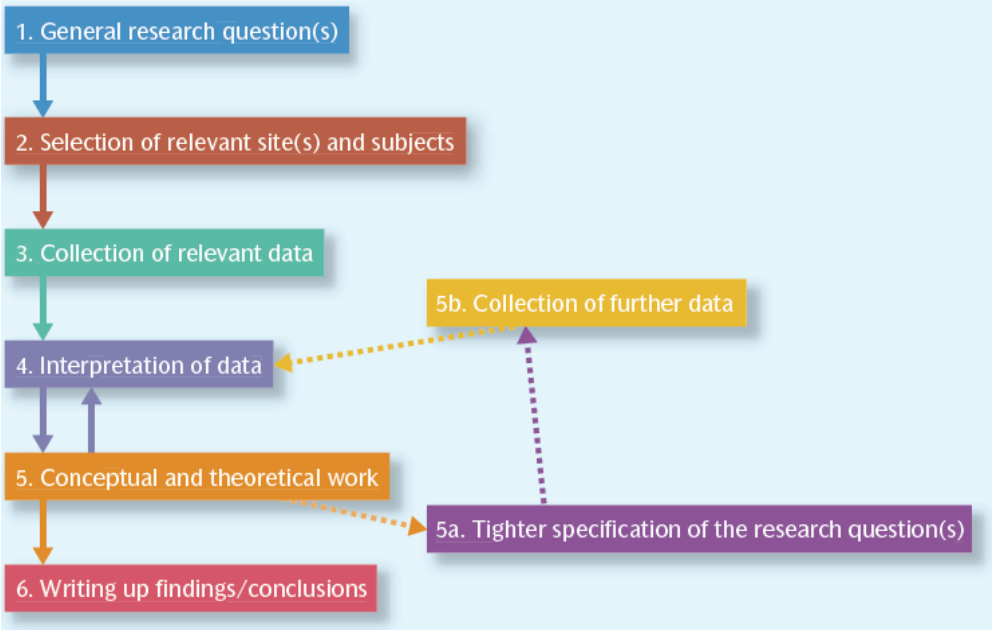


Figure 3.2. Main steps of qualitative research, Source: Bryman (2012)

Mafuwane (2011) cites Michael Quinn Patton as defining qualitative research as (Mafuwane, 2011, pp. 73 - 74):

> an approach that uses a naturalistic approach which seeks to understand phenomena in context-specific settings, such as real world settings, where the researcher does not attempt to manipulate the phenomena of interest…it is any kind of research that produces findings not arrived at by means of statistical procedures or other means of quantification, but instead the kind of research that produces findings derived at from real-world settings where the phenomena of interest unfold naturally

This definition is consistent with the scenarios stated by Rosenthal (2016), concerning when a researcher can make use of qualitative research as a methodology of preference, for example “employed when the researcher is interested in understanding the “why” behind peoples' behavio[u]rs or actions” (Rosenthal, 2016, pp. 510). Within the framework of this methodology, the research will implement the following research strategies: 1) document analysis and 2) case study.

3.2 Research strategy

The researcher used the research strategies: case study approach and document analyses, to answer the study questions (Saunders et al., 2007).

3.3 The Case Study Approach

The entire public university system in South Africa is made up of several units of analysis affected by government policy, that is all 26 universities comprising of traditional, comprehensive and universities of technology. Therefore, to acquire an in-depth understanding of the phenomena within the operations of public university institutions, this research adopted a single case study approach with the embedded unit of analysis being identified as a single public university (Saunders et al., 2007; Wisker, 2008; Yin, 2009; Petty et al., 2012). Even though public universities are autonomous and have varying operational models, as members of TENET they acknowledge the importance of cyberinfrastructure for teaching and learning. Therefore, a single university is sufficient for the study with an understanding that the impact of cyberinfrastructure policy and investment will vary at each public university based on other historical factors.

The researcher's choice of selecting the University of the Witwatersrand for exploratory case study purposes was based on proximity and research convenience of the institution. The University of Witwatersrand is one of the public institutions that make use of TENET as a service provider for network connectivity. DST's strategy on SANReN and the DHET's policies on higher education influences the public university's cyberinfrastructure requirements.

Therefore, the University of Witwatersrand as an embedded unit illustrates the context of national policy and the influence of public universities strategies within the framework of policy based on principles outlined by Yin (2009). Taking into consideration the historic context of South African public universities, it is reasonable to expect a lack of consistency between all 26 universities. But amongst the traditional universities, the University of Witwatersrand is homogenous enough to be considered as an embedded unit of analysis.

Yin (2009), Bhattacherjee (2012) and Creswell (2003) argues that a case study research is undertaken when: a) there is a requirement for in-depth analysis of the phenomenon within its context in reference to time and activity as it is essential to the study; 2) the researcher is required to collect detailed data by making use of diverse collection techniques, or 3) the researcher has no control of how participants interact with the subject within their context. Yin (2009) goes further by indicating that the edges of the phenomenon and context may be indistinct.

Bhattacherjee (2012, pp. 94) further argues that case study research is appropriate for "studying complex organisational processes that involve multiple participants and interacting sequences of events, such as organisational change and large-scale technology implementation projects". Therefore, the case research covers the design rationale, data collection procedures, and the particular tactics used for data analysis (Yin, 2009).

The research explores how cyberinfrastructure policy at national and public university levels affects the university's mandate through digital transformation. The exploratory embedded case study will assist the researcher to study in-depth the link between; 1) national and institutional policy on cyberinfrastructure; and 2) the extent of digital transformation in public universities (Yin, 2009). The "case" studied is digital transformation at the University of Witwatersrand as a representative "case" of public universities in the context of existing policy both at national and institutional levels (Yin, 2009). The choice of the University of Witwatersrand was based on easy access to the institution and proximity.

3.3.1 Archive materials

The researcher has analysed publicly available institutional documentation to understand better historical, current and future strategies likely impacting on digital transformation at public universities through the deployment of cyberinfrastructure (Saunders et al., 2007; Bryman, 2012; Taylor, Bogdan & DeVault, 2016). The archive material analysed included the strategies and reports from the Departments of Science and Technology and Higher Education and Training, and from the University of Witwatersrand.

3.3.2 Interview protocol

The interview guide/protocol was initially developed based on the literature review undertaken and revised based on consultation with the supervisor. The protocol was then shared with friends and colleagues for their inputs (Bryman, 2012). The following issues regarding the protocol, *among other things*: 1) repetitive or vague questions; 2) inclusion of unnecessary qualifiers to questions; 3) questions too broad or not generic enough; 5) questions too complicated; 6) questions unrelated to the research question; 6) incorrect order of questions; etc.

Based on the audio recorded pilot of the protocol with a colleague, the following issues were raised: 1) pitch of the interviewer; 2) interviewer unnecessarily

interrupted interviewee; 3) interviewer not relaxed during the interview; 4) digressed a bit from the interview guide; and 5) interviewer not prioritising questions when met with time constraints. After the responses, the researcher repeatedly practised asking questions and audio recorded these sessions for self-review.

3.3.3 Interview participants

The sampling methodology for this study deliberated on the following: 1) practicality of access respondents; 2) cost implications of accessing respondents; 3) schedule for the completion of the dissertation; and 4) cost and turnaround times for the transcription of the recorded interviews (Saunders *et al*., 2007). The initial requirement for sampling targeted ten (10) interviews spread across the following institutions; University of the Witwatersrand ("Wits"), DHET, TENET and SANReN. The sample is small because the researcher was targeting organisational data only, thereby focusing on the dynamic qualities of a phenomenon/subject as opposed to explaining the relationship, and therefore the sample size has little meaning on achieving objectives (Saunders *et al*., 2007).

The researcher targeted middle and senior management participants from each institution for in-depth interviews, and additional organisations were added based on the issues raised by the respondents (Taylor *et al.*, 2016). The additional organisations included for interviews were the DTPS and ICASA. Participants were chosen on principle to ensure best the possibility of the research questions being answered and to enhance the researcher's understanding of the phenomenon under study (Saunders *et al*., 2007). All research questions were answered with a varying level of depth.

The final number of respondents ended up being eight (8) due to the non-availability of some of the respondents approached, or, seconded/referred for interviews. Due to time constraints and the quality of the answers from the respondents, the researcher decided to proceed with the final analysis.

3.4 Data Collection

Bryman (2012) states several options for data collections methods in qualitative research, primarily; 1) ethnography; 2) interviewing; 3) focus group; and 4) documents analysis. Ethnography or participant observation is defined about the time a researcher spends interacting and living within the social surroundings of a

cultural group, not only observing, but actively participating in discussions (Bryman, 2012; Saunders et al., 2007; Wisker, 2008).

Data can also be collected through formal or informal interviews (Bryman, 2012; Saunders et al., 2007; Wisker, 2008) and document analysis (Bryman, 2012).

Unlike structured interviews, semi-structured interviews enable the interviewer to change the sequencing of questions (Bryman, 2012; Saunders et al., 2007; Wisker, 2008) and to pose further questions for purposes of clarity or seek further details in response to noteworthy responses (Bryman, 2012). Unstructured or in-depth interview (Bryman, 2012; Saunders et al., 2007; Wisker, 2008) is an informal process where the researcher makes use of an interview guide. With this type of interview, how and the order in which the questions are asked will differ from interview to interview (Bryman, 2012).

Focus group is a setting facilitated by a moderator where participants are either subject matter specialists or have/are actively involved in the workings of the specific topic (Bryman, 2012; Saunders et al., 2007). The purpose of the focus group is to discuss and the joint "construction of meaning" (Bryman, 2012, pp. 502) of the specific topic in discussion without the prerequisite to reach consensus (Bryman, 2012; Saunders et al., 2007). Lastly, document interpretation provides secondary analysis in data collection for qualitative research (Bryman, 2012; Saunders et al., 2007). Documentation to be analysed is determined based on the following criteria; 1) has the document been authenticated; 2) is the material credible; 3) how representative is the evidence in the document; and 4) does the report convey evidence clearly and is it reasonable (Bryman, 2012).

This study employed semi-structured in-depth interviews and documentary analysis as the primary data collection methods.

For in-depth interviews, the researcher adopted face-to-face semi-structured interview method with open-ended questions "to obtain an in-depth understanding of the participants' experience, perceptions, opinions, feelings, and knowledge" (Rosenthal, 2016, pp. 10).

The second method adopted by the researcher required documentary analysis of government policies or white papers, public university operational strategies, relevant regulations, etc. (Petty, Thomson & Stew, 2012).

3.5 Data Analysis

To enable the researcher to interpret the data collected, the information must be reduced to the extent it is can be better understood (Bryman, 2012; Taylor, Bogdan & DeVault, 2016). Qualitative data analysis requires the researcher to implement a process that includes “inductive reasoning, thinking, and theorizing” (Taylor, Bogdan & DeVault, 2016, pp. 168). The outcome of data analysis provides pattern or theme identification and information coding when evaluating the data collected (Bryman, 2012; Taylor, Bogdan & DeVault, 2016).

To ensure the consistency of the data analysis process the researcher performed the following iterative tasks: 1) evaluation of data accuracy; 2) meticulous and comprehensive analysis; and 3) addressing researcher bias when analysing data (Yin, 2011). The consistency of data analysis can be ensured through the creation and maintenance of “methodological note” (Yin, 2011, pp. 177) also referred to as memoing. The data collected was sort according to themes, then coded and determined through content analysis the existence of a theoretical framework.

3.6 Ethics in qualitative research

Ethics is inherent in all stages of qualitative research (Given, 2008; Saunders, Lewis & Thornhill, 2007). Its purpose and significance is to guide and regulate all decision making processes of qualitative research “from problem formulation to presentation of results” (Given, 2008, p. 276), to guarantee integrity in the research activity and protect participants from harm (Given, 2008; Fouka & Mantzorou, 2011; Wisker, 2008; Saunders et al., 2007). The recurring themes on ethics in research contains requirements for informed consent; beneficence; privacy; anonymity and confidentiality; the right to withdraw; and data security (Given, 2008; Fouka & Mantzorou, 2011; Saunders et al., 2007). The researcher obtained ethical clearance prior to undertaking interviews. The ethical clearance certificate is included in Appendix E of the report.

Armiger is cited by Fouka and Mantzorou (2011, p. 4) defining informed consent with regards to “a person knowingly, voluntarily and intelligently, and in a clear and manifest way, gives his[/her] consent”. Beneficence addresses the need to make sure that during all stages of research, the participants are not exposed to any form of harm (Saunders, Lewis & Thornhill, 2007). Fouka and Mantzorou (2011) cites Levine arguing that an individual’s privacy is linked to the freedom to choose the

circumstances, context and timing under which their private information may be publicly shared or withheld.

Anonymity requires the researcher to make sure that the participant cannot be identified through recorded interview responses and to safeguard confidentiality by managing private information (Fouka & Mantzorou, 2011). The researcher must make sure that the participant is aware of their right to withdraw at any given time and stage of the research (Fouka & Mantzorou, 2011; Saunders, Lewis & Thornhill, 2007).

Data security relates to the storage of observations to make positive beneficence, privacy, anonymity and confidentiality. This was ensured firstly by instructing the transcription service provider not to include participants names in the data (Bryman, 2012). All data about participants was stored in password-protected files in a password secured cloud (Bryman, 2012). To ensure that the passwords are secure, the researcher made use of a password generator application. Identifier codes were used during the textual data analysis.

The researcher has conducted qualitative research on how the cyberinfrastructure deployed for research and development (R&D) influenced digital transformation in public universities. The respondents' interview responses are valuable in mapping the data relevant to understanding how the current cyberinfrastructure programmes impact public universities. The answers were used for the Master's Research report, for related scholarly publishing and capacity building, and may be used for future research.

The respondents' words, inputs and personal details were kept anonymous in any publications, by utilising a naming convention rather than actual names or other identifiers, unless the responded/s expressly requests that their name/s or position/s be published. Confidentiality was observed concerning any information and matters discussed in the interview that the responded/s do not wish to be published and the anonymised data and quotations will be stored in a password-protected cloud.

Participation was entirely voluntary, and respondents were advised of the option to withdraw from the interview at any time during or after. The choice to withdraw was not dependent on the responded/s giving reasons to do so, and any responses provided was not reported on.

3.7 Research strengths: reliability and validity measures considered

Reliability refers to the consistency of “data collection techniques or analysis procedures” (Saunders et al., 2007, pp. 149) in yielding similar results because of the same methods applied repetitively over time by different researchers (Saunders et al., 2007; Bryman, 2012; Creswell, 2014; Babbie, 2013). To ensure reliability and accuracy of the data collected, the researcher is required to implement a data collection method and measurement appropriate to the type of information needed taking into consideration what previous researchers did for similar methods (Bryman, 2012). For exploratory-qualitative research, data collection was done through in-depth interviews and documentary analysis.

Creswell (2014) references Yin (2009) in suggesting that the researcher needs to include as many steps as possible when documenting the “procedures of their case studies” (Creswell, 2014, pp. 252) and recording a comprehensive “case study protocol and database”. (Creswell, 2014, pp. 252). Creswell (2014) further references Gibbs (2007) regarding the following additional measures to be adopted by the researcher to ensure reliability; 1) ensuring accuracy of transcripts, and 2) ensuring consistency of coding and related definitions. Saunders, Lewis & Thornhill (2007) also argue that the timing of data collection and expectation of respondent impact on the reliability of information collected. It is on this basis the data collection will occur on Wednesday, where possible. Anonymity and confidentiality were emphasised during interviews to encourage respondents to provide responses unconstrained.

Researcher bias and errors during the data collection process also impact on the reliability of information collected (Saunders et al., 2007). To limit bias, the researcher watched videos on how to conduct interviews to learn and understand best practice; additionally an interview guide was designed to ensure consistency in the process (Saunders et al., 2007). The researcher also took the responsibility of self-reflection and recorded thoughts and feelings during interviews as part of a process of owning up to one’s perspective (Taylor et al., 2016).

Validity measures the magnitude to which the conclusions of the research relates to the issues of cyberinfrastructure strategy, higher education policy and digital transformation in public South African universities (Saunders et al., 2007; Bryman, 2012; Creswell, 2014; Babbie, 2013). The researcher needs to ensure that the conclusions of the study are accurate from the perspective of the respondents and

the researcher (Creswell, 2014). Validity was ensured through the appropriate methods of data collection and analysis, to guarantee that the findings accurately represent the context of the phenomenon studied (Yin, 2011).

The researcher has adopted the following proposals from Yin (2011) & Creswell (2014) with regards to ensuring validity of the study: 1) the triangulation of several sources of data to determine the convergence of themes; 2) the review the draft findings with the participants to assess accuracy of analysis; 3) the inclusion of researcher bias on the interpretation of data; 4) include in the report representation of data supporting the research and also data that is contrary to the study; and 5) make use of the research supervisor for "peer debriefing" (Creswell, 2014, pp. 252).

Figure 3.3 below illustrates the concept of validity and reliability, including the difference between the two concepts. The first diagram shows the consistency in the researcher's data collection and analysis methods, while also highlighting the failure of the researcher to collect and analyse data relevant to the context and phenomenon studied (Babbie, 2013). The second diagram portrays the situation of valid data collection and analysis while also demonstrating inconsistency in findings (Babbie, 2013). The last diagram depicts the scenario the researcher seeks to replicate, that is valid data collection and analysis producing consistent and accurate findings (Babbie, 2013).

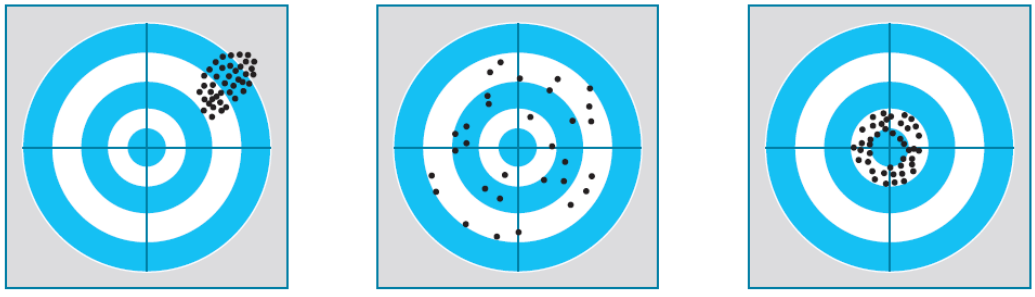


Figure 3.3. An Analogy of Validity and Reliability. (Source: Babbie, 2013, pp. 193)

A proper measurement technique should be both valid (measuring what it is intended to measure) and reliable (yielding a given measurement dependably).

3.8 Research weaknesses: technical and administrative

The research limitations exist due to constraints on research design or strategy, exploratory case study, and these factors may impact the findings of this study. The procedures and methods for data collections and analysis my have limitations such as time constraints for collection. Additionally, the analysis may not necessarily fit well within the standard categories.

Chapter 4: Contextualising the cyberinfrastructure policy intention in South African public universities

The chapter presents themes and emerging issues from the data collection. Included in this chapter is an effort to link data, the research sub-questions and the elements of the analytical framework. The chapter provides the foundation for a discussion on the implications of findings, which takes place in chapter 5.

4.1 Emerging themes and issues emerging from the data collection

The following themes emerged during data collection: 1) providing access to cyberinfrastructure; 2) cyberinfrastructure strategy emphasis; 3) the effect of access and usage of cyberinfrastructure; 4) cyberinfrastructure applications; and 5) digital transformation at the University of the Witwatersrand. Figure 4.1 illustrates the relationships between the research sub-questions, elements of the framework discussed in Chapter 2, and the themes identified. *Table 4.1* outlines the themes and emerging issues discussed in this chapter.

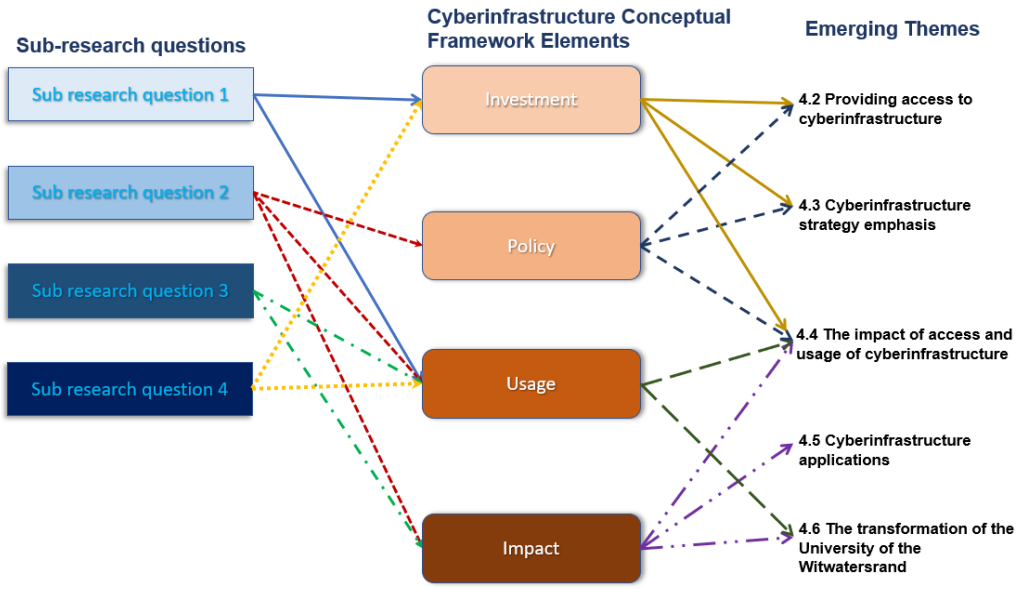


Figure 4.1 Relationship between the sub-research questions, elements of the framework, and emerging themes

Emerging Themes	Emerging Issues
4.2 Providing access to cyberinfrastructure	4.2.1 The historical development of the cyberinfrastructure 4.2.2 South Africa defining cyberinfrastructure 4.2.3 Investment in cyberinfrastructure 4.2.4 Investment in research and development at higher education institutions
4.3 Cyberinfrastructure strategy emphasis	4.3.1 The Department of Higher Education and Training strategy 4.3.2 Connecting rural or remote campuses to the SANReN network
4.4 The impact of access and usage of cyberinfrastructure	4.4.1 South Africa – European Council for Nuclear Research programme 4.4.2 Reducing the digital divide at rural/remote campuses 4.4.3 Cost friendly international collaboration and human capital development 4.4.4 Monitoring and evaluation by the Department of Science and Technology
4.5 Cyberinfrastructure applications;	4.5.1 Cyberinfrastructure applications at public universities
4.6 The value of digital transformation at University of the Witwatersrand.	4.6.1 The digital transformation of the University of the Witwatersrand. 4.6.2 The University of the Witwatersrand redefining learning spaces 4.6.3 Curriculum renewal at the University of the Witwatersrand.

Table 4.1. Relationship between emerging themes and emerging issues

4.2 Providing access to cyberinfrastructure

4.2.1 The historical development of the cyberinfrastructure

The history of the South Africa NREN begins with the formation of Uninet, Universities Network, in the late 1980s (SANReN_1). Supported by the National Research Foundation (NRF), previously the Federation for Research and Development, Uninet was an ISP for universities and science campuses and was responsible for leasing capacity from Telkom on their behalf (SANReN_1). Until the late 1990s, Uninet was effectively the country's NREN (SANReN_1). SANReN_1 stated that Universities left Uninet in the late 1990s as a result of a pricing policy impasse and the dissatisfaction of not having full control of decisions made.

The collapse of Uninet in 1999 resulted in universities forming TENET, a non-profit organisation run by Universities themselves:

> So TENET had pretty much the same role (as Uninet), currently a non-profit company and the management was managed through the Board which has membership within the institutions that have signed up for services with TENET, that's by and large all 26 universities now, initially 24 (SANReN_1)

TENET's role and capacity, as the effective NREN then, was assessed by the DST in 2003 as a country made its intention of hosting the SKA project known (SANReN_1). The DST was concerned about the state of South Africa's capability to host large science initiatives requiring processing and exportation of large data for projects such as the SKA and the CERN Large Hadron Collider research collaboration (CSIR_1; SANReN_1). Taking into consideration TENET's expertise, the DST commissioned to undertake a global study on NREN best practices (SANReN_1).

4.2.1.1 The formation of the South African National Research Network Competency Area (SANReN CA)

SANReN_1 stated that the global benchmark study report presented by TENET convinced the DST to approach the Treasury for funding and the DST then approached TENET to implement and operate the South African NREN, due to the latter's technical expertise,. SANReN_1 stated that the insistence of universities on having full control over TENET led to the decline of funding from the DST that would have made the entity South Africa's NREN. According to SANReN_1, this

resulted in the formation of the South African National Research Network Competency Area (SANReN CA) under the management of the CSIR to rollout cyberinfrastructure on behalf of the government and then to handover the network to TENET to operate.

> The DST then wanted TENET to be the contracting partner to take the funding and actually go and buy infrastructure and TENET actually declined that offer. I think for various reasons, but probably the primary one was the institutions wanted to retain control of TENET, and as soon as the State becomes the primary funding party, that would be lost, I think (SANReN_1)

4.2.2 South Africa defining cyberinfrastructure

South Africa's definition and programme on cyberinfrastructure conforms to the outcomes expressed in the global benchmark study undertaken by TENET. One respondent stated:

> So, our NREN wasn't quite geared for it, too *low bandwidth*, *too expensive*, and the issues had to be resolved. So, the *DST had no proper understanding, and* they actually commissioned TENET to do a study. So, TENET went, and they looked at what NRENs do globally (SANReN_1)

Respondents CSIR_1 and SANReN_1 stated that the need to define cyberinfrastructure influenced governmental funding requirements. CSIR_1 explains cyberinfrastructure for South Africa as being research infrastructure that comprises of the following: high-speed broadband connectivity; large scale computing resources; large data; repositories; human competency; and the interconnection between all research activities that produce data. CSIR_1 states:

> So, what we are most focused on are only those entities of the computing the data, and the high-speed network, to link, to enable other entities. So, I might not get into those parts of …, how the SKA (works), SKA is part of cyberinfrastructure (SANReN_1)

CSIR_1 and SANReN_1 noted that the global benchmark study provided the impetus for investments into cyberinfrastructure which in turn led to South Africa's research infrastructure evolving to the extent that the international community of researchers supported the awarding of a large portion of the global SKA project to South Africa.

4.2.3 Investment in cyberinfrastructure

The DST's intervention regarding the cyberinfrastructure requirements consists of investment in the CHPC, DIRISA and SANReN (Sithole, 2016). *Figure 4.2* illustrates the extent of investment done through SANReN. All universities connect their international traffic through the SANReN network (Sithole, 2016, p.2).

> Cyberinfrastructure refers to information technology systems that provide particularly powerful and advanced capabilities. It encompasses a combination of massive processing capability, high-speed connectivity, massive storage facilities and highly skilled personnel. Leading nations have invested significantly in these facilities and closely aligned them with their economic activities. South Africa has in the past decade invested in national cyberinfrastructure to enable cutting-edge research and development within its academic and research institutions as well as industry. (Sithole, 2016)

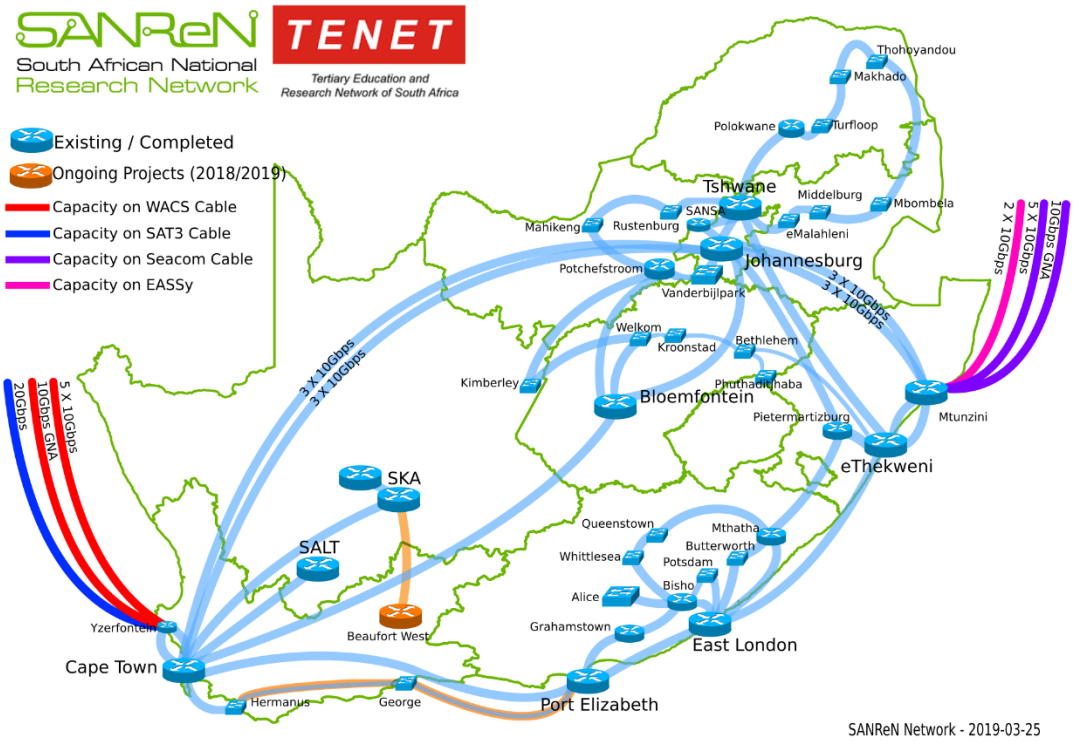


Figure 4.2. SA NREN Backbone Map indicating International Capacity

Concerning high-performance computing the DST through DIRISA in 2007 invested in the purchasing of 2.5 TFLOPS (10^{12} FLOPS) infrastructure and in 2016 further upgrades were made to increase to 1 PFLOPS (10^{15} FLOPS, or 1000

TFLOPS). Floating-point operations per second (FLOPS) is a start measure for performance capabilities of supercomputers, especially in scientific computing fields. The DST invested in data-storage through DIRISA (Sithole, 2016).

> 4 PBytes-storage system split between the Pretoria and Cape Town campuses of the CSIR has been designed for data-driven applications and near-real-time synchronisation to provide for full disaster recovery of all research data. This facility provides storage for big data resources in support of data-intensive research activities. (Sithole, 2016, p.2)

4.2.4 Investment in research and development at higher education institutions

The DHET funding for research at public higher education institutions equates to 10% of the department's budget allocation, which in turn amounts to 20% of the public sector funding for the same (NACI, 2017a). The DST supports research at public universities through the creation of Centres of Excellence programmes and the e-science learning platform, additional to providing funding for the NICIS (NACI, 2017a; e-science, n.d). Wits received a R60 million grant for the establishment of the national e-science teaching and learning platform and R99 million towards the MRC/Wits University Rural Public Health and Health Transitions Research Unit (Wits, 2015).

> … to address national research, higher education and human capital development challenges pertinent to national goals the Department of Science and Innovation (DSI) initiated several national interventions, the National Integrated Cyberinfrastructure System (NICIS) being one of these. However, NICIS can only be exploited to the full if the requisitely skilled cohort of e-Researchers exists. The development of human capital with the necessary knowledge and skills to conduct cutting edge research in the field of e-Science in line with the South African Research Infrastructure Roadmap (SARIR), the Square Kilometre Array (SKA) and other actions is the main objective of this programme. (e-science, n.d).

Figure 4.3 illustrates government funding for universities between 2004 and 2014 (NACI, 2017b).

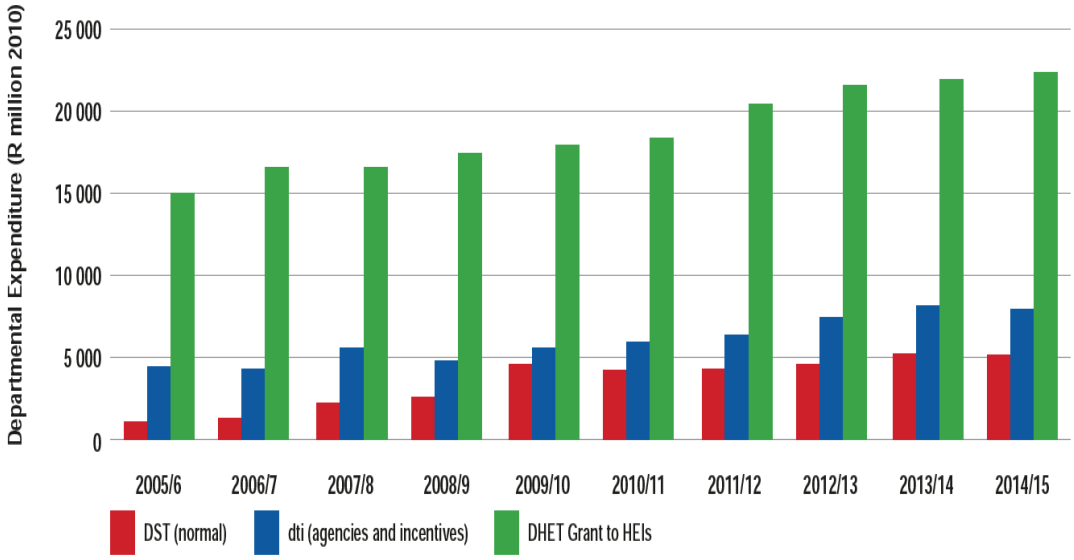


Figure 4.3. Government funding for universities between 2004 and 2014 Source: NACI (2017b)

4.3 Cyberinfrastructure strategy emphasis

4.3.1 The Department of Higher Education and Training strategy

DHET_1 stated that the DHET's strategy concerning ICT infrastructure for research, teaching and learning conforms with the principle of open learning. "The use of cyberinfrastructure for modalities of education (e.g. blended learning) must be in line with learners' needs" stated DHET_1. The DHET's strategy and funding regarding ICT infrastructure for research, teaching and learning are to reduce the digital divide between urban and rural/remote campuses (USFf, 2016). Between the period 2011 – 2019 the DHET provided grants for a phased project linked to the connectivity of rural/remote campuses to the SANReN network (USAf, 2019b). Phase II (2014-2019) of this project took into consideration the objectives of the *White Paper on Post-School Education and Training* (USAf, 2016; TENET, 2018).

4.3.1.1 Promoting open learning

The DHET seeks to achieve the NDP targets of increased quality in research, teaching and learning through policies such as, but not limited to, the proposed framework motivating for open learning principles (DHET_1). With the use of ICT to empower open learning, DHET_1 advocates that the use of technology must assist in removing or drastically reducing the

barriers to, *inter alia*, access to higher education; increasing of throughput rates; quality education; student-centric education; fundingteaching and learning without regard to disabilities, gender, race; lifelong learning; and other barriers flexible learning; etc. DHET_1 further stated:

> to increase access, (as) there is no money to build universities. That is the bottom line. So, how can we work with what we have to be more cost-effective? And that is where the whole issue of utilising ICTs as an enabler for teaching and learning comes in.

Even though USFf (2017) support open learning principles, they raise the issue of reviewing existing frameworks and funding requirements to enable public universities to implement the proposed policy framework.

4.3.2 Connecting rural or remote campuses to the SANReN network

At the cost of R119 million over nine years (2011 -2019) the rural campuses connection project (RCCP) has managed to provide increased bandwidth, as well as faster and more stable internet connectivity to 134 university sites across South Africa (USAf, 2019b). In the same period, some institution upgraded their institutional ICT infrastructure and managed to make use of the enhanced internet connectivity to improve research, teaching and learning (USAf, 2019c).

4.3.2.1 Rural Campuses Connection Project I

In 2010 USAf (then HESA) and TENET sought funding from the DHET intending to connect 53 rural/remote campuses to the SANReN network (USaf, 2016). Though the DHET approved R28 million for what became Rural Campuses Connection Project I (RCCP I), R127 million was the initially requested budget (USAf, 2016). USAf and TENET approached the DHET for funding out of fear that the SANReN's connectivity project excluded rural campuses on technical reasons and this was likely going to increase the existing digital divide (USAf, 2019a).

> HESA's purpose of the Rural Campuses Connection Project (RCCP) was to improve broadband connectivity of rural or remote university campuses to the SANReN. It was believed that increased internet access would improve teaching, learning and research capability, thus eliminating the gap of internet access between campuses located in well-resourced metropoles and their more remotely based counterparts. (USAf, 2019a)

RCCP I sites	
Institution	**No of sites**
Cape Peninsula University of Technology	1
Mangosuthu University of Technology-Main Campus + 1	2
Tshwane University of Technology	1
University of KwaZulu-Natal	1
University of Limpopo - Main campus + 2	3
University of South Africa	5
UNISA/VUT shared site	1
University of Venda - Main campus with failover path	2
University of Zululand	2
Vaal University of Technology-Main Campus plus 2	2
Walter Sisulu University	2
TOTAL	**22**

Table 4.2. List of public university sites completed as part of RCCP I source: USAf (2019a)

The implementation agency was TENET with the guidance of a steering committee composing of USAf, SANReN, TENET, Association of South African University Directors of Information Technology (ASAUDIT) and the DHET (USAf, 2016; USAf, 2019a).

> For most of these campuses, the increment in capacity amounted to a qualitative change in connectivity, allowing them to do things that would have been previously inconceivable. To this extent, the project was a success and delivered most of the planned benefits. (USAf, 2016)

RCCP I, despite its implementation challenges, was accepted by beneficiaries and judged as being transformative (USAf, 2015; USAf, 2019a). *Figure 4.4* illustrates

the impact of RCCP I, in that average bandwidth increased from 8 MB/s in 2010/11 to 350 – 400 MB/s in 2014 (USAf, 2015). RCCP I created new opportunities and positive prospects for the connected institutions (USAf, 2015).

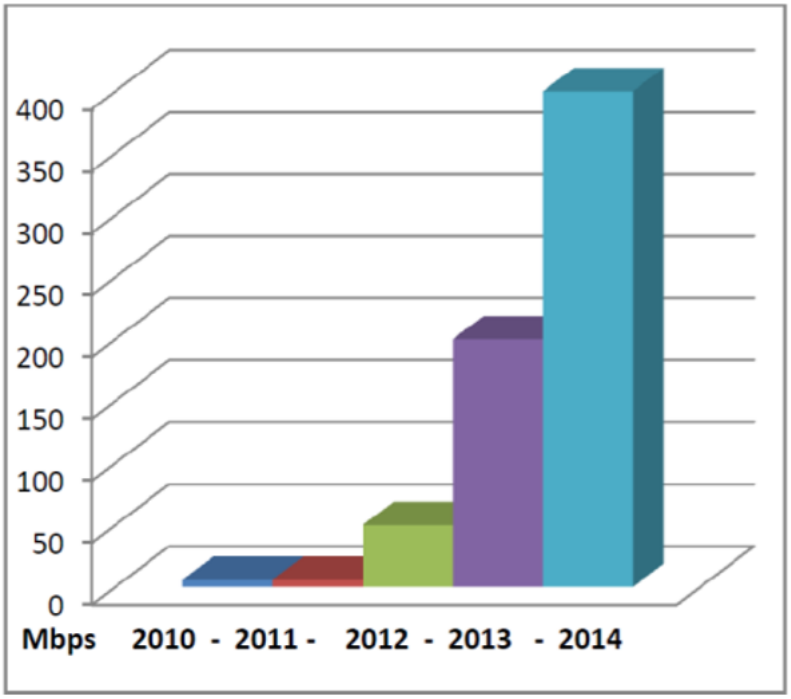


Figure 4.4. The average increase in bandwidth to beneficiary sites source: USAf (2015))

4.3.2.2 Rural Campuses Connection Project II

Towards the end of RCCP I, USAf (then HESA) and TENET approached the DHET for another grant to connect additional rural campuses to the SANReN network. The RCCP II proposal suggested the connection of additional campuses while also addressing the challenges experienced in RCCP I. For RCCP II the DHET approved a budget of R71 million for the connection of an additional 57 sites (USAf, 2016; USAf, 2019). The projection catered for technical and organisational capacity requirements, taking into consideration the challenges faced during the implementation of RCCP I (USAf, 2016).

> To best realise its benefits, consideration should be given to the further roll-out of the RCCP to additional institutions. In the view of the evaluators, the universities would benefit from a further roll-out / upscaling of the project to ensure that the provision of broadband services 'assists in strengthening the teaching and learning processes, creating equitable access to online

educational resources and strengthening administrative resources with the aim of improving the quality of education. (USAf, 2015)

RCCP II sites	
Institution	**No of sites**
University of Pretoria	2
Cape Peninsula University of Technology	2
University of Cape Town	12
University of South Africa	2
University of the Western Cape	1
Mangosuthu University of Technology	2
University of the Witwatersrand	6
University of Mpumalanga	1
University of Limpopo	3
Stellenbosch University	2
The University of Venda for Science and Technology	1
Rhodes University	1
University of Fort Hare	1
Vaal University of Technology	1
North-West University	28
Walter Sisulu University of Technology and Science	19
The University of Kwazulu-Natal	4
Sefako Makgatho Health Sciences University	3
TOTAL	**91**

Table 4.3. List of public university sites completed in RCCP II (source: (USAf, 2019a))

Table 4.3 Lists the public university sites completed in RCCP II, including sites from RCCP I where wireless connections made way for optical fibre access (USAf, 2019a). Concerning human capacity development, 881 people representing 25 of the 26 universities received training, technical or organisational, between the period 2016 and 2019 (USAf, 2019a).

Figure 4.5 illustrates RCCP linkage to the SANReN network (red line) source: USAf (2019a).

4.3.2.2.1 Challenges with Rural campuses connection project I

The RCCP II proposal suggested the connection of additional campuses and addressing the challenges experienced in RCCP I. The main challenges raised related to the following: lack of consensus on the definition of rural; the co-payment, operations and maintenance costs; and the lack of consistency in the usage of the connectivity (USAf, 2015; USAf, 2016; USAf, 2019a). Though the issue regarding the definition of rural remains unresolved, a pragmatic stance was adopted concerning connectivity (USAf, 2016). The co-payment, operations and maintenance became a challenge because the SANReN (DST) connectivity project did not require financial input from institutions (USAf, 2019a). The co-payment requirement was abandoned and, the RCCP II carried operations and maintenance costs for a limited period (USAf, 2019a). The usage of the connectivity varied between connected campuses, with the main issue being the need for training and that was considered in the planning for RCCP II (USAf, 2015; USAf, 2016; USAf, 2019a).

4.3.2.2.2 Improvement through Rural Campuses Connection Project II

RCCP II seeks to address the digital divide between urban and rural campuses by addressing the following challenges for faculty, students and support staff: limited access to online resources; limited exposure to global collaboration; and support staff challenges with respect to upskilling as a result of budget and time challenges as a result of travelling requirements (TENET, 2018). RCCP II included staff and student awareness programmes to encourage uptake of the connectivity and considered the issues of research, teaching and learning highlighted in the White Paper on Post-School Education and Training (USAf, 2016; TENET, 2018).

> Thus a significant training component was included in the RCCP II proposal – not merely for formal technical skill building but also more complex capacity problems such as policy and process development capabilities. In this way, it is hoped to deliver not simply better connectivity but also better ability to use the connectivity for organisational purposes, particularly for research and for teaching and learning. (USAf, 2016)

4.3.3 The Telecommunications regulatory framework challenges

Six of the respondents agreed on the challenge of the high cost to communicate in South Africa (SANReN_1; TENET_1; DHET_1; Wits_1; DTPS_1; ICASA_1). SANReN_1 mentioned that the diffusion of technology through commercial fixed/mobile operators is important for NREN activities linked to the adaption of existing technologies for teaching and learning purposes. DHET_1 highlighted the importance of a balanced view when addressing issues of connectivity, mainly: speed, cost, and infrastructure. DHET_1 emphasised the need for appropriate technology for teaching and learning, at a reasonable cost to the students.

DHET_1 raised the challenges with the oversight of the e-rate regulations concerning the provisioning of connectivity for public universities. ICASA_1 argued that the provision on the e-rate in the Electronic Communications Act required reviewing during the discussions on the amendment of the legislation. ICASA_1 further stated that the Universal Service and Access Fund (USAF) in its current form is not effective in addressing connectivity challenges. The respondent stated that the DTPS needs to determine the country's access gap before the review of the existing USAF model. DTPS_1 and DTPS_2 argued that the proposed introduction of the Digital-Development Fund (DDF) legislation is designed to address the access gap and address the shortcomings pointed out by the USAF, but this cannot be confirmed until the legislation is passed. DTPS_1 and DTPS_2 stated that the 2016 National Integrated ICT Policy White Paper broadly covers public university connectivity needs by seeking to stimulate demand in ICT infrastructure, services, devices, content, capacity and skills. DTPS_2 emphasises that the policy advocates for digital inclusion and digital participation by citizens.

4.4 Providing access to cyberinfrastructure

4.4.1 South Africa - European Council for Nuclear Research programme

The most notable impact of the NICIS in South Africa is a collaboration of South African public universities within the umbrella SA-CERN (South Africa - European Council for Nuclear Research programme), participating in global projects aimed at making discoveries (SA-CERN, n.d.; ; Wits, 2015; Sithole, 2016; SANReN_1, 2018; UCT, 2018). The local DST funded programme thus far has enabled the continued participation of the following public universities: University of the Witwatersrand; University of Cape Town; University of Johannesburg; Durban University of Technology; University of Kwa-Zulu Natal; University of the Western Cape; and the University of Zululand (SA-CERN, “n.d.”; UCT, “n.d,”; Sithole, 2016). SA-CERN using the NICIS has enabled significant human capital development for students and researchers through collaboration and participating in global projects such as *A Large Ion Collider Experiment (ALICE); A Toroidal LHC Apparatus Experiment (ATLAS); Isotope Separator On Line Device (ISOLDE); and CERN theoretical research programme called High Energy Physics and Nuclear Physics* (SA-CERN, n.d.; Sithole, 2016; UCT, 2018).

> The SA-CERN programme gives scientists and research students in South Africa access to the data obtained at CERN and allows them to take part in the running of experiments in Geneva. The outcomes are world-class research, participation in global science, high-level capacity development, innovation and technology transfer leading to competitive industry and infrastructure, the attraction of high-quality young South Africans into the Science and Technology system and the development of the public understanding of science (SA-CERN, n.d.).

The participation of South African public universities has seen research output for South Africa linked to some of the CERN topics increase at least 2.5 times the global average (Wits, 2018b).There has also been an increase in interest and participation from postgraduate students as a result of the globally competitive master's and doctoral degrees, and the valuable and globally sought-after experience attained by the participating students (Wits, 2015; Wits, 2018b). Wits claims that the SA-CERN programme has elevated South Africa’s research credibility and resulted in the country retaining its skills sets while attracting skills from the rest of the continent (Wits, 2018b).

The sustained interest and participation in the SA-CERN programme has enabled participating public universities to continue developing human competencies contributing to the country's capacity to effectively manage and encourage an increased scope of data intensive theoretical projects (Wits, 2018b). Participation exists in projects such as the Square Kilometre Array project; the CHPC; the SA-Grid (the Radioactive Ion Beam project at iThemba Labs; the High Throughput Electronics Facility project at the University of the Witwatersrand; the high-performance computing cluster at UJ. (Sithole, 2016; Wits, 2018b).The SA Grid forms the basis for public universities to access data and implement demanding computational physics analysis processes and procedures.

> South Africa is embarking on a major expansion of its scientific capacity. This expansion particularly will need to be accompanied by a corresponding increase in local general knowledge and in the skills base in nuclear physics in South Africa. For this to succeed, it is necessary to enhance teaching and research in nuclear physics at South African universities. Such an increase should be done with the active support of what is the best on offer in the world today. This support is undoubtedly available through CERN, where the large number of international collaborative activities provides a unique networking opportunity for SA scientists and students. (SA-CERN, 2017)

4.4.2 Reducing the digital divide at rural/remote campuses

Even with the challenges raised, CSIR_1, SANReN_1 and TENET_1 in some of their responses painted a resilient, progressive picture regarding the impact of cyberinfrastructure since 2007. CSIR_1 and SANReN_1 believe that policy influence on continued investment in cyberinfrastructure enabled historically black universities to access research infrastructure, at a level of skill competency for the infrastructure the institutions could not afford through their annual budgets. CSIR_1 indicated that the expansion of cyberinfrastructure to historically disadvantaged universities included training, not only on the use of the infrastructure but also on the minimum required skills to enable the use of the cyberinfrastructure.

CSIR_1 highlighted that the assistance provided to new universities (Sol Plaatje University and University of Mpumalanga) ensures that they are enabled to conceptualise their curriculum with regards to cyberinfrastructure and can, therefore, integrate teaching and learning with their cyberinfrastructure. These

efforts are influential in encouraging demand and effective usage, and subsequently, impact stated CSIR_1 and SANReN_1. Cyberinfrastructure is now playing a crucial role in addressing historical disparities and is levelling the playing field, to some extent, with regards to access to research infrastructure. CSIR_1, TENET_1 and SANReN_1 further posit that even though all public universities are not in the same standing financially, the NREN has ensured that all are connected and have the same capacity and access to the cyberinfrastructure. TENET_1 added that

> the SANReN team have been great in their approach to this thing because they have tried to connect everybody at every main campus at 10 gigabytes per second. Whether you are at UCT or Fort Hare, you get 10 gigabytes per second connection. And it was an enormously farsighted decision on their side because it is equalised, it has levelled the playing field to use their cliché to quite a substantial degree.

4.4.3 Cost friendly international collaboration and human capital development

CSIR_1 and SANReN_1 highlighted that the impact of investment in cyberinfrastructure was not only crucial for the awarding of the large portion of the global SKA project to South Africa. In addition, public universities had access to international connectivity that was not a financial burden to the institutions. The investment in cyberinfrastructure has enabled public universities to undertake research previously not possible and connect them to global research communities, including international research programmes. SANReN_1 states:

> The commercial world designs networks with as little bandwidth as they can charge you for, we design and provide you with large bandwidth for as little as we can charge. We believe in the quality of service through over-provisioning, so, there should be more capacity than we need now.

Investment in cyberinfrastructure to some extent takes into consideration, *among other things*, the requirements of public universities, including the importance of consistency about quality of service and quality of (user) experience, stated SANReN_1. Sithole (2016) states that investment and successful implementation of the national cyberinfrastructure has created benefits and opportunities that has elevated the country's research, development and innovation status. Between 2007 and 2016 South African higher educations institutions have experienced the following benefits: 1) decrease in bandwidth cost from R43,000/1 Mbps/month to

R6,000/1 Gbps/month; 2) human capital development through annual national and international competitions relating to high-performance computing; 3) increase in the number of postgraduate qualifications in high performance computing -related fields; 4) noticeable increase in the number of publications originating from South Africa included in high impact journals. (Sithole, 2016). “It is evident that South Africa’s ability to compete globally is receiving a substantial boost through significant bandwidth; massive processing facilities and data storage systems, driven by high-end skills” (Sithole, 2016).

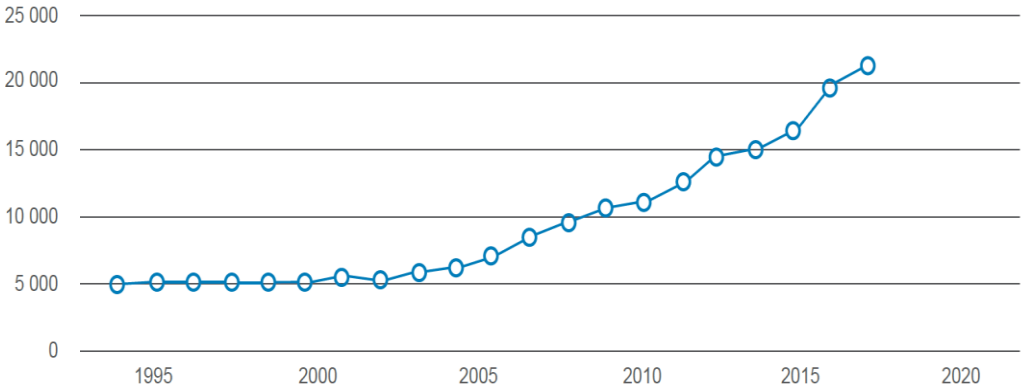


Figure 4.6. South African publications between 1995 and 2016 Source: NACI (2017b)

4.4.4 Monitoring and evaluation by the Department of Science and Technology

CSIR_1 indicates that accountability regarding access and usage of cyberinfrastructure was crucial to the investment provided by the DST. It is on this basis that the DST monitors the use of the cyberinfrastructure locally, adds the respondent. The DST through the National Advisory Council on Innovation (NACI) annually publishes science, technology and innovation (STI) indicators to monitor the impact of the National System of Innovation (NSI) with respect to building “scientific excellence and innovation capacity, with the ultimate aim of reducing poverty, unemployment and inequality” (NACI, 2017b, p. 8). *Figures 4.7 and 4.8* below illustrate two of the many indicators monitored. Figure 4.7 relates to human capital development, and Figure 4.8 shows publications from public universities.

	2007	2008	2009	2010	2011	2012	2013	2014	2015
Total SET graduations ('000)	36.4	39.3	41.5	42.8	46.1	48.8	53.2	55.6	58.1
Percentage of SET graduations	29.5	29.9	28.7	27.6	28.6	29.6	30.1	30.6	30.7
Percentage of undergraduate SET graduations	28.8	29.4	28.9	27.9	28.7	29.4	29.4	30.0	30.3
Percentage of postgraduate SET graduations	26.4	27.6	29.4	28.7	28.9	29.1	27.7	28.5	29.3
Percentage of female SET graduations	49.2	49.5	49.3	49.1	49.4	49.4	50.0	50.2	50.6
Percentage of PDIs' total SET graduations	64.1	66.4	67.7	69.2	70.1	71.5	72.8	74.1	74.0

Figure 4.7. Public universities' science, engineering and technology graduation rates Source: NACI (2017b)

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Traditional universities	**7 318**	**8 337**	**9 049**	**9 399**	**10 858**	**12 539**	**13 240**	**14 294**	**15 107**	**16 200**
University of Cape Town	1 744	1 882	1 978	2 093	2 303	2 609	2 749	3 027	3 021	3 264
University of the Witwatersrand	1 215	1 310	1 396	1 546	1 740	2 067	2 032	2 261	2 519	2 687
University of Pretoria	1 165	1 296	1 416	1 360	1 568	1 697	1 804	1 855	2 138	2 295
University of KwaZulu-Natal	898	1 150	1 184	1 144	1 477	1 662	1 953	2 118	2 108	2 242
University of Stellenbosch	1055	1 184	1 351	1 375	1 535	1 802	1 917	2 056	2 065	2 185
Other traditional universities	1241	1 515	1 724	1 881	2 235	2 702	2 785	2 977	3 256	3 527
Comprehensive universities	**677**	**828**	**1 082**	**1 151**	**1 611**	**1 824**	**1 838**	**2 173**	**2 677**	**2 968**
University of Johannesburg	266	309	434	462	708	856	844	1 039	1 265	1483
University of South Africa	191	233	243	254	295	375	452	494	686	738
Other comprehensive universities	220	286	405	435	608	593	542	640	726	747
Universities of Technology	**264**	**303**	**403**	**553**	**665**	**660**	**753**	**812**	**905**	**974**
Tshwane University of Technology	128	156	186	231	297	300	355	361	397	371
Other universities of technology	136	147	217	322	368	360	398	451	508	603

Figure 4.8. Number of scientific publications per type of university Source: NACI (2017b)

4.5 Cyberinfrastructure applications

4.5.1 Cyberinfrastructure applications at public universities

According to SANReN_1, access to cyberinfrastructure has enabled universities to improve in fulfilling their mandate and resulting in teaching and learning being influenced by the subsequent connectivity and technology development. CSIR_1 also indicated that the capacity provided enables students to share videos of lectures or access lectures remotely in real-time. CSIR_1 further added that the high-speed network enables less-resourced universities to make use of the cyberinfrastructure managed by the NREN or connected via the NREN, thereby enabling institutions to run simulations or virtualisation processes even when they only have the minimum infrastructure.

Some of the secondary benefits TENET_1 indicated relate to how the experience attained by the NREN is used to provide IT support to public universities, including providing value-added services at no additional costs. SANReN_1 mentioned how this interaction further enables the NREN to understand cyberinfrastructure

requirement of public universities better. SANReN_1 further mentioned the NREN's flexibility, especially on how the continuous investment in cyberinfrastructure from the DST has enabled it to provide more than just connectivity, including specialised services for beneficiary institutions. One respondent expressed that:

> "In the R&D platforms, there's things like research data management platforms and solutions for the whole community. So we are looking at building a portfolio of things that will effectively allow institutions to better use their bandwidths, and the result of that is better participation."

CSIR_1, SANReN_1 and TENET_1 mentioned that value-added services such as eduroam enables increased quality in research, teaching and learning. CSIR_1 further stated that eduroam enhances open learning principles, while TENET_1 insists that its benefits can be better experienced when universities provide enough bandwidth for the services. TENET emphasised that:

> We are the custodians of the eduroam service in South Africa, and that is also not charged to universities. And then there is a variety of additional services … like our video conferencing solution is free at the point of use.

CSIR_1 indicated that before the introduction of eduroam (secure global Internet roaming across university campuses) at South African universities, the administrative authentication process for visitors to access university internet at a campus other than their own was a long, onerous process. TENET_1 explained the importance of eduroam beyond campus use:

> This makes it possible for people in suburbs of the city which are not readily within reach of university campuses, particularly the poorer suburbs. It makes it possible for them to get access to free internet access on the academic network just by going to their local library or their local community centre, their local municipal authority; things like that…Extending eduroam out of the university communities. Still a service for the university community, but it is available in areas outside of the university community.

4.5.1.1.1 Learning Management System

The increased bandwidth and reliable internet connectivity have enabled public universities to adopt computerised learning management systems (LMS) for blended teaching and learning. Universities such as NW, UCT, UNISA and Wits

adopted Sakai LMS. UFS, DUT, UL, CPUT, UJ, UP and TUT have adopted Blackboard LMS. LMS can empower academics to enrich teaching and learning by making study materials electronically accessible to students regard less of their location (USAf, 2019c). Campus WiFi and access to the LMS has changed how academics approach pedagogy. A student at UL provides the following example concerning their lecturer's teaching methodology

> When he introduced new concepts, he assigned us right away to research them from the internet and threw questions at us, via Blackboard, to answer and discuss in class. By class time, he would be summarising and getting us to analyse our readings, comparing one scholar's perspective to another's. (USAf, 2019c)
>
> Coming to assessments, … always prided himself for never duplicating the questions between students. We had a class of 200, and everyone's questions were different from the next person's. So peeping over your neighbour's shoulder in the computer lab to see how they were tackling a particular question was bound to be futile. (USAf, 2019c)

4.5.1.1.2 Enhancing research and human development through Centres of Excellence

The DST supports research at public universities through the creation of Centres of Excellence programmes concentrating on performance in the following five key areas: research/knowledge production; education and training; information brokerage; networking; and service rendering (NRF, 2014; NACI, 2017a).

> The Centres of Excellence (CoEs) are physical or virtual centres of research that concentrate existing research excellence and capacity and resources, to enable researchers to collaborate across disciplines and institutions on long-term projects that are locally relevant and internationally competitive, in order to enhance the pursuit of research excellence and capacity development (Wits, n.d.).

4.6 The transformation of the University of the Witwatersrand

4.6.1 The digital transformation of the University of the Witwatersrand

The University of the Witwatersrand has a 2022 strategy that seeks to make the institution an IT savvy and world-renowned African research-intensive university. Wots hosts the largest number of Centres of Excellence, funded by DST/NRF, and

developed a R700 million technology hub researching mining-related topics (Wits, 2015)

Wits (2018a) states that the university's Vision 2022 has incorporated technology to enhance teaching and learning at the institution. Wits_1 stated that one of the pillars relevant to the study in the Wits 2022 Vision is the Wits experience. One of the strategies of embedding the Wits experience is through the investment in technology to enhance on-campus teaching, and learning experience stated Wits_1. For example, Wits_1 highlighted the extensive campus Wi-Fi coverage provided to learners to enable the flexibility regarding learning space and time. It is clear that the investment is also meant to address the challenge of shortage of classroom space stated Wits_1. Furthermore, the lack of space necessitate a Wits project to create smart classrooms (Wits, 2017a), also of interest to other universities.

> "…should, we be not looking towards some form of blended learning, face-to-face and technological online learning, and having an interaction between the two in a much more innovative way?" (GIBS, 2016)

Wits_1 expressed that the use of technology as one of the methods the university has chosen to improve throughput and counter background-influenced challenges mainly faced by first-year students. It is evident that smart classrooms will enable Wits to repurpose spaces through technology for blended teaching and learning, and spaces dedicated to student collaboration activities stated Wits_1. Wits_1 added that:

> We have processes around picking up through institutional research, people who are likely to flounder as early as possible in the 1st year experience process. So, students (are) at risk of floundering, and we are trying to have special interventions so that they don't get dropped out or left behind and whatnot. And so, in trying to respond in those needs, you need a range of teach[ing] and different interventions. So, ja classroom teaching is still important, but you would use videos online and all various means so that you know, if you miss a lecture for whatever reason, there is a way to catch it up. So, I am sure it's a way to try and make teaching more accessible, more effective and helping all the student body to be effective.

The institution also makes use of technology to remain relevant in the era of the data-intensive revolution (Wits, 2015; Wits, 2017b). For example, Wits has

established the Tshimologong Digital Innovation Precinct to pursue research in virtual reality, artificial intelligence and other areas of digital innovation. Furthermore, the institution "invested R500 million in an ICT upgrade, adopted a new cutting-edge research strategy and introduced innovative blended learning options, including digital campus, new online courses and high-tech classrooms" (Wits, 2018b).

4.6.2 The University of the Witwatersrand redefining learning spaces

Wits are using technology to improve and enhance teaching and learning, including redefining pedagogy through the concept of eZones (Wits, 2017b). The definition of eZones relates to "physical learning space that uses cutting-edge technology and advanced e-learning tools to deliver education that prepares students for the 21st Century" (Wits, 2017b). Wits (2017b) characterises eZones as classrooms of the future for digital natives:

> The eZone is equipped with broadband Wi-Fi, 80 laptops, 20 iPads, and 20 Galaxy tablets. Here students can connect to Skype or Google Hangouts and interact with academic experts worldwide instantly. There's a split projector on the wall that enables group learning by reflecting multiple images posted by students simultaneously, for comparison and discussion. There are GoPros for students to take into the field for assignments and other content development so that they can edit the footage. (Wits, 2017b, p. 24)

eZones empower innovative teaching and learning in a data-intensive paradigm (Wits, 2017b):

> …eZone allows for true connectivity where students can learn together, in a tethered community of practice, where the lecturer guides their learning path. They can access global experts instantly, live stream into clinical placements anywhere, and pose questions to each other or others elsewhere to develop new ideas and knowledge to meet the needs of our communities. It's about taking learning out of the classroom and into the real world, even if you can't leave the classroom… (Wits, 2017b, p. 25)

4.6.3 Curriculum renewal at the University of the Witwatersrand

Wits have begun reviewing data-dependent curricula due to the impact of the data-intensive revolution (Wits, 2017b). The review takes into consideration data

science, the study of where the information originates, what it represents, and how it can be used (Wits, 2017b). Some of the faculties dependent on data are Engineering and the Built Environment; Health Sciences; and Science.

> Digital data are continually being generated. Mining and analysing this data has profound implications for economies and societies. Understanding big data – ginormous datasets – thus represents the next frontier in research and innovation (Wits, 2017b, p. 34).

4.7 Conclusion

This chapter addressed the results from the textual data analysis and therefore laid the foundation for the discussion on the implications of the findings . The chapter also highlighted the link between the research sub-questions and the themes/categories adopted from the analytical framework. The presentation of the findings included textual data from the interviews and secondary document analysis, including video files, to enhance and triangulate information. Tables and figures were used to enhance the presentation of findings.

Chapter 5: Contextualising the cyberinfrastructure policy intention in South African public universities

5.1 The main research question

The primary purpose of the research was to examine the effect that national policies on cyberinfrastructure have had on teaching and learning in higher education, including the role organisational strategies have played in addressing issues of limited participation and quality of research at public universities. For this exploratory-qualitative research, data collection was via semi-structured in-depth interviews and documentary review.

The main question dealt with the effect of policy and investment in cyberinfrastructure, and the associated implications for digital transformation at public universities. The main question was broken down into the following sub-research questions:

1. How has the cyberinfrastructure funded through DST influenced the university's research capacity?
2. How do the cyberinfrastructure strategy impact on the university's teaching and learning?
3. How were the challenges on the use of cyberinfrastructure addressed?

This chapter highlights key points of analysis.

5.2 The e-rate oversight

The discussions on the oversight in the e-rate framework was unexpected. The researcher's initial interpretation of DHET_1's comments on e-rate assumed the discussion referred to the scope of the regulations that excluded public universities. The bases of the 2009 regulations is a section of the 2005 Electronic Communications Acts as amended (ECA) requiring a minimum 50% discounted rate for Internet services (connectivity, equipment and usage) or leasing of capacity from network services operator received by all public schools and all public further education and training institutions. The oversight is that the regulations remain unchanged even though the 2014 amendments to the ECA included all public higher education institutions. Between 2006 and April 2014, the e-rate framework was not applicable to public university Internet service requirement. In May 2014,

the amended legislation corrected the oversight, and therefore, e-rate regulations amendments were obligatory.

What is unclear about the e-rate provision in the legislation is concerning the reach of the minimum discount rates. It is not clear whether the legislation empowers public universities to qualify for the minimum discount rate when acting as a mobile virtual network operator (MVNO) limited to the institution's student populace. It is reasonable to expect the university will only offer services relating to teaching and learning as an MVNO.

5.3 Cyberinfrastructure strategy and provisioning of access

5.3.1 The importance of defining a cyberinfrastructure framework

The formulation of a definition of cyberinfrastructure and an NREN are central to the significance, purpose and investment considerations addressed in national policy. Katz & Proctor (2014) further posit that the consequence and sustainability of cyberinfrastructure are reliant on the intention or purpose. The researcher acknowledges Cho's (2015) argument that the formation and definition of cyberinfrastructure would outline the recurring investment requirements for technologies considered by the NREN. Foley (2016) argued that the definition of an NREN determines the funding model, especially when supposing 'public good'.

In the case of South Africa, the relationship between technical considerations, social challenges and political influence are incorporated into the purpose of the broad strategy and actual practice. Related to this is the investment in cyberinfrastructure, including the funding model for sustaining investment into the NREN (CSIR_1; SANReN_1).

The definition adopted by the DST emphasises the importance of a research infrastructure network consisting of multiple institutions collaborating to create knowledge and human development through participation in global research projects. Priority projects defined by the government are central to the composition of the country's NICIS and the role of public universities. Influencing the South African funding model for the NREN is the fact that tier-1 elements fall within the government work plan. Universities manage and operate some of the tier-3 elements through a combination of self-funding, industry support and indirect government funding.

5.3.2 Investing in cyberinfrastructure and its usage

Adams (2016) argued that the creation and sustainability of NRENs would require synergy between the following principles: commitment; coordination; connectivity; capability; content and services; and financial requirements. Many of the stated principles did guide the initial investment in South Africa's NREN based on the study commissioned by the DST. The study undertaken by TENET influenced the country's investment in cyberinfrastructure mainly to, 1) secure the global SKA project; 2) participate in the worldwide research science programmes, and 3) for commercial activities that were determined would benefit from the research infrastructure as stated. The research infrastructure needs of public universities was one of the main considerations for the initial investment.

The government funding, through DST, required a specialised agency to manage the prioritised projects, and this led to the formation of SANReN CA as a result of TENET drclining to accept funding directly from the government, due to public universities autonomy issues. By requesting TENET to operate the SANReN network, the DST acknowledged the competency of the agency.

5.3.2.1 DST investment in cyberinfrastructure usage

The DST investment in cyberinfrastructure is mainly in the following elements: data-storage through DIRISA; high-performance-computing through CHPC; and connectivity through SANReN (CSIR_1; SANReN_1). The number of international projects public universities are participating and contributing in is a testament to the success of the ongoing investment made to elevate the country's research competence profile at a global level. The skills and technology transfer resulting from participating and collaboration in projects such as the CERN and SKA is expected to transfer to other fields due to the multi-disciplinary nature of such projects. This transfer can in turn create interest in the cyberinfrastructure elements and usage of data by other disciplines as they discover value through data mining. Agarwal and Dhar (2014), Kitchin (2014) and Smith & Veldsman (2018) support this view when arguing that technology development and artificial intelligence enable new, cheaper, more flexible and better techniques of managing, processing analysing and storing data.

The hosting of the SKA and participation in the CERN projects implies that the country's NREN status and sustainability was vetted and deemed appropriate, resulting in the NREN's recognition as a crucial component of the coordinated

global research network. The continued collaboration illustrates the robustness of South Africa's NREN. Robust NRENs enable positive socioeconomic and inclusive development nationally, regionally and globally (Bankole & Assefa, 2017; Kashefi et al., 2016). It is also important to note that the data-driven revolution necessitates public universities to be highly dependent on NRENs if they are to succeed to be globally competitive and to deal with localised challenges appropriately (Foley, 2016; Kashefi et al., 2018; Smith & Veldsman, 2018; Yaver et al., 2016).

5.3.2.2 DHET investment in cyberinfrastructure and usage

The DST, through SANReN, successfully invested in a national backbone network to which all public universities are connected and treated equally. The DHET investment in RCCP I and RCCP II complemented the SANReN's project of connecting all public universities by ensuring that connectivity to rural andremote institutions was not hindered and not delayed by the lack of commercial infrastructure. Foley (2016) has argued that developed nations are demonstrating more efficient use of NREN elements because of the low cost to communicate, high fibre penetration and the ubiquitousness of the Internet, but complementary investments are clearly required in countries where affordability is a challenge.

The RCCP was relatively successful in addressing the challenge of the discrepancies between urban and rural/remote campuses by contributing to the following issues affecting faculty, student and support staff: improved access to online resources; improved exposure through global collaboration; and upskilling of support staff. Principles on the use of appropriate technology for research, teaching and learning highlighted in the *White Paper on post-School Education, and Training* received consideration, including improvement in connectivity usage through training and awareness programmes, a key success factor discussed by a few authors (Adams, 2016; Foley, 2016; Kashefi et al., 2018). Foley (2016) advances the view that the presence of trained staff, appropriate equipment, access to content and services by public universities ensures the proper usage of cyberinfrastructure.

Public universities took advantage of the investment made by the DST and DHET by upgrading their ICT infrastructure and managed to exploited the enhanced Internet connectivity to improve research, teaching and learning (USAf, 2019c). The investment made by the DST and DHET is enabling public universities struggling financially to offer quality education through accessing on-line

resources, peering and collaboration a view supported by authors such as Carabine (2016), and Smith and Veldsman (2018), among others.

5.3.3 The funding model for cyberinfrastructure

Foley (2016) advances the view that cyberinfrastructure is a 'public good' and states that best practice suggests that NRENs should have a funding matrix that includes the government, donors, higher education and research institutions. Adams (2016) supports Foley's (2016) conclusions and adds that the funding matrix should assign the cost of initial and on-going capital expenditure to the government and donors, while higher education and research institutions are responsible for operational expenses.

The South African funding model is a variation of the model supported by Adams (2016) and Foley (2016). The government, via the DST and its agencies, funded the initial capital expenditure and continue to fund recurring costs.

Funding from the government covers special projects such as the SKA, SA-CERN and Centres of Excellence, and human development programme linked to the plans. Indirectly the government funds some infrastructure requirements at public universities. Public universities support some of their research infrastructure requirements and TENET's operational costs. The current funding model creates several difficulties for rural/remote campuses.

The rural/remotes campuses generally have a challenge of access to financial resources due to historical difficulties. The institutions have the added disadvantage of lack of adequate commercial ICT resources and therefore resulting in higher costs for intervention measures. Chapter six (6) will include recommendations on how to improve the funding model.

5.3.4 Challenges with supporting strategies for connectivity

The digital divide between the leading metropolitan and rural/remote areas is affecting research, teaching and learning at rural/remote public universities and campuses. SANReN_1 indicated that the proliferation and diffusion of ICT infrastructure, services and devices empowers the NREN to introduce appropriate and cost-effective solutions for research, teaching and learning. The high cost of communication burdens students at remote public universities and campuses. The students face the unnecessarily challenge of travelling to a connected campus to access the Internet. ICASA's failure to amend e-rate regulations inline with

changes to Electronic Communications Act has hindered public universities' ability to use the legislated discount for research, teaching and learning purposes. ICASA_1 comments on the lack of definition of the access gap for South Africa, while the e-rate challenges and the USAf failures highlight the lack of synergy between departments concerning interdependencies with respect to addressing government imperatives.

5.3.5 Overview of the DST initiatives

The significance of the findings on the value of cyberinfrastructure to digital transformation at public universities cannot be underrated, especially when taking into consideration that higher education requirements for teaching and learning are important to the mandate of the DST as well as the DHET. By introducing practices to measure the use of cyberinfrastructure, the DST has managed to influence the benefits that can be derived from the research infrastructure. The measured output weighed against the investment made, provides a framework for monitoring progress, while striving to influence future investments positively. The framework, in turn, encourages public universities to have some level of accountability, productivity and relevance, concerning the government funding provided for research, teaching and learning.

Therefore, the DST is shown to have introduced a very important policy instrument that has significantly influenced teaching and learning and quality of research in public universities. The outcomes illustrate a relevance to the objectives of the 1996 White Paper on Science and Technology, the 2002 National Research and Development Strategy, the 2008 Ten-year Innovation Plan for South Africa (2008 – 2018) and the National Development Plan. It is important to note that the research's intention was not to compare progress against targets set in the policy. The varying influence on public universities is not surprising, taking into consideration the disparities between higher education institutions. The findings illustrate the continued complexity of improving teaching and learning, research quality and throughput at public universities.

5.3.6 Overview of the DHET initiatives

If the DHET contributes one-tenth of its annual allocated budget towards research at public higher education institutions, it is reasonable to expect that contribution towards projects such as the RCCP will be a tiny percentage of the funding made available for research at public universities. The grant, however, makes a marked

contribution to the rural and remote campuses,empowering each public university to reduce the digital divide between its main campus and rural/remote sites, thereby striving to standardise education experience within the same institution. The reduction in the digital gap between well-resourced and under-funded public universities is an important benefit derived from the investment.

5.4 **The extent of cyberinfrastructure access and usage**

The findings indicate that the effect of the cyberinfrastructure strategy on public universities' mandate is notable, as the increased in participation and collaboration in global research projects coincides with an increase in connectivity and technology development. The increase in connectivity and technology availability also empowered students to share content linked to teaching and learning. The improvement in connectivity is significant because it enabled public universities to introduce innovative measures to improve teaching and learning and research quality without incurring enormous costs. Increased access to cyberinfrastructure enabled historically underfunded universities to improve their services offerings and to be attractive to prospective students. It is reasonable to argue that by making all public universities attractive to an equitable pool of prospective students, it decreases the burden faced by better-resourced urban-based public universities.

As stated earlier, cyberinfrastructure strategy may have greater benefit for historically underfunded and new public universities' given the lack of appropriate infrastructure and training before the government interventions. It is also important to note that the government interventions through the NREN empower public universities to address new challenges brought about by the data-driven revolution. The data-driven paradigm is having a significant effect on universities, creating new ways of utilizing cyberinfrastructure including universities to undertake certain activities more efficiently and cost-effectively (Xing & Marwala, 2017; MOHE, 2018). For example, CSIR_1 explained how 3D printing is making prototyping easier and quicker. Public university research competency will further benefit from technology drivers such as Internet of Things, Internet of Services, hyper-connectivity, artificial intelligence; quantum computer processing, autonomous machines, robotics, nanotechnology. (Prisecaru, 2016; Schwab, 2016; Bahrin, Othman, Azli & Talib, 2016; Pereira & Romero, 2017; Xing & Marwala, 2017). These developments will expose universities to massive accurate data and

analysis tools thereby encouraging more precise research and is likely to revolutionise the processes and procedures of how research progresses.

The data-driven paradigm further effects public universities because of the requirement for new skills sets and multi-disciplinary competencies (MOHE, 2018). Therefore, it is unthinkable that public universities will not review their operational models to embrace technological developments that can enhance pedagogy and ensure competencies relevant to the paradigm. Public universities will willingly transform taking into consideration their evolving mandate, need for relevance and goal to become and remain globally competitive.

The transformation enables public universities to acknowledge the impact of the data-driven paradigm and produce the type of students that will empower a pioneering and competitive economy. Schwab (2016) indicates that the paradigm is still in its infancy, thereby requiring public universities to have agile strategies because the impact of technological developments on its mandates is still not fully known.

5.4.1 Participation in international projects

NRENs responsibility is to ensure that the interconnection of networks empower sharing of resources (computing power, storage, raw data, instrumentation, course material, etc.); innovation; discoveries; collaborative research; increased access to higher education; among other things (Cho, 2015; Foley, 2016; Pacheco, Nascimento & Weber, 2018). The collaboration and participation of public universities in global projects have enhanced research, teaching and learning concerning quality, competency development, innovation and technology transfer in the related academic fields. The use of cyberinfrastructure has enabled public universities to become globally competitive as research outputs linked to projects has significantly increased. The collaboration and participation of public universities are in line with the objectives, plan and priority projects set out in policies documents such as the 1996 White Paper on Science and Technology; the 2002 National Research and Development Strategy; and the 2008 Ten-year Innovation Plan for South Africa.

The institutions funded by the DST to continue to collaborate and participate in the CERN project are a good representation of the different types of public universities in South Africa. The composition of public universities speaks to the objectives of ensuring the elevating the role of public universities; developing human resources;

knowledge creation; and collaboration on research and development. Access to cyberinfrastructure and the continued collaboration and participation in international projects has empowered the country's journey towards sustainable economic growth. The retainment of the sought-after skills because of continued funding and participation creates excellent prospects of economic growth (Wits, 2018b). There has also been evidence of an increase in interest and involvement in masters and doctoral degrees in the related studies (Wits, 2015; Wits, 2018b). The interest is a welcome development towards the attainment of the NDP targets.

5.4.2 The reduction of the digital divide through cyberinfrastructure

Based on the accounts from the respondents CSIR_1 and SANReN_1, one of the significant impacts of CI policy on public universities, is the role it played in striving to level the playing field taking into consideration the adverse effects of the apartheid policies. Historically underfunded public universities are not only provided access to cyberinfrastructure at no cost but are also capacitated to use the infrastructure, thereby encouraging demand for research infrastructure. Encouraging demand should lead to increased research outcomes and add to the university's credibility, and hopefully, in the future, attract a significant number of top minds. TENET_1 raised an important issue of how SANReN ensured that all public universities even though financially they are not on the same standing, were provided with the same capacity. Pacheco, Nascimento & Weber (2018) highlight the importance of cyberinfrastructure in enhancing pedagogy and increasing credibility through inter-institution or student research collaboration.

It is, therefore, reasonable to conclude that historically distance learning institutions and historically under-funded universities will likely benefit more in the use of cyberinfrastructure to improve research, teaching and learning outputs.

Even with its unique context, underfunded universities in South Africa can ensure credibility through shared use of research infrastructure to enable data-based teaching and learning solutions for activities such as "online learning, virtual labs, global research networks and worldwide sharing of computer facilities" (Pacheco, Nascimento & Weber, 2018, p. 4). This view received support from Cho (2015) and Spyridonis *et al*. (2015). Based on accounts from DHET_1, CSIR_1 and SANReN_1, there is support for this view, even though they raised the concern that data-based teaching and learning solutions struggle against the high cost to communications in South Africa.

5.4.2.1 Impact of cyberinfrastructure on public universities research capacity

According to CSIR_1, SANReN_1 and TENET_1, the DST's investment in CI has had varying effects on public universities. The different impact is a challenge brought about by the historic nature of the funding principles in public universities. CSIR_1 posit that historically underfunded public universities generally have lower demand for cyberinfrastructure usage than commonly better-funded institutions such as Wits. Therefore, DST's strategy of capacitating historically underfunded public universities in the use of CI played an essential role in encouraging both demand and usage. The effort of capacitating historically underfunded public universities, in turn, will continue to encourage more academics and students to make use of research-based infrastructure and therefore empower the institution's competency to continue to undertake quality research.

Institutions such as the Wits who are historically better-funded are strategically defining themselves as globally recognised research-intensive institutions with African influence. The institution has consistently made use of the DST funded cyberinfrastructure as a research-intensive active public university (Sekgobela, 2015). As a research-intensive public university, Wits is empowered to determine innovative solutions for even more complex research activities. The digitisation of the library resources, subscribing to internal journals/books and the introduction of the Wits Institutional Repository on DSpace (WIREDSpace) enables students and academia to expediently and effortlessly access resources for ease of learning and teaching and research purposes (Sekgobela, 2015).

Regardless of whether the institutions are generally underfunded or well-funded, cyberinfrastructure enables public universities to collaborate with local, regional and global research institutions and communities even if it is not on the same scale. Access to CI enables public institutions to participate in more and broader research programmes. Peixoto *et al*. (2017) and Spyridonis et al. (2015) support this view by indicating that institutions are empowered to collaborate on largescale and innovative research projects through the NREN. The authors also suggest that this collaboration extends, through connectivity, to remote institutions as they are also empowered to form part of virtual research communities by accessing other institutions' advance research infrastructure and services.

The impact of cyberinfrastructure funded through the DST at public universities extend beyond the issues stated above. Some of the aspects influencing an

institution's research competence is the type of students and academia the public university attracts. By attracting more top students, institutions spend more resources on creating an enabling environment to leverage the potential of the students. There is less effort towards making funds available for corrective measures. Therefore, the practical usage of cyberinfrastructure enables the institutions to put together more convincing arguments when attracting top students and academia. The combination of top students, academia and efficient usage of cyberinfrastructure influences the institutions' research competency, the number of annual scientific publications, the number of journals cited globally, and the number of yearly patent registrations.

5.4.3 Lowering the cost for international connectivity

Chapter two (2) discussed the importance of high speed, and uninterrupted connectivity for global participation and collaboration, including enabling the use of local infrastructure to support local scientific needs (Cho, 2015; Spyridonis, Taylor, Abbott, Barbera, Nungu, Gustafsson, Pehrson, Oaiya & Banda, 2015). Investment in cyberinfrastructure elements has enabled South Africa to reduce the cost of accessing international connectivity at much lower rates. Between 2007 and 2016 public universities witnessed reductions to bandwidth rates/month to the magnitude of at least 7200 times. This significant reduction in costs enabled the inclusion of more institutions and provisioning of higher data throughput. The decline in bandwidth costs ensures robust connectivity crucial for a conducive environment seeking to guarantee quality research, teaching and learning outcomes for socio-economic growth and innovation.

5.4.4 Annual Monitoring of Science, Technology and Innovation Indicators

The DST through the National Advisory Council on Innovation (NACI) has created a framework to monitor, evaluate and publish Science, Technology and Innovation (STI) indicators annually. This framework enshrines both policy and institutional accountability. The framework measures against the objectives, priorities and plans outlined in the 1996 White Paper on Science and Technology; the 2002 National Research and Development Strategy; the 2008 Ten-year Innovation Plan for South Africa; and the NDP.

It is important to note that there is no targeted reporting, within the framework, on the impact of an investment made in cyberinfrastructure, nor is the need. The contributions as a result of cyberinfrastructure usage are broadly reported on in

several indicators, such as *Number of scientific publication,* and *Most prolific research producers* indicated in the annual reports. The framework empowers the government to have reference points when reviewing policy, legislation and priority projects linked to the reduction in poverty, unemployment, and societal inequality.

5.4.5 South Africa's goal of transitioning from a developmental to a pioneering nation.

Policy and investment in cyberinfrastructure, and subsequently the NREN, is part of the broader strategy to intending on transitional South Africa from a developmental to a pioneering nation. The government's more comprehensive policy framework includes making use of science and technology as a catalyst for South Africa's sustainable economic growth and the distribution of the socio-economic benefits to the general public. Continued investment in the NICIS and programmes such as e-science and Centres of Excellence empowers the country's innovation goals. The characterisation of innovative, or pioneering, countries such as the USA, German, South Korea and Japan is low unemployment rates, low-interest rates and high manufacturing outputs.

The pioneering nations are producing more future proof jobs than those lost as a consequence of the data-driven revolution. WEF (2017) contends that pioneering countries have a high number of events of collaboration between academia and business, including the development of future-proof skills. Duc (2017) presented the argument that pioneering countries have highly ranked universities, high rate of research outcome and referencing, sizeable investment and performance in the R&D sectors and high young population attending universities to obtain skills required for the data-driven revolution. Sithole (2016) argues that leading countries invest significantly in cyberinfrastructure as they closely align with economic interests. The NICIS framework and the supporting programmes empower public universities to address challenges brought about by the data-driven revolution.

5.5 **The digital transformation of public universities**

The concept of digital transformation discussed in chapter two (2) outlines the principle of how people and processes can be efficiently and purposefully integrated through technology adoption, with the rationale of tackling identified present and future challenges (i-scoop, "n.d"; Seufert & Meier, 2016; Wilms *et al.,* 2017). Transformed universities are increasingly seen using pervasive campus connectivity and elements of REN and NREN to deal with large classes by

incorporating on-campus, blended learning with revised pedagogy methodologies to enhance teaching and learning (Bankole & Assefa, 2017; Foley, 2016). The findings indicate there is the varying extent of transformation at public universities resulting from the use of the elements of cyberinfrastructure and the complementing teaching and learning software.

The varying extent of digital transformation is a consequence of several factors, such as but not limited to 1) remoteness of campuses; 2) financial standing of the institution; 3) consequence of apartheid policy. Rural or remote campuses are generally affected by far more factors than the urban-based/metropolitan-based campuses concerning the rate of digital transformation. Some of the elements are the lack of ICT infrastructure in rural/remote areas and the high cost to communicate, resulting in higher prices for interventions targeted at addressing the digital divide. The rural/remote institutions face difficulties of retaining and attracting skills as better-funded institutions seem more attractive. The challenge of financial resources, mainly as a consequence of apartheid policies, impacts the competence required to exploit the use of elements of the cyberinfrastructure and complementing software. Foley (2016) argues that the presence of an advanced NREN provides little value to students if the campuses network is not fit for purpose.

5.5.1 The increasing importance of data science

In Chapter two (2) an argument highlighting the importance of public universities exploiting cyberinfrastructure elements by coordinating infrastructure resource sharing (Adams, 2016; Kashefi et al., 2018; Songu, Powell, Barry and Brar, 2016; Carabine, 2016). The participation and collaboration of South African universities in the CERN project epitomise this principle. For this participation to be successful public universities, require organisational culture and business model change. Public universities are competitors. The institutions compete for the following, among other things, research funding from the industry, attracting teaching skills, and highly talented students. The same institutions must share resources, transfer technology and developed capacity when collaborating towards a common goal. Therefore, there is a need for transformation through business model and cultural change to enable the success of the SA-CERN. The continued funding from the DST is also essential.

The NICIS, managed by the NREN (SANReN and TENET) is crucial to these collaborations. To realise cost-efficiencies through the usage of NREN infrastructure, all participating public universities must interconnect through the national network (Adams, 2016; Kashefi et al., 2018; Songu et al., 2016). The SA-CERN and SKA projects illustrate the importance of data science in a data-intensive revolution. The DST-funded e-science learning platform situated at Wits demonstrates the significance of data-science competence requirement for the SA-CERN and SKA, amongst others. The establishment of the platform reflects the impact of big-data on pedagogy and curricula. Xing and Marwala (2017) state that the effects of research, teaching and learning stem from the data-driven paradigm technology drives affecting processes and procedures through data sharing, visualisation, high-performance computing, high-speed connectivity, simulations, etc.

Kitchin (2014) advances the view that the digital transformation of research, teaching and learning is also as a result of the use of AI to manage and analysis big-data. The consequence of science in the fourth paradigm transformations research, teaching, and learning at epistemological and ethical levels as the use of AI enables the determination of different models induced from data without prior hypothesis (Agarwal & Dhar, 2014; Kitchin, 2014).

5.5.1.1 Epistemological changes to research

The technology drivers of the data-driven revolution have impacted the research process and procedures. Developments in IoT and hyper-connectivity empowers researchers to collect data directly from where it originates and enable a variety of sources of data. This view supports Smith and Veldsman's (2018) argument that technology developments have reduced the cost implications and challenges linked with data acquisition, management and storage. The algorithms developments, AI, empower the researcher through the use of elements of the NICIS, such as high-performance computing and data storage, to analyse raw and stored data, from other sources, simultaneously.

Cyberinfrastructure allows researchers to access applications of artificial intelligence that deploy innovative forms of data analytics capable of managing big data and determining patterns without prior hypothesis (Agarwal & Dhar, 2014; Kitchin, 2014). The use of AI goes against the historical belief that knowledge of theories is the foundation of data analysis. AI requires inputs to determine patterns

and optimise analysis, but the arguments presented imply that prior hypothesis is not necessarily the information needed. The effects of big-data have resulted in some public universities reviewing their data-dependent curricula because they have acknowledged that big-data is the next edge in research and innovation (Wits, 2017b).

5.5.2 The exploitation of cyberinfrastructure through applications

The use of AI to influence digital transformation in research, teaching and learning illustrates the growing importance and development in software applications. As stated earlier, digital transformation at public universities is the outcome of cultural and business model changes, amongst other things. Public universities are required to automate some of their processes, review pedagogy, and create self-service portals, to successfully transform research, teaching and learning through the use of the software. The availability of appropriate bandwidth, reliable Internet connection and access to WiFi complements the use of software systems such as learning management system (LMS) to enhance teaching and learning. The developments software applications have transformed lecturers from dispensing education to guiding the scope of training.

LMS empowers lecturers to make study materials available electronically, while face-to-face sessions are for summarising, question and answer sessions. The system enhances teaching and learning, especially for large classes (USAf, 2019c). Applications such as eduroam strengthen teaching and learning for travelling students. eduroam enables travelling students to participate remotely or catch-up on learning, provided there is access to participating institutions. TENET_1 has indicated that eduroam rolled out in local libraries, community centres and municipal facilities in Cape Town is providing free Internet access on the academic network to daily students residing in poor communities. The burden of students in impoverished areas travelling to a public university to access the Internet is removed, thereby enabling the students to spend more time learning and less travelling. The installation of eduroam on municipal facilities extends the reach of public universities, by making the facilities satellite ‘campuses’.

5.5.2.1 Digital transformation at the University of Witwatersrand

Wits display several characteristics of a digitally transforming public university discussed in Chapter two (2). The institution exemplifies its innovative psyche element by establishing the Tshimolong Digital Innovation Precinct and the hosting

of the largest number of Centres of Excellence, amongst other things. Digital transformation elements such as competency development and value creation characterise the expected outcomes of such projects. The projects display leadership support and commitment to the institution's goal of being the highed African-centred public university in the world. Xing & Marwala (2017) advise that public universities must embrace and adopt emerging and disruptive technologies enhancing pedagogy and nurture competencies required for the data-driven revolution. Wits host the e-science learning platform dedicated to competency development for data-science.

Agarwal & Dhar (2014) posit that by adopting disruptive technology and ensuring training for the use of cyberinfrastructure, the enhanced researcher and scholar experience exposes them to opportunities and challenges brought about by big-data. The institution has invested in the upgrading of its ICT infrastructure and deployment of campuses-wide WiFi coverage. The investment empowers Wits to enhance pedagogy through a combination of face-to-face and blended learning methods. The combination of providing learning spaces with dedicated ICT devices, applications, campus-wide Wifi coverage and enhanced pedagogy offers a solution to the problem of lack of infrastructure for face-to-face teaching and learning. The solution provides a similar experience between blended learning and face-to-face because the institution has provided all the required resources on campus. The learning spaces offer students, whether in the same field or not, with the opportunity to collaborate or form discussions group in areas of mutual interests.

Wits_1 indicated that the institution adopted technologies that will encourage increased student throughput by introducing timeous interventions enabling students to access educational materials, recorded lectures, etc. at a time and space convenient to the learner. Wits display psyche of an institution that has taken into consideration some of the digital transformation elements discussed in chapter two (2). The main features are: 1) innovative psyche; 2) reinventing operational practices; 3) destroying departmental silos; 4) competency development; 5) value creation; 6) resource optimisation; and 7) accommodating people subtleties (Sharma, 2015; i-scoop, n.d; Wilms *et al.,* 2017).

5.6 Conclusion

This chapter presented and discussed the meaning of the analysis of the data presented in chapter 4 concerning the body of knowledge reviewed in chapter 2. The discussion was presented in a similar structure as shown in chapter four (4) for ease of understanding.

Chapter six: A summary and conclusion of the research

This chapter concludes the study and deliberates on the research objectives based on the body of knowledge and conceptual framework presented in chapter two (2); data presented in chapter four (4) and the discussion on the data in chapter five (5). Chapter six (6) describe the limitations of the research, proposes potential areas for future research, and provides recommendations based on the outcome of the study.

The insight obtained from the data collected in chapter 4 and the analysis undertaken in chapter 5 contextualises why this qualitative case study of the University of Witwatersrand presents complexities in the understanding of digital transformation at public universities. The complexities of digital transformation determine how and for what public universities make use of cyberinfrastructure.

The literature review indicates that policy and public universities' strategies are some of the underlying concepts influencing digital transformation at public universities. Additionally, the literature review highlights the importance of research and innovation in developing countries seeking to create pioneering economies to mitigate against the negative ramification of the fourth industrial revolution paradigm. The fourth industrial revolution paradigm necessitates not only the review of the role of public universities in the journey towards digital economies but also the evaluation of how education is attained and the type of students the institutions must produce.

6.1 Summary of the research

The study begins by outlining a short history of the South African academic research network and the linkage with public universities. The presentation of the characterisation of the cyberinfrastructure introduces the likely scope of the concept. Linked to the cyberinfrastructure concept is a brief overview of the function of NRENs and their global interconnection. The research presents the National Integrated Cyberinfrastructure Systems (NICIS) concepts; elements of the NICIS; the accompanying services and; the management component of the NREN. Included in the introduction is the ownership and relationship between the two (2) entities (SANReN and TENET), de facto NREN, tasked with managing the NICIS. Furthermore, the purpose of the rural campuses connectivity projects (RCCP) funded by the Department of Higher Education and Training (DHET) is mentioned.

The introduction concludes by providing the policy framework influencing the DST strategies on science and technology research. The 1996 White Paper on Science and Technology affects the DST concerning the use of science and technology to support National System of Innovation (NSI), a vehicle chosen to address socio-economic issues. Supporting the White Paper is the National Research And Development Strategy and the Ten-year Innovation Plan, addressing issues of funding and outlining priority research projects. Lastly, the policy framework covers the following: the overarching development policy (NDP); and the draft open learning policy framework proposing the use of ICT to remove research, teaching and learning barriers affecting public universities.

The study progresses by determining critical concepts and determining body knowledge of knowledge for literature review. The key concepts identified are the following: digital transformation; National Research and Education Network (NREN); cyberinfrastructure; data-driven revolution and; policy and investment in cyberinfrastructure. The literature review discussed and analysed previous research linked to the key concepts and aspects of the topic. The study outlined what is known and what is unknown about the topic of research. The literature review section concluded by proposing a conceptual framework outlining key concepts crucial to measuring the impact of cyberinfrastructure at South African public universities. The conceptual framework is an interpretation of Katz and Proctor's (2014) cyberinfrastructure sustainability model.

The research continues by describing the preferred methodology principles, and artefacts applied to the study, as a measure of ensuring consistency and validity of data collection. The study outlines how the collected data was analysed, including detailings on how data was gathered and processed. A qualitative single case-study methodology was used to understand the underlying concepts of the study. The researcher collected data through in-depth interviews with senior managers at the DHET, DST, DTPS, ICASA, and University of Witwatersrand, and documentary analysis.

The study presented emerging themes from the collected data to contextualise the research problem and the conceptual framework. Included in the research is the link between sub-research questions, conceptual framework and emerging themes, and sub-sections of the emerging themes providing possible answers to the sub-research questions. The emerging themes from the collected data are as

following, providing access to cyberinfrastructure; cyberinfrastructure strategy emphasis; the impact of access and usage of cyberinfrastructure; cyberinfrastructure applications; and the transformation of the University of the Witwatersrand.

Finally, the research discusses the meaning of the collected data presented. Presented again are the main research question and the sub-research questions. The discussion section in the study followed a similar structure at the one in the data collection presentation. The study examines an issue, namely e-rate, that presented interpretation challenges. The grouping of the discussion of the data is given based on the following sub-headings; cyberinfrastructure strategy and provisioning of access; the impact extend of cyberinfrastructure access and usage; and the digital transformation of public universities.

6.2 Revisiting the research purpose

The purpose of the research is to determine what role national and organisational policies and strategies have played in creating an enabling environment for effective digital transformation through the deployment of cyberinfrastructure, which in turn promotes improved research, teaching and learning at public universities.

The study sought to answer the research sub-questions raised by grouping the data according to the themes that emerged. When taking into consideration the presentations made in chapter two (2), four (4) and five (5), there is a need to develop an appropriate response to the sub-research questions further.

Stated below is the main research question:

> What has been the effect of policy and investment in cyberinfrastructure on digital transformation at public universities, concerning teaching and learning, and knowledge creation, and why?

The researcher will next answer this fundamental question with the use of the conceptual framework.

6.3 Framework

6.3.1 Investment in cyberinfrastructure

6.3.1.1 How has the cyberinfrastructure funded through DST influenced the university's research capacity?

The findings indicate that the DST implemented an effective multi-pronged strategy regarding the use of the country's NICIS. The DST at some point realised that investment in infrastructure alone did not provide the desired outcome, concerning utilisation that will beget knowledge creation and innovation. The DST also realised that there were utilisation and output discrepancies between public universities. The DST invested in cyberinfrastructure awareness and training to address the matter in a manner proportionate to the standing of public universities. The institutions were encouraged to consider upgrading their ICT infrastructure to ensure appropriate participation.

The DST's efforts enabled some public universities to access cyberinfrastructure and effectively collaborate with other research institutions. The competency to effectively use the cyberinfrastructure enabled increased research outputs, improved research quality, introduced technology transfer, human development, increased the scope of research at public universities, enabled public universities to collaborate and host sections of international projects, etc. Well-funded public universities such as Wits and UCT are empowered to attract industry research funding, and to innovation, centres tasked to pursue the institutions' research priorities. The body of knowledge reviewed agree with the research findings.

6.3.1.2 How were the challenges on the use of cyberinfrastructure addressed?

As stated above, the DST invested in cyberinfrastructure awareness and training to address some of the challenges. The DST also funded public universities such as Wits to create platforms dedicated to developing and harnessing skills required for the priority projects. The investment ensures that the country addresses some of its skill shortage. The DHET through the RCCP invested in training for rural/campuses. The investment by the DHET, even though it may be considered small, was significant because it was not a budgeted expense.

6.3.2 Policy decision on cyberinfrastructure

6.3.2.1 How has the cyberinfrastructure funded through DST influenced the university's research capacity?

The policies, strategies and plans influencing the mandate of the DST define the countries long-term research priorities and in turn, enable public universities to align accordingly. The government research priorities affect future skills requirements and knowledge generation, especially when the objective is to create new industries and technologies. Radical innovation forms a significant part of the pioneering nations' strategy. Therefore, policy consequently affects the type of programmes provided at public universities. The body of knowledge alludes to the epistemological changes to research, teaching and learning processes due to big-data.

The findings indicate how valuable access and usage of cyberinfrastructure is to the university research capacity. Access and usage of cyberinfrastructure empowers universities to gain global credibility and prominence. By participating and collaborating in global research projects, South African universities provide African perspective to global issues and benefit by accessing research inputs and/or outputs from the global research communities. Furthermore, the university staff and students obtain valuable knowledge and experience and thereby becoming globally recognized. The usage of cyberinfrastructure and participation in global research projects enables universities to attract funding and first-class students, leading to initiating and/or taking part in pioneering research projects

6.3.2.2 How do the cyberinfrastructure strategy impact on the university's teaching and learning?

The findings indicate policy influencing cyberinfrastructure was for dedicated research projects and that teaching, and learning issues were the unintended beneficiaries. The body of knowledge reviewed, and the data collected imply that repurposing of technologies for teaching and learning is made possible by the innovative developments in software and diffusion of devices. Public universities took advantage of these developments by enabling their students to receive education outside the classroom and to ensure access to educational material any time of the day.

6.3.3 Usage of Cyberinfrastructure

6.3.3.1 How do the cyberinfrastructure strategy impact on the university's teaching and learning?

All public universities make use of elements of the cyberinfrastructure and have varying demands. The findings indicate that usage of the cyberinfrastructure to enhance teaching and learning is dependent on challenges needing requiring addressing or individual, institutional goals. Some public universities create solutions for teaching and learning for big classes, others for designing teaching and learning overflow spaces. Another institution is empowered to address the issue of cheating through applications running on the cyberinfrastructure. Well-funded public universities provide devices in dedicated areas to create smart learning.

The findings indicate that there is a commonality amongst public universities in some of the applications used to enhance teaching and learning, but better resourced public universities can do much more with teaching and learning opportunities presented by accessing cyberinfrastructure. It is reasonable to make a general statement that the usage of cyberinfrastructure has improved research, teaching and learning in all public universities, with some institutions creating much more better value for themselves.

6.3.4 The impact of cyberinfrastructure

6.3.4.1 How do the cyberinfrastructure strategy impact on the university's teaching and learning?

As stated earlier, the effect of cyberinfrastructure varies amongst public universities. Generally, public universities have been empowered to improve credibility and research, teaching and learning throughputs. The varying impact has added to the scenario of lack of uniformity concerning the perceived value attached to certificates and the issuing public university.

6.3.4.2 How were the challenges on the use of cyberinfrastructure addressed?

The provisioning of training helped in striving to reduces the inconsistency in the impact. The issue of varying effect is the problem that is going to exist for some time to come. The DHET is hoping in the future to address some of the challenges on teaching and learning through the introduction of a policy on open learning.

6.4 Limitations of the study

The study had a challenge of availability and securing interviews, even when prospective interviewees initially agreed. Some potential interviewees, due to their position, struggled to confirm the interview date due to work commitment and were unsuccessful in arranging alternative people. The inclusion of additional documentary analysis was meant to address the limitation. The outcome of the study could have benefitted from interviewing representatives from at least a single rural/remote public university, as mitigation against the limited representativity of data.

6.5 Future research

The study has highlighted the impact of big-data on research, teaching and learning processes and procedures. It will be interesting to determine the effect of cybersecurity issues on research, teaching and learning as a result of big-data on public universities. Another possible starter is the impact of intellectual property rights on research, teaching and learning as a result of big-data on public universities.

The diffusion of ICT infrastructure, devices and services are crucial to the NREN's ability to repurpose facilities for teaching and learning. With the expected mass introduction of 5G-based services, research on the overall impact of 5G influenced technologies on research, teaching and learning in public universities is required.

Future research could contemplate the impact of cyberinfrastructure and the use of applications such as augmented reality and virtual reality on pedagogy in public universities.

6.6 Conclusion

The findings of the study indicate areas of research, teaching and learning that have benefitted from policy and investment in cyberinfrastructure. The research clearly outlines activities and applications epitomising aspects of digital transformation at public universities. The findings indicate the varying impact of digital transformation at public universities, concerning research, teaching and learning. It is, therefore, expected that the different impact influences of digital transformation and the geographic positioning with respect to the density of ICT infrastructure directly affect the number of projects or government-funded intervention programmes in which public universities participate.

It is evident that cyberinfrastructure funded through the DST has positively influenced the teaching and learning, and research capacity at public universities. The increase in participation in of global research projects and the growth in the number of Centers of Excellence based at public universities is testament to the funding. The SANReN network has empowered universities in contrasting financial standing to collaborate and create environment for equal opportunities and access. State and institution cyberinfrastructure strategy and investment has empowered some public universities to strive to be world-class research institutions, while others made use of technology to address issues of access to research resources and furthermore, address issues of shortage of classroom space.

It is clear that factors outside the scope of the policy consideration for cyberinfrastructure also influence the dissimilarity in the state of digital transformation at public universities. As stated earlier, it is plausible to make a general statement that the usage of cyberinfrastructure has improved research, teaching and learning in all public universities, with some institutions creating much more better value for themselves. The factors affecting the uniformity of digital transformation at public universities dissuades the research from generalising the outcomes of the study. The analysis can be generalised to historically white and well-funded public universities.

6.7 Recommendations

Chapters 2, 4 and 5 activated several thoughts regarding possible suggestions as outcomes of this study.

6.7.1 Public higher education institutions

The findings indicate how valuable access and usage of cyberinfrastructure is to the university research capacity. There is a need to increase government research funding for South Africa to empower more higher education institutions. The funding is required to spread Centers of Excellence and therefore empower equal opportunities and access.

6.7.2 Research funding through industry participation

The South African government needs to create an economic framework that will encourage the industry to house their research projects at institutions of higher learning. The ability of institutions of higher learning to attract more research funding enables them to raise capital and depend less on government funding.

6.7.3 The use of the Universal Services Access Fund

Section of the ECA dealing with the scope of intervention concerning money in the Universal Service and Access Fund (USAF) must be amended to include public universities as defined in the Higher Education Act. Amendments to any other section of ECA supporting the inclusion of public universities must also be incorporated.

6.7.4 The University of the Witwatersrand e-zones

The University of the Witwatersrand's e-zone concept should be considered as standard practice in all public universities. The USAF can be used as a vehicle to assist rural/remote campuses.

6.7.5 The use of e-rate

ICASA must amend the e-rate regulations as soon as possible because the 2009 regulations are outdated and not in compliance with the ECA. The amendments to the regulations must enable TENET to be an MVNO dedicated to providing Internet access to registered students limited access to public university educational material remotely. The recommendation requires ICASA to accommodate TENET in the numbering plan.

6.7.6 The use of eduroam

The implementation of WiFi spots in Cape Town municipal facilities, as implemented by TENET, to enable public universities students from impoverished areas to access eduroam must be standardised and implemented nationally. ECA processes must support TENET. ICASA is scheduled to begin the licensing process of additional mobile spectrum. The recommendation is that when ICASA publishes the invitation to apply, TENET must lobby the Regulator to include in the obligations attached to the licence a list of municipal areas requiring ICT infrastructure for teaching and learning purposes.

6.7.7 The Digital-Development Fund

Consideration towards the development of the Digital-Development Fund legislation must determine the digital gap and intentionally bridge this divide to bring media, internet, and digital literacy to all public university students. The legislation must propose an implementation strategy that will prioritise deployment

based on the highest impact on teaching and learning, not only on the most accessible institution.

6.7.8 ICT policy for teaching and learning

The DHET requires an ICT policy for teaching and learning to ensure that the university systems uniformly benefit from the use of ICTs. The policy must create a strong linkage with other relevant policies from other departments. Technology advancement is continuous, and the benefits are so vast and regularly changing that the policy needs to be agile. Technology standards such as 5G are enabling applications such as augmented reality and virtual reality to be used for teaching and learning.

5G is expected to simplify the adoption of various modalities of teaching and learning. Public universities situated in urban areas are guaranteed to benefit from these technological developments because when deploying new technologies, commercial ICT service providers prioritise the main metropolitans. It will be the responsibility of the policy to introduce intervention measures that will normalise technology adoption for teaching and learning purpose at public universities. The policy must create a framework for identifying teaching and learning legislative challenges brought about by the adoption of new technologies.

6.7.9 Industry research

The DST and Department of Trade and Industry (DTi) must consider a joint policy framework that will encourage more industry players to locate their research in public universities. The framework must promote the equitable inclusion of all public universities

List of References

Adams, L. (2016). Riding the National Research and Education Networking Train in Africa: A policy brief for stakeholders. https://www.aau.org/wp-content/uploads/sites/9/2018/05/Riding-the-National-Research-and-Education-Networking-Train-in-Africa.pdf

Agarwal, R. & Dhar, V. (2014). Big Data, Data Science, and Analytics: The opportunity and challenge for IS research. *Information Systems Research 25(3), 443-448.* https://doi.org/10.1287/isre.2014.0546

Ardizzone, V., Becker, B., Gazendam, A., Eck, A., Vaux, G., Murray, S., Ballestrero, S., Ives, N., Barbera, R., Giorgio, E. & Ricciardi, G. (2009). The South African national compute grid. https://www.researchgate.net/publication/235799617_The_South_African_National_Compute_Grid

Babbie, E. (2013). The practice of social research. 13th Edition. Canada: International Edition.

Bahrin, M. A. K., Othman, M. F., Azli, N. H. N. & Talib, M. F. (2016). Industry 4.0: A review on industrial automation and robotic. *Jurnal Teknologi (Sciences & Engineering), 78, 137 – 143*. doi:10.11113/jt.v78.9285 https://www.researchgate.net/publication/304614356_Industry_40_A_review_on_industrial_automation_and_robotic

Balliah, D. (2001). Elijah's Network: Building the Internet from copperwire. https://docplayer.net/123127570-Dinesh-balliah-elijah-s-network-building-the-internet-from-copperwire-1.html

Bankole, F. & Assefa, Z. (2017). Improving the quality of education and research output in Africa a case of Ethiopian education and research network (Ethernet). *Journal of Applied Global Research (JAGR), 10 (24), 31 – 51*. https://www.researchgate.net/publication/320417204_IMPROVING_THE_QUALITY_OF_EDUCATION_AND_RESEARCH_OUTPUT_IN_AFRICA_A_CASE_OF_ETHIOPIAN_EDUCATION_AND_RESEARCH_NETWORK_ETHERNET

Benešová, A. & Tupa, J. (2017). Requirements for education and qualification of people in industry 4.0. *Procedia Manufacturing, 11, 2195 – 2202*. https://doi.org/10.1016/j.promfg.2017.07.366

Bhattacherjee, A. (2012). Social science research: principles, methods, and practices. 2nd Edition. Florida: Creative Commons Attribution. http://scholarcommons.usf.edu/oa_textbooks/3

Bryman, A. (2012). Social research methods. 4th Edition. New York: Oxford University Press Inc.

Carabine, D. (2016). How ICTs and collaboration with NRENs are changing the face of higher education. https://repository.ubuntunet.net/bitstream/handle/10.20374/240/carabined.pdf?sequence=1&isAllowed=y

Cho, M. (2015). An empirical analysis of worldwide cyberinfrastructure. *Asian Journal of Innovation and Policy 4 (3), 381-396*. http://scholar.google.co.za/scholar_url?url=http%3A%2F%2Fwww.kpubs.org%2Farticle%2FarticleDownload.kpubs%3FdownType%3Dpdf%26articleANo%3DGSHSS5_2015_v4n3_381&hl=en&sa=T&oi=gga&ct=gga&cd=0&d=7032605650514152109&ei=JGRAXNW1EISNmgGV0KHQBw&scisig=AAGBfm3Tj342Z5w0UofEeIdw3XrGn2-mQA&nossl=1&ws=1455x690&at=An%20Empirical%20Analysis%20of%20Worldwide%20Cyberinfrastructure

Creswell, J. W. (2003). Research design: Qualitative, quantitative, and mixed method approaches. 2nd Edition. California: Sage Publications, Inc.

Creswell, J. W. (2014). Research design: qualitative, quantitative, and mixed methods approaches. 4th edition. California: SAGE Publications, Inc.

CSIR. (n.d.). Explore the CSIR. https://www.csir.co.za/about-us

DHET. (2015a). Strategic plan 2015/16-2019/20. Pretoria: Department of Higher Education and Training. http://www.dhet.gov.za/Strategic%20Plans/Strategic%20Plans/Department%20of%20Higher%20Education%20and%20Training%20Strategic%20Plan%202015-16%20-%202019-20.pdf

DHET. (2015b). National Assembly for oral reply question 56: internal question paper 06 of 2015). Cape Town: Parliament. http://www.dhet.gov.za/Parliamentary%20Matters/March%202015/Reply%20to%20Question%2056.pdf

DHET. (2017). Draft open learning policy framework for post-school education and training. Pretoria: Department of Higher Education and Training. http://pmg-assets.s3-website-eu-west-1.amazonaws.com/170407openlearningframework-postschooleduc.pdf

DHET. (2018). Investment trends in post-school education and training in South Africa. Pretoria: Department of Higher Education and Training. www.dhet.gov.za/Planning%20Monitoring%20and%20Evaluation%20Coordination/Investment%20Trends%20on%20Post-School%20Education%20and%20Training%20in%20South%20Africa%20-%202018.pdf

DPME. (2011a). Our future-make it work: National Development Plan 2030. Pretoria: Department of Planning, Monitoring and Evaluation. http://www.nationalplanningcommission.org.za/Pages/NDP.aspx

DPME. (2011b). Our future-make it work: National Development Plan 2030 (Executive Summary). Pretoria: Department of Planning, Monitoring and Evaluation. http://www.gov.za/sites/www.gov.za/files/Executive%20Summary-NDP%202030%20-%20Our%20future%20-%20make%20it%20work.pdf

DST. (1996). White Paper on Science and Technology. https://www.gov.za/sites/default/files/gcis_document/201409/sciencetechnologywhitepaper.pdf

DST. (2002). South Africa's National Research And Development Strategy. https://www.dst.gov.za/images/pdfs/National%20research%20%20development%20strategy%202002.pdf

DST. (2008). The Ten-Year Plan for Science and Technology. https://www.dst.gov.za/images/pdfs/The%20Ten-Year%20Plan%20for%20Science%20and%20Technology.pdf

DST. (2013). National Integrated Cyberinfrastructure System: A framework for the establishment and maintenance of a sustainable NICIS. Pretoria: Department of Science and Technology. http://www.dst.gov.za/images/NICIS_Framework_Report_December_2013_26_May_2014.pdf

DST. (2018). Annual Performance Plan 2018/19. https://www.dst.gov.za/images/DST-APP-2018-NEW-WEBVersion2.pdf

DTPS. (2016). National Integrated ICT Policy White Paper. Pretoria: Department of Telecommunications and Postal Services. Retrieved from https://www.dtps.gov.za/images/phocagallery/Popular_Topic_Pictures/National_Integrated_ICT_Policy_White.pdf

Duc, K. T. (2017). The fourth industrial revolution: The role and mission of the universities in delivering a high quality workforce. *National Institute for Vocational Education and Training, 51 (12), 33 – 38.* http://jvet.org.vn/index.php/jvet/article/view/10/8

eduroam. (2018). eduroam: the worldwide Wi-Fi roaming service for academia. Retrieved from https://www.eduroam.org/wp-content/uploads/eduroam-leaflet-1.pdf

Elçi, A., Vural, M. & Elçi, A. (2017). Changing Role of Faculty Members in Technology Enhanced Learning Environments Faculty Members 4.0. *The Turkish Online Journal of Educational Technology (TOJET), Special Issue for ITEC 2017, 1004 – 1009*. Retrieved from https://www.researchgate.net/publication/322530444_Changing_Role_of_Faculty_Members_in_Technology_Enhanced_Learning_Environments_Faculty_Members_40

Ferreyra, M. M., Avitabile, C., Álvarez, J. B., Haimovich Paz, F. & Urzúa, S. (2017). Overview. *At a Crossroads: Higher Education in Latin America and the Caribbean*. Washington, DC: Directions in Development—Human Development (World Bank), (1 – 38). https://openknowledge.worldbank.org/handle/10986/26489

Foley, M. (2016). The Role and Status of National Research and Education Networks in Africa. *World Bank Education, Technology & Innovation: SABER-ICT Technical Paper Series (#05).* Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/26258

Fouka, G. & Mantzorou, M. (2011). What are the Major Ethical Issues in Conducting Research? Is there a Conflict between the Research Ethics and the Nature of Nursing? *Health Science Journal, 5, 3 – 14.* http://www.hsj.gr/medicine/what-are-the-major-ethical-issues-in-

conducting-research-is-there-a-conflict-between-the-research-ethics-and-the-nature-of-nursing.pdf

Galagan, D. & Looijen, M. (2009). National Research and Education Networks: Analysis of Management Issues. https://web.archive.org/web/20100311063454/http://www.isoc.org/isoc/conferences/inet/99/proceedings/3h/3h_1.htm

GIBS. (2016, April 12). *Prof Adam Habib - Challenges Facing Higher Education [video file]*. www.youtube.com/watch?v=cynKMX3TUU

Given, L. M. (2008). *The Sage encyclopedia of qualitative research methods*. California: SAGE Publications Incorporated.

Greaves, D. (2016). The Rural Campuses Connection Project (RCCP). http://www.usaf.ac.za/

Greaves, D. (2019). RCCP I and II: an overview. https://www.usaf.ac.za/

HESA. (2015). Rural Campuses Connection Project: Evaluation Report.

http://www.usaf.ac.za/wp-content/uploads/2016/09/RCCP-Evaluation-Exec-Summary-restructured-report.pdf

Inamorato dos Santos, A., Punie, Y. & Castaño-Muñoz, J. (2016). Opening up Education: A support framework for higher education institutions. JRC Science for Policy Report, EUR 27938 EN. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC101436/jrc101436.pdf

i-scoop. (n.d.). Digital transformation: Online guide to digital business transformation. https://www.i-scoop.eu/digital-transformation/

Kashefi, A., Taylor, J.E.S., Abbott, P., Anagnostou, A., Tessa, M.O., Oaiya, O., Barry, B. & Alline, D. (2018). User requirements for national research and education networks for research in West and Central Africa. https://journals.sagepub.com/doi/full/10.1177/0266666918774113

Katz, D. S. and Proctor, D. (2014). A framework for discussing e-research infrastructure sustainability. *Journal of Open Research Software, 2(1): e13, 1-4*. DOI: http://dx.doi.org/10.5334/jors.av

Kitchin, R. (2014). Big Data, new epistemologies and paradigm shifts. *Big Data & Society, 1 -12*. https://journals.sagepub.com/doi/full/10.1177/2053951714528481

Knoch, C. (1997). Uninet: The South African academic and research network. https://pdfs.semanticscholar.org/4969/1f6e47155a186a1067bd438f0803a25b3594.pdf

Khunga, B. & Kunda, D. (2017). Impact of NRENs in Universities: The ZAMREN Experience. *MANAS Journal of Engineering ,5 (2)*. https://dergipark.org.tr/en/download/article-file/576035

Lopes, P.R.L., Simoes, N., Coury, W., Ribeiro, J. L., Caetano, D., Machado, P., Pereira, M., Meireles, I., Brito, T.D. L. V., Messina, I.A., Pisa, I.T., Haddad, A.E. & Al-shorbaji, N. (2015). National research and education networks to support healthcare: The Brazilian telemedicine university network RUTE. Retrieved from https://repository.ubuntunet.net/handle/10.20374/223

Mafuwane, B. M. (2011). The contribution of instructional leadership to learner performance (Doctoral dissertation). University of Pretoria, Pretoria. Retrieved July 1, 2016 http://repository.up.ac.za/bitstream/handle/2263/24016/Complete.pdf?sequence=10

Manda, M. I. & Backhouse, J. (2017). Digital transformation for inclusive growth in South Africa: challenges and opportunities in the 4th industrial revolution. https://www.researchgate.net/publication/318395119_Digital_transformation_for_inclusive_growth_in_South_Africa_challenges_and_opportunities_in_the_4_th_industrial_revolution

MOHE (Department of Higher Education Malaysia). 2018. Framing Malaysian higher education 4.0: Future-Proof Talents. https://www.researchgate.net/publication/324491091_FRAMING_MALAYSIAN_HIGHER_EDUCATION_40_FUTURE-PROOF_TALENTS

NACI. (2017a). Review of the White Paper on Science and Technology. http://www.naci.org.za/wp-content/uploads/2010/01/Review-of-the-White-Paper-on-Science-and-Technology.pdf

NACI. (2017b). South African Science, Technology and Innovation Indicators 2017. http://www.naci.org.za/wp-

content/uploads/2018/07/South_African_Science_Technology_And_Innovation_Indicators_Report_2017.pdf

National Treasury. (2018). *Annexure D: Public-sector infrastructure update*. Budget Review. Pretoria: National Treasury. http://www.treasury.gov.za/documents/national%20budget/2018/review/Annexure%20D.pdf

NRF. (2014). Centres of Excellence. https://www.nrf.ac.za/division/rcce/instruments/centre-of-excellence

Pacheco, S. C. R., Nascimento, E. & Weber, O.R. (2018). Digital Science: Cyberinfrastructure, e-science and citizen science. https://www.researchgate.net/publication/323395791

Peixoto, F. T., Martinazzo, A. L. & Weber, O. R. (2017). Cyberinfrastructure requirements for research communities. https://www.researchgate.net/publication/319269132

Pereira, A.C. and Romero, F. (2017). A review of the meanings and the implications of the Industry 4.0. concept. *Procedia Manufacturing, 13, 1206 – 1214.* https://doi.org/10.1016/j.promfg.2017.09.032

Petrova, P. & Kostadinova, I. (2017). Higher education in the era of digital transformation. *Proceedings of EDULEARN17 Conference 3rd – 5th, Barcelona, Spain*. https://www.researchgate.net/publication/318685439_HIGHER_EDUCATION_IN_THE_ERA_OF_DIGITAL_TRANSFORMATION

Petty, N. J., Thomson, O. P. & Stew, G. (2012). Ready for a paradigm shift? Part 2: Introducing qualitative research methodologies and methods. Manual Therapy, 17, 378-384. http://www.sciencedirect.com/science/article/pii/S1356689X12000549

PICC. (2012). Presidential Infrastructure Coordinating Commission: A summary of the South African National Infrastructure Plan. Pretoria: Economic Development Department. http://www.economic.gov.za/downloads/presidential-infrastructure-coordinating-commission/#piccbook

Prisecaru, P. (2016). Challenges of the fourth industrial revolution. *Knowledge Horizons: Economics, 8, 57 – 62.* http://orizonturi.ucdc.ro/arhiva/khe-vol8-nr1-2016/09.%20Petre%20Prisecaru.pdf

Rosenthal, M. (2016). Qualitative research methods: Why, when, and how to conduct interviews and focus groups in pharmacy research. Currents in Pharmacy Teaching and Learning 8,509–516. DOI: http://dx.doi.org/10.1016/j.cptl.2016.03.021

RSA. (2014, June 2). Infrastructure Development Act No.23 of 2014. Government Gazette No. 37712. Pretoria: Republic of South Africa. Retrieved from https://www.gov.za/documents/infrastructure-development-act

Salmon, G. (2014). Learning Innovation: A framework for transformation. *European Journal of Open, Distance and e-Learning, 17 (2), 220 – 236*. https://www.researchgate.net/publication/276516858_Learning_Innovation_A_Framework_for_Transformation

SA-CERN. (n.d.). South African scientific collaboration with CERN. https://sa-cern.tlabs.ac.za/

SA-CERN. (2017). Third Quarterly Report 2017/18: SA-CERN. https://sa-cern.tlabs.ac.za/wp-content/uploads/sites/15/2017/07/SA-CERN-Q1-2017-2018-final.pdf

SANReN. (n.d.). https://www.sanren.ac.za/relationships/

Saunders, M., Lewis, P. & Thornhill, A. (2007). Research methods for business students (fourth Ed.). Harlow: Pearson Education Limited.

Schwab, K. (2016). *The fourth industrial revolution (first Ed.)*. UK: Penguin Random House.

Sekgobela, E. (2015). Chapter 1: NREN as ICT infrastructure and bandwidth provider for collaborative research. *NRENs as ICT infrastructure to support e-services at universities: A case of wits university*. http://wiredspace.wits.ac.za/xmlui/bitstream/handle/10539/21980/Eugenia%20Sekgobela_MA%20Research%20Report.pdf?sequence=1&isAllowed=y

Seufert, S. & Meier, C. (2016). From eLearning to Digital Transformation: A framework and implications for L&D. *International Journal of Advanced*

Corporate Learning (iJAC), 9(2), 27 - 33. http://dx.doi.org/10.3991/ijac.v9i2.6003

Sharma, C. S. (2015). Keys to Digital Transformation – People, mindset & culture. *Research Journal of Science & IT Management, 05 (02), 39 – 46*. www.theinternationaljournal.org/ojs/index.php?journal=rjitsm&page=article&op=view&path%5B%5D=4522

Shaw, V. (1991). An Update on UNINET-ZA: The Southern African academic and research network. *The South African Computer Journal (SACJ), 5.* http://uir.unisa.ac.za/bitstream/handle/10500/23952/1991_SACJ_05_Shaw.pdf?sequence=1&isAllowed=y

Sithole, H. (2016). Cyberinfrastructure for international competitiveness. https://www.dirisa.ac.za/wp-content/uploads/2016/10/csir_sci_v8_n2_a32.pdf

Smith, I. & Veldsman, S. (2018). Data driving sustainability: The African open science platform project. https://hal.archives-ouvertes.fr/hal-01816711/document

Spyridonis, F., Taylor, J. E. S., Abbott, P., Barbera, R., Nungu, A., Gustafsson, L. L., Pehrson, B., Oaiya, O. & Banda, T. (2015). A study on the state-of-the-art of e-infrastructures uptake in Africa. Palgrave Communications, Vol. 1, 1 - 7. https://ssrn.com/abstract=2645237

Steward, A. C., Simms, S., Plale, B., Link, M., Hancock, M. & Fox, C. G. (2010). What is cyberinfrastructure? *SIGUCCS '10 Proceedings of the 38th annual ACM fall conference: navigation and discovery. 37 – 44.* https://scholar.google.com/citations?user=Lx7VX2QAAAAJ&hl=en

Suresh, N. (2016). Chapter two: Literature review. *NRENs cloud architecture framework (NRENs-CAF): enhancing cloud connectivity among national research education networks in SADC*. http://repository.unam.na/bitstream/handle/11070/1684/Suresh_2016.pdf?sequence=1&isAllowed=y

Taylor, J. S., Bogdan, R. & Marjorie L. DeVault, M. L. (2016). Introduction to qualitative research methods: a guidebook and resource. 4th edition. New Jersey: John Wiley & Sons, Inc.

TENET. (n.d.). About TENET. https://www.tenet.ac.za/about/about-tenet-1

TENET. (2018). Theory of change: *Rural Campus Connection Project II* https://tenet-rccpii.github.io/rccpii-2018/images/RCCPII_ToC2018-03-12.pdf

UCT. (2018). 10 years of South African collaboration with CERN. https://www.news.uct.ac.za/article/-2018-11-28-10-years-of-south-african-collaboration-with-cern

Ursuleanu, M., & Graur, A. & Dimian, M. (2010). Developing cyberinfrastructure for advanced research with high performance computing. *Proceedings - 9th RoEduNet IEEE International Conference, 364 - 367*. https://www.researchgate.net/publication/224164680_Developing_cyberinfrastructure_for_advanced_research_with_high_performance_computing

USAf. (2015). Rural campuses connection project. http://www.usaf.ac.za/wp-content/uploads/2016/09/RCCP-Evaluation-Exec-Summary-restructured-report.pdf

USAf. (2016). The rural campuses connection project (RCCP). http://www.usaf.ac.za/wp-content/uploads/2016/11/Discussion-document-The-Rural-Campuses-Connection-Project.pdf

USAf. (2017). Rural Campuses Connection Project Phase II (RCCP II): Progress Report as at 30 September 2017. http://www.usaf.ac.za/

USAf. (2019a). RCCP I and II: an overview. https://www.usaf.ac.za/wp-content/uploads/2019/05/Final_RCCP-Overview_9-May-2019-3.pdf

USAf. (2019b). Rural campuses connection project increases teaching, learning and research potential at remote university campuses. https://www.usaf.ac.za/rural-campuses-connection-project-increases-teaching-learning-and-research-potential-at-remote-university-campuses/

USAf. (2019c). Improved internet connectivity can improve teaching when academics use it to the full. https://www.usaf.ac.za/improved-internet-connectivity-can-improve-teaching-when-academics-use-it-to-the-full/

Wilms, K., Meske, C., Stieglitz, S., Decker, H., Fröhlich, L., Jendrosch, N., Schaulies, S., Vogl, R. & Rudolph, D. (2017). Digital Transformation in Higher Education – New Cohorts, New Requirements? *Twenty-third Americas Conference on Information Systems, Boston.* https://www.researchgate.net/publication/317717549

Wisker, G. (2008). The postgraduate research handbook: Succeed with your MA, MPhil, EdD and PhD. 2nd Edition. New York: Palgrave Macmillan.

Wits. (2010). Wits Vision 2022: Strategic Framework. https://www.wits.ac.za/media/wits-university/footer/about-wits/governance/documents/Wits%20Vision%202022%20Strategic%20Framework.pdf

Wits. (n.d.). Centres of Excellence. https://www.wits.ac.za/research/areas-of-excellence/centres-of-excellence/

Wits. (2015). 2014 Annual Report of the University of the Witwatersrand. https://www.wits.ac.za/media/wits-university/research/documents/2014%20Research%20Report.pdf

Wits. (2017a, October 09). *Adam Habib Shares Wits Vision [video file].* www.youtube.com/watch?v=aWQb7kbbE9A

Wits. (2017b). Curiosity Issue 2. https://issuu.com/witscommunications/docs/curiosity_issue_2

Wits. (2018a). 10 years of South African collaboration with CERN. https://www.wits.ac.za/news/latest-news/research-news/2018/2018-11/10-years-of-sa-cern-.html

Wits. (2018b). 2017 Annual Report of the University of the Witwatersrand. https://www.wits.ac.za/media/wits-university/giving-to-wits/documents/Wits%20Annual%20Report%202017.pdf

World Economic Forum (WEF). (2017). The Future of Jobs and Skills in Africa: Preparing the Region for the Fourth Industrial Revolution. Cologny/Geneva: WEF. http://www.digitalfoundation.org.za/2017/05/world-economic-forum-report-future-jobs-skills-africa/

Xing, B. & Marwala, T. (2017). Implications of the Fourth Industrial Age on Higher Education. *The Thinker, 73, 10 – 15.* http://www.thethinker.co.za/resources/73%20xing%20and%20marwala.pdf

Yaver, A., Sánchez-Torres, J.M., Amórtegui, M.A. & Giraldo-Ríos, L. (2016). A participatory Foresight for National Research and Education Networks. https://doi.org/10.1007/s40309-016-0101-5

Yin, R. K. (2009). Case study research: design and methods. 4th edition. California. SAGE Inc.

Yin, R. K. (2011). Qualitative research from start to finish. New York: The Guilford Press

Appendices

Appendix A: Participant Information Sheet

Dear Participant,

I kindly request your participation in this research study, details outlined below.

Research Investigator: Thato Toko
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Research Supervisor: Kiru Pillay (PhD)
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PARTICIPANT INFORMATION SHEET AND INTERVIEW REQUEST

This serves to introduce the researcher Mr. Thato Toko, a Master's students at University of the Witwatersrand. I am conducting research on how the cyber infrastructure deployed for research and development (R&D) influences digital transformation in public universities. I invite you to read the brief background below and to consider participating in this research, given your knowledge of and insight into the Department of Science and Technology (DST) and the Department of Higher Education and Training (DHET) strategy and university practice. Your inputs will be valuable in mapping the data relevant to understanding how the current cyberinfrastructure programmes impact public universities. The interview will last approximately one hour. I kindly request that the interview be audio-recorded.

The responses you provide will be used for the purposes of the Masters Research report, for related scholarly publishing and capacity building, and may be used for future research. Your words, input and personal details will be kept anonymous in any publications, by utilising a naming convention rather than your actual name or other identifiers, unless you expressly require that your name and/or position be published. Confidentiality will be observed with respect to any information and matters discussed in the interview that you do not wish to be published and the anonymised data and quotations will be stored in a password-protected computer. Participation is entirely voluntary. Should you wish to withdraw from the interview at any time during or after, you are free to do so without giving reasons and any responses provided will not be reported. Please feel free to ask questions for clarification.

This research project is designed for public benefit, not for any personal benefit to the participants. Should you require, you may contact my supervisor, details found above.

BACKGROUND TO THE STUDY

Digital transformation in public South African universities is of interest to many higher education stakeholders, students, academics and all tiers of the academic research community, particularly the DHET and the DST. Digital transformation needs cyber infrastructure. The reason why digital transformation in universities is important to South Africa as an emerging economy is that university-based research and development, and innovation encourages economic growth. Access to cyber infrastructure affects research participation and influences the quality of research at universities, because it offers access to scholarly writing and participation in local and international research collaborations. Hence, relevant policy is important.

Yours sincerely, Thato Toko

Appendix B: Informed Consent Form for Interviews

I hereby agree to participate in the research study **Title:** Investigating cyber infrastructure strategy, higher education policy and digital transformation in South African public universities. I will participate in the interview in which I will give my views on the value of cyber infrastructure for R&D. The research has been explained to me and I understand the study. I have been informed of (i) the name and affiliation of the researcher; (ii) the purpose, content, objectives and potential benefits of the study; (iii) the fact that the content of my responses may be reported, anonymously, in the study's published outputs; (iv) the study's procedures for storage and use of the data collected from the interview in a manner that ensures anonymity and confidentiality of the data; and (v) the steps I can take if I have questions or concerns or feel that I have been harmed by the research. I understand that this is a research project whose purpose is not to benefit me personally.
Please initial box

1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving a reason. ☐
3. I understand that the research will not identify me by name or position in any publications using information obtained from this interview; that the data will be stored in a way that preserves confidentiality; and that any views I express will be kept confidential by the researchers where such confidentiality is required; **OR** ☐
4. I agree to my name being listed as a participant in this study in the Annexure to the report, but not explicitly stated in the reporting of data; that the data will be stored in a way that preserves confidentiality; and that any views express will be kept confidential by the researchers where such confidentiality is required. ☐
5. I agree to the interview being audio recorded. ☐
6. I agree to the use of anonymised quotes in any publications. ☐
7. I agree that data gathered from me in this study may be stored (after it has been anonymised) and may be used for future research. ☐

Name of Research Participant	Date	Signature
Name of Researcher	Date	Signature

Appendix C: Interview questions

1. **Interview questions: DHET**
    a) How has the advancement in ICT, ubiquitous computing and increased availability in raw and processed data affected the intended socioeconomic purpose and value of cyber infrastructure for public universities?
    b) What are the guiding principles in government ("DHET") strategy on cyber infrastructure investment/funding for public university research purposes, and why?
    c) How has the government sort to address challenges resulting from misalignment of national strategy on cyber infrastructure for public universities and technological developments affecting the intended socioeconomic purpose and value of cyberinfrastructure?
    d) Timely access to cyber infrastructure affects research participation and influences the quality of research at public universities. How is the government intending on using policy to influence cyber infrastructure and postgraduate research for public universities?
    e) Taking into consideration competing fiscal requirements within the public university ecosystem, what policy principles will assist government influence commensurate private investment for cyber infrastructure developments?
    f) What kind of digital transformation is occurring in university research and why?
    g) DST has the mandate to rollout cyberinfrastructure for improving R&D, innovation and subsequently inclusive economic growth and knowledge creation. How should DHET influence the strategy on cyber infrastructure?
    h) To what extend is government empowered to influence digital transformation at public universities for inclusive and increased participation, using cyber infrastructure policy as the priority driver, and why?
    i) What are the strengths and weaknesses of the existing government policies on cyber infrastructure for digital transformation at public universities, and why?
    j) In the absence of policy, how has the government's mandate on cyber infrastructure for an inclusive and increased participation been implemented?

2. Interview questions: DST (CSIR and SANReN)

a) How has the advancement in ICT, ubiquitous computing and increased availability in raw and processed data affected the intended socioeconomic purpose and value of cyberinfrastructure for public universities?

b) What are the guiding principles in government ("DST") strategy on cyber infrastructure investment/funding for public university research purposes, and why?

c) How is the DST intending on using policy to influence cyberinfrastructure and postgraduate research specifically for public university purposes?

d) To what extent has the DST succeeded in addressing human and research capacity needs for public universities through the department's cyberinfrastructure strategy?

e) Taking into consideration competing fiscal requirements within the public university ecosystem, what policy principles will assist government influence commensurate private investment for cyber infrastructure developments and why?

f) DST has the mandate to rollout cyberinfrastructure for improving R&D, innovation and subsequently inclusive economic growth and knowledge creation. What role should the DHET play in the implementation of the DST strategy on cyberinfrastructure for public university education and research purposes?

g) What challenges has the DST faced in implementing cyberinfrastructure strategy affecting public universities, and why?

h) The DST strives to make use of the National Research and Development Strategy to create "inclusive information society, where ICT-based innovation flourishes". The strategy's "human and research capacity needs" "focuses on ICT R&D in creating a robust innovation value chain".

i) How has the DST determined socio-economy factors that must be addressed in creating an inclusive information society?

j) How has the DST determined the priority of what socio-economic factors to be addressed first?

3. Interview questions: TENET

a) How has the advancement in ICT, ubiquitous computing and increased availability in raw and processed data affected the intended socioeconomic purpose and value of cyberinfrastructure for public universities?

b) DST has the mandate to rollout cyberinfrastructure for improving R&D, innovation and subsequently inclusive economic growth and knowledge creation. What role should the DHET play in the implementation of the DST strategy on cyberinfrastructure for public university education and research purposes, and why?

c) What challenges has TENET faced in implementing DST cyberinfrastructure strategy affecting public universities, and why?

d) What challenges has TENET faced in implementing HESA cyberinfrastructure strategy for public universities, and why?

e) To what extent are the individual strategies from SANReN (DST), DHET (RCCP) and HESA co-ordinated to encourage effective implementation of cyberinfrastructure for public universities?

f) To what extent is the HESA strategy sufficiently incorporated into the DST and DHET cyberinfrastructure strategies, and why?

g) What components of the individual strategies from SANReN (DST), DHET (RCCP) and HESA may require review to encourage effective implementation of cyberinfrastructure for public universities, and why?

h) To what extent does the historical and financial support of individual public universities impact the progress and quality of cyberinfrastructure for research and education purposes?

4. Interview questions: University of the Witwatersrand

a) How has the advancement in ICT, ubiquitous computing and increased availability in raw and processed data affected the value of cyber infrastructure for public universities?
    i. How has the usage of cyberinfrastructure been affected?
    ii. How have the investment requirements for cyberinfrastructure been affected?
    iii. What policy considerations where considered to ensure that these changes do not negatively influence cyberinfrastructure functionality?

b) How has the cyberinfrastructure funded through DST influenced the university's research capacity?

c) What guiding principles are implemented by the university to ensure that its cyberinfrastructure elements are sustainable and its strategies are linked to the DST's?

d) What considerations in the university's cyberinfrastructure strategy contributes to the employment of skilled and relevant workforce, and why?

e) What considerations in the university's cyberinfrastructure strategy contributes to the purpose of inclusive and increased participation?

f) To what extend should government be empowered to influence digital transformation at public universities for inclusive and increased participation, using cyberinfrastructure policy as the priority driver, and why?

g) How does cyberinfrastructure strategy impact on the university's mandate for education, innovation and research?

h) Taking into consideration competing fiscal requirements within the public university ecosystem, what kind of investment model will best fit sustainable cyberinfrastructure for public universities, and why?

i) What kind of digital transformation is occurring within the university's research environment, and why?

j) How does connected devices (e.g. access to raw data from IoT devices) affect the university's strategy on cyberinfrastructure, research (R&D) and innovation?

Appendix D: Interviewees

A Participant Entity	Naming Convention
CSIR	CSIR_1
DHET	DHET_1
DTPS	DTPS_1, DTPS_2
ICASA	ICASA_1
SANReN	SANReN_1
TENET	TENET_1
Wits University	WITS_1

Appendix E: Clearance Certificate

SCHOOL OF Literature, Language and Media RESEARCH ETHICS COMMITTEE

CLEARANCE CERTIFICATE **PROTOCOL NUMBER: SLLM/M18/LK/06**

PROJECT TITLE Investigating cyber infrastructure strategy, higher education policy and digital transformation in public South African universities

INVESTIGATOR Mr Thato Toko

SCHOOL/DEPARTMENT SLLM/ LINK

DATE CONSIDERED 15 August 2017

DECISION OF THE COMMITTEE Approved

This ethical clearance is valid for 3 years and may be renewed upon application.

EXPIRY DATE December 2021

ISSUE DATE OF CERTIFICATE December 2018 **CHAIRPERSON**

cc: Supervisor : Lucienne Abrahams

DECLARATION OF INVESTIGATOR

To be completed in duplicate and **ONE COPY** returned to the Chairperson of the School/Department ethics committee.

I fully understand the conditions under which I am are authorized to carry out the abovementioned research and I guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee.

Signature **Date** _____/_____/_____

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES