Feasibility Study to Connect All African Higher Education Institutions to High-Speed Internet

Report 1:

A Connectivity Gap Analysis and A Review of Existing Programs

DIGITAL DEVELOPMENT PARTNERSHIP

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Abbreviations

Term	Description
AAU	Association of African Universities
ASREN	Arab States Research and Education Network
ARN	Algerian Research Network
ASN	Autonomous System Number
AUC	African Union Commission
BERNET	Burundi Education and Research Network
BotsREN	Botswana Research and Education Network
CAP	Country Action Plan
CapEx	Capital Expenditures
CCK	Computing Center Al Khwarizmi
CENIC	Corporation for Education Network Initiatives in California
CRAN	Communications Regulatory Authority of Namibia
CV	Curriculum Vitae
DE4A	Digital Economy for Africa initiative
DNS	Domain Name System
DS4DE4A	Digital Skills for Digital Economy for Africa
EthERNet	Ethiopian Education and Research Network
EMIS	Education Management Information System
ENSTINET	Egyptian National Scientific and Technical Information Network
EUN	Egyptian Universities Network
FASOREN	Burkina Faso Research and Education Network
GabonREN	Gabon Research and Education Network

Term	Description
GARNET	Ghanaian Academic and Research Network
Gbps	Gigabits per second
GhREN	Ghana Research and Education Network
Gn-REN	Guinea Research and Education Network
HEI	Higher Education Institution
ICT	Information and Communications Technology
iRENALA	Research and Education Network for Academic and Learning Activities
IRU	Indefeasible Right of Use
ISCED	International Standard Classification of Education
ISP	Internet Service Provider
IRU	Indefeasible Right of Use
ITU	International Telecommunications Union
IXP	Internet eXchange Point
KCL	Knowledge Consulting Ltd
KENET	Kenya Education Network
LMD	License-Master-Doctorate
LRREN	Liberia Research and Education Network
MaliREN	Mali Research and Education Network
MAREN	Malawi Research and Education Network
MARWAN	Moroccan Research and Education Network
Mbps	Megabits per Second
MDAs	Ministries, Departments and Agencies of Government
MoRENet	Mozambique Research and Education Network
NgREN	Nigeria Research and Education Network

Term	Description
NigerREN	Niger Research and Educations Network
NREN	National Research and Education Network
NSRC	Network Startup Resource Center
OER	Open Educational Resource
OpEx	Operating Costs
PoP	Point of Presence
PPP	Public–Private Partnership
RBER	Réseau Béninois d'Education et de Recherche
RCIP	Regional Communications Infrastructure Program (World Bank)
REC	Regional Economic Community
RERBENIN	Reseau d'Education et de Recherche du Benin
RENU	Research and Education Network for Uganda
RITER	Réseau Ivoirien de Télécommunications pour l'Enseignement et la Recherche
RREN	Regional Research and Education Network
SDG	Sustainable Development Goal
SETDA	State Educational Technology Directors Association
SLREN	Sierra Leone Research and Education Network
snRER	Senegal Research and Education Network
SudREN	Sudan Research and Education Network
Tbps	Terabits per second
TchadREN	Tchad Research and Education Network
TERNET	Tanzania Education and Research Network
TogoRER	Reseau d'Education et de Recherche du Togo
TVET	Technical and Vocational Education and Training

Term	Description
TVWS	Television White Space
UIS	UNESCO Institute of Statistics
UNESCO	United Nations Education Scientific and Cultural Organization
WACREN	West and Central Africa Research and Education Network
WARCIP	West Africa Regional Communications Infrastructure Program
WBG	World Bank Group
ZAMREN	Zambian Research and Education Network

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	Organisation	Interviewee/Respondent
	African NRENs	
1	Benin (RBER)	Adéfèmi Christelle Agossou
2	Burundi (BERNET)	Grégoire Njejimana and Pierre-Claver Rutomera
3	Chad (TchadREN)	Zaki Sabit
4	Côte d'Ivoire (RITER)	Issa Traoré
5	Ethiopia (EthERNet)	Zelalem Assefa
6	Gabon (GabonREN)	Ousmane Balira Konfe and Anicet Andjouat
7	Ghana (GARNET)	Lucas Chigabati and Emmanuel Togo
8	Ghana (GhREN)	Benjamin Eshun
9	Guinea (Gn-REN)	Kodiougou Diallo

10	Kenya (KENET)	Meoli Kashorda
12	Madagascar (iRENALA)	Harinaina Ravelomanantsoa
13	Malawi (MAREN)	Solomon Dindi
14	Mali (MaliREN)	Pierre C. B. Traoré
15	Morocco (MARWAN)	Redouane Merrouch
16	Mozambique (MoRENet)	Lourino Chemane
17	Nigeria (NgREN)	Joshua Atah, Patricia Eromosele, Gaurav Gupta
18	Senegal (SnRER)	Ibrahima Niang
19	Sierra Leone (SLREN)	Thomas Philip Songu
20	Somalia (SomaliREN)	Abdullahi Bihi Hussein
21	South Africa (TENET)	Duncan Greaves
22	Tanzania (TERNET)	Magreth Mushi
23	Togo (TogpRER)	Eyouleki Palanga
24	Tunisia (CCK)	Habib Youssef
	Other NRENs	
1	GRENA (Georgia)	Ramaz Kvatadze
2	AMRES (Serbia)	Bojan Jakovljevic
3	CENIC (California)	Louis Fox
4	JISC (UK)	Rob Evans
5	Red CEDIA (Ecuador)	Juan Pablo Carvallo
6	RNP (Brazil)	Eduardo Cezar Grizendi
	RRENs	
1	ASREN	Yousef Torman
2	GÉANT	Cathrin Stöver, Daniel Wustenberg, Leila Dekkar
3	Red CLARA	Luis Escadenas
4	UbuntuNet Alliance	Tiwonge Banda and J Kimaili
5	WACREN	Boubakar Barry
	Major Backbone Services Providers	
1	Liquid Telecom	Ben Roberts
2	SEACOM	Michael Otieno
	Key Informants	
1	ISOC	Michuki Mwangi
2	NSRC	Steve Huter and Steve Song

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Executive Summary

As part of the Digital Economy for Africa (DE4A[1]) initiative, the World Bank commissioned a feasibility study to develop an operational roadmap to connect all African higher education institutions (HEIs) to high-speed Internet. The DE4A initiative, among others, aims to digitally enable every African individual, business, and government by 2030. The African higher education sector comprising public and private universities, colleges, technical training institutes, and vocational schools plays a critical role in training a skilled workforce, conducting research, and building the knowledge base and the human capital necessary for countries' transition to digital economies.[2] However, higher education institutions do not have access to affordable and functional quality broadband connectivity. Furthermore, the available bandwidths are often expensive and limited in capacity, and are thus unable to meet modern institutions' research and education requirements. Connecting HEIs and research institutions is crucial for expanding the opportunities for teaching, learning and innovation to attain a DE4A goal of fostering relevant digital skills on the continent.

The feasibility study aims to establish a roadmap for connecting all African HEIs, and other closely related institutions, to high-speed Internet. Drawing on quantitative data from secondary sources and interviews with providers and various stakeholders in both the education and telecommunication value-chains, this report discusses the current higher education connectivity environment and associated policy, regulatory, institutional, human capacity and funding challenges on the continent. This study has received funding from the Digital Development Partnership (DDP)[3].

There is an increasing understanding of the implication of broadband connectivity for active learning, teaching, research, and innovation; and administrative efficiency and effectiveness in higher education. The COVID-19 pandemic has amplified demands for broadband infrastructure to support blended and ongoing learning. UNESCO's data shows that 14 million African higher education students are experiencing disruptions in their studies due to the closure of higher education institutions. Higher education connectivity requires a series of activities, including making user devices available to students, building and managing resilient campus networks, training users and campus network administrators, establishing and maintaining connectivity to a national research and education networks, and achieving inter-regional and global connections.

Africa’s global connections provide the first-mile link to higher education. The review indicates that the African continent is in its second wave of submarine cables roll-out on the western, eastern and southern coasts, presenting tremendous opportunities for connecting the higher education sector to the rest of the word. Additional capacity is expected to be available in

1 *See https://www.worldbank.org/en/programs/all-africa-digital-transformation.*

2 *The study uses the term Higher Education, also known as Tertiary Education in some countries, to refer to all post-secondary education, including both public and private universities, colleges, technical training institutes, and vocational schools https://www.worldbank.org/en/topic/tertiaryeducation*

3 *https://www.worldbank.org/en/programs/digital-development-partnership.*

2021 and subsequent years through Ellalink, Equiano and SHARE that would double the international bandwidth in Western Africa; and METISS, DARE1 and PEACE, that are projected to increase the available bandwidth in Eastern and Southern Africa. The second wave of submarine cables links to Africa, coupled with a proposed Facebook 2Africa project (180 Tbps), are expected to improve bandwidth availability for social and economic growth in general and higher education connectivity in particular.

The region has also seen an increase in the amount of terrestrial backbone coverage. By June 2020, the amount of operational fibre-optic network reached 1,072,649 km compared to 622,930 km in 2015. By the same date, there was a further 119,496 km of fibre optic network under construction, 95,057 km of planned fibre and 69,702 km of proposed fibre. However, there are a series of challenges in cross-border connectivity. These range from different legal and commercial conditions, to diversity of the quality of terrestrial fibre optics connections, ongoing vandalism, and fibre cuts during other construction works—especially roads.

National fibre coverage in Africa varies widely, again influenced by geography, level of competition and investment by public and private sector operators. The national backbone assessment indicates that small geographic-sized nations like Burundi, Cape Verde, Mauritius, Rwanda and São Tomé and Príncipe and digitally advanced countries like Morocco, South Africa and Tunisia have made good progress in building country-wide terrestrial backbone networks. A superposition of the fibre optics map and population density indicates that Angola, Algeria, Cameroon, Egypt, Gambia, Ghana, Kenya, Mozambique, Senegal, Tanzania, Uganda, Zambia and Zimbabwe have networks that align with the population's geographic settlements and that could support their higher education connectivity needs. Over half of African countries still need substantial investment in building their terrestrial fibre backbone networks to support their higher education connectivity. Still, the presence of an extensive public backbone of sufficient capacity does not necessarily lead to adequate broadband connectivity to HEIs (Rwanda, Tanzania, and Ethiopia are examples). Bandwidth availability should be accompanied by a competitive policy, regulatory and business environment that allows higher education institutions to build, own, and operate broadband networks.

Connectivity of higher education institutions in Africa is coordinated through Regional Research and Education Networks (RRENs) and National Research and Education Networks (NRENs). Three major RRENs cover the African continent: the Arab States Research and Education Network (ASREN) that covers North Africa but whose core members are outside Africa; the West and Central African Research and Education Network (WACREN), and the UbuntuNet Alliance (UA). It should be noted that Research and Education Network (REN) connectivity is so different from commercial internet connectivity that any price comparison is fallacious: the approaches to capacity dimensioning; cooperation and collaboration across the globe; seamless national and global roaming centred around identity federation; and services that ride on top of all this place REN connectivity in a category of its own.

Forty of the 54 African countries are currently associated with these RRENs, but their capacity to make the best use of regional aggregation varies widely due to different readiness levels. RRENs aggregate traffic from over 20 countries across Africa, and interconnect with GEÁNT to reach Europe and RRENs in other parts of the world.

There are also variations in the development of NRENs. NREN readiness is achieved when sufficient government commitment is secured, and a formal organisation that is recognised and supported by the public and private higher education institutions is created. The organisation needs to be adequately staffed to handle both administrative and technical matters and to have the capacity to negotiate connectivity deals on behalf of its members. Countries that are not actively associated with one of the three regional RENs face even a more significant challenge in getting cheap and high-capacity broadband connectivity to HEIs.

The vision of the stakeholders is *"An African continent where all higher education institutions achieve global parity in intellectual output and development impact through access to, and exploitation of broadband connectivity at capacities, quality, and costs comparable to the rest of the world."* To meet this, African institutions must also develop the necessary pre-conditions to ensure that sufficiency and affordability of broadband can be seized as opportunities to improve learning and research outcomes, as well as employability in the emerging digital economy and the context of the fourth industrial revolution.

Higher education networks need to ensure optimal access depending on whether users are interested in the essential day-to-day teaching and learning activities or research work that demands burst and bandwidth-intensive applications. The variability in the availability and affordability of bandwidth indicates the enormous gap between the African higher education institutions and their counterparts.

Preliminary estimates based on number of students indicate that based on a minimum bandwidth need of 200 Mbps per 1,000 users during 2021, rising to 2 Gbps per 1,000 users by 2025, and to 20 Gbps per 1,000 users by 2030 provides, the progressive estimates for global connectivity for higher education are 4.6 Tbps in 2021, 54.8 Tbps in 2025 and 507 Tbps in 2030.

Data from institutions indicates that current bandwidth per university ranges between 10 Mbps to 10 Gbps. An exception among the countries that responded to the survey is South Africa where some large universities that have 50 Gbps are now moving to 100 Gbps connections. Bandwidth prices around the continent range from US$3 to US$900 per Mbps/month depending on the volume of bandwidth consumed, the market structure and the regulatory environment.

Our survey indicates that the environment in higher education connectivity is as diverse as the countries involved; therefore, the challenges can be complex, specific and contextual. However, it is possible to highlight the overall trends across countries. The high cost of bandwidth, lack of enabling policy and regulatory, capacity and awareness of decision makers and technical personnel are among the most critical challenges to higher education connectivity in Africa. Other issues that were raised by NREN stakeholders across Africa include:

- Inadequate campus networks
- Lack of adequate data centres and storage infrastructure
- Unreliable power supply
- Limited access to devices by students and staff of higher education institutions,

- Limited application and services,
- Limited technical capacity of network engineers
- Lack of sustainable National Research and Education Networks
- Lack of sustainable funding, especially for National Research and Education Networks.

The regulatory environment is not clear-cut in all countries with regard to licensing NRENs as closed user-groups delivering connectivity to higher education institutions. The success of NRENs tends to depend on regulatory maturity and the effectiveness of the interaction between NREN champions, the concerned ministries of higher education, the ministries responsible for the ICT, heads of higher education institutions and the regulators.

Cross-border connectivity was cited as a major challenge by RRENs. Limited cross-border connectivity, compounded by poor regulatory environments, limits the potential for regional connectivity and network performance. Ongoing efforts to improve regional backbones and promote regulatory and policy harmonisation engagement on cross-border interconnection will need to be pursued to facilitate competitive regional prices. The African Continental Free Trade Area provides opportunity for addressing cross-border challenges.

Campus networks are the main bottlenecks for higher education connectivity. It is the most important frontier for improving higher education connectivity. Several factors contribute to or compound connectivity gaps at the campus levels. These include the number of staff and students, the intensity of applications and services, the available bandwidth, the quality of campus wireless and wired networks and competence of staff in information technology and network management, which in turn is influenced by the institutional ICT policy and support environment. Campus networks must be designed to support users' requirements, including research and innovation needs. Optimal bandwidth is typically needed to conduct teaching, learning, research and administration. Researchers need intensely faster file transfer speeds for both uploads and downloads.

The future of higher education lies in blended education that requires the streaming of video and actual real-time collaboration and coordination with researchers and laboratories across the globe. This, however, is limited by the absence of organisational ICT policies and strategies, the limited technical competences, and the inability to translate broadband to benefit through improved learning outcomes and research outputs. The analysis shows that except for a few countries like South Africa, higher education was unable to provide a bare minimum bandwidth of 200 Kbps per user in 2020. Even here, there is a wide gap between connectivity, learning outcomes and research output.

Experience from an ongoing project, the AfricaConnect project, indicates that connecting African HEIs requires coordination at all levels, especially at the National Research and Education level, where foundations of the national, regional and campus-level connectivity can be built. It should be noted that REN connectivity is so different from commercial internet connectivity that any price comparison is fallacious: the approaches to capacity dimensioning; cooperation and collaboration across the globe; seamless national and global roaming centred around identity federation; and services that ride on top of all this place REN connectivity in a category of its own. Since the challenges identified fall under different government ministries (ICT, Education, and Finance) as well as the leadership of HEIs, these should be recognised at the outset as key leaders and partners in the planning and implementation of any intervention.

1. Introduction

1.1 Background

The African higher education sector comprising public and private universities, colleges, technical training institutes, and vocational schools[4] plays a critical role in training a skilled workforce, conducting research and building the knowledge base and the human capital necessary for countries' transition to digital economies. Digital technologies provide opportunities for addressing the challenges facing higher education—growing demand for higher education, falling quality, the mismatch between education and employability and disconnection between research and development challenges. However, higher education institutions do not have access to affordable and functional quality broadband connectivity. In addition, the available bandwidths are expensive and limited in capacity, thus unable to meet modern institutions' research and education requirements. Ultimately, this negatively affects national education goals and targets as enshrined in the Sustainable Development Goals (SDGs) and various country specific Development Plans.

As part of the Digital Economy for Africa (DE4A[5]) initiative, the World Bank commissioned a feasibility study to develop an operational roadmap to connect all African HEIs to high-speed Internet. The initiative, in support of the African Union Digital Transformation Strategy for Africa (2020-2030)[6], aims to digitally enable every African individual, business, and government by 2030. Connecting HEIs and research institutions is crucial for expanding the opportunities for teaching, learning and innovation to foster relevant digital skills on the continent. This study has received funding from the Digital Development Partnership (DDP)[7].

The establishment of Research and Education Networks (RENs) has already shown that academic networks serve as anchors for high-capacity bandwidth delivery and as catalysts for communities' digital literacy, broadband deployment, and adoption. Connecting higher education institutions will also respond directly to Sustainable Development Goals 4 (Quality Education) and 9 (Industry, Innovation, and Infrastructure) and also support the enabling environment for the achievement of all SDGs.

4 *We use the term Higher Education, also known as Tertiary Education in some countries, to refer to all post-secondary education, including both public and private universities, colleges, technical training institutes, and vocational schools* *https://www.worldbank.org/en/topic/tertiaryeducation*

5 *See https://www.worldbank.org/en/programs/all-africa-digital-transformation.*

6 *https://au.int/en/documents/20200518/digital-transformation-strategy-africa-2020-2030.*

7 *https://www.worldbank.org/en/programs/digital-development-partnership.*

1.2 Objective

This report examines the connectivity gap of African higher education institutions for the World Bank's feasibility study to develop an operational roadmap to connect all African HEIs to high-speed Internet. The feasibility study aims to establish a roadmap for connecting all HEIs, and other closely related institutions, to high-speed Internet and estimate the costs based on different options. This is achieved through three sub-objectives:

i. Production of a gap-analysis report addressing the connectivity, ecosystem challenges (policy, regulation, institutions, human capacity, etc.), and funding.

ii. Development of cost estimates.

iii. Development of a high-level strategy to leverage the campus connectivity to achieve learning outcomes in higher education.

This report addresses the first task. It discusses the current higher education connectivity environment and associated policy, regulation, institutions, human capacity and funding challenges on the continent.

1.3 Organisation of the Report

The report is organised as follows: after the introduction in Chapter 1, the methodology used in the analysis is summarised in Chapter 2. This is followed by the definition of the Vision and Targets for connecting higher education institutions in Africa in Chapter 3. Chapter 4 defines the Universe of Target Institutions, looking at Rwanda as an example and referencing UNESCO's International Standard Classification for Education (ISCED) as guidance on institutions considered part of the higher education sector. Chapter 5 discusses the connectivity status and gaps in Africa's higher education sector, highlighting the multiple divides at the global, regional, national, campus, and individual levels. Drawing on Chapter 5, the supply and demand-side challenges are discussed in Chapter 6, pointing to potential intervention areas. There are both historical and ongoing initiatives in the universities' connectivity agenda that provide important lessons, and these are discussed in Chapter 7. The conclusion is given in Chapter 8. Appendices summarise findings from stakeholder interviews and NREN surveys and provide detailed tables with data used for and from various analyses.

2. Methodology

Various sources of data and diverse methodologies were used in arriving at findings. Surveys covering research and education networks, operators and key informants were conducted to establish the current connectivity environment, gaps and challenges in higher education. Data on enrolment rates were collected from Ministries of Education and cross-checked with figures available from the UNESCO Institute of Statistics. Country cases were conducted to deep-dive into connectivity challenges at national levels. Table 1 provides a methodological summary as well as assumptions made in our analysis.

Table 1: Methodological Summary

	Output/Data/ information Required	Sources of data and information	Analytical methods	Assumptions/Gaps
1	Target state of connectivity and utility (Vision)	i. Desk study (e.g., GÉANT and TEIN compendia for 2018); ii. Specific current data from NREN CEOs in Europe, USA, and South America; iii. Data from RREN and NREN CEOs on definition of broadband as well as current and projected states	i. Benchmarking; ii. Comparative examination and projections, taking into account the different views and perspectives as well as historical trends and technology projections	Comparative information online normally lags about 2 years. Addressed through interviews to get a feel of current thinking as well as current data.
2	Current state of connectivity (user, campus, national, regional, global)	i. Desk study; data from multiple sources (Telegeography, ITU, GSMA, etc.) ii. Questionnaires to NRENs; iii. Interviews with NREN CEOs, large connectivity providers, and key informants.	Tabulation of data from multiple sources, basic statistical analysis and data presentation through combination of tables and graphs	Most current data on connectivity lags about 1 year. Addressed through interviews with NRENs and multinational bandwidth providers and survey with NRENs.
3	Current Enrolment in TVETs and universities	Data from UNESCO Institute of Statistics (UIS), complimented with recent data from		Data on enrolment is not uniform across the region. Effort was made to complete the

		Ministries of Education/Higher Education, accreditation and quality assurance bodies where available		data using multiple sources.
4	Projected enrolment for 2025 and 2030,	Data from UNESCO Institute of Statistics (UIS), complimented with recent data from Ministries of Education/Higher Education, accreditation and quality assurance bodies where available	Calculated using historical data of student enrolment in high education level based on compound growth rate method	Countries had varying number of years of enrolment data. Used compound rates to address potential volatility that may arise from using average growth rates in this case
5	Quantifying connectivity gaps	Desk study; data from multiple sources (Telegeography, ITU and UIS)	Projected bandwidth needs by multiplying number of higher education students in each country by the progressive targets in Table 3. To determine bandwidth gap, we deducted recent ITU estimates for International bandwidth usage per Internet per country[8] and multiplied the result by projected higher education student enrolment.	Assumed that closing bandwidth gap for higher education students should not affect the access and use experience of other Internet users in a country.
6	Identifying connectivity gaps and challenges	i. Desk study; ii. Interviews with selected RREN and NREN CEOs as well as multinational connectivity providers and key sector informants; iii. Questionnaires to NRENs; iv. Deep-dive country cases; v. KCL knowledge base	Qualitative analysis to identify key issues and common threads	

8 *https://itu.foleon.com/itu/measuring-digital-development/bandwidth/.*

3. The Vision

3.1 Introduction

A gap analysis must be guided by comparing the current state against reasoned targets, which are, in turn, set according to the Vision. This Chapter, therefore, develops arguments for what the Vision for Broadband Connectivity for higher education in Africa should be.

The African continent has embarked on a series of initiatives to accelerate access to broadband for social and economic development, for example, the DE4A initiative for doubling connectivity by 2021 and reaching universal access by 2030. The African Union's *Digital Transformation Strategy for Africa (2020 – 2030)*[9] states, that *"By 2030 all our people should be digitally empowered and able to access safely and securely to at least (6 mb/s) all the time where ever they live in the continent at an affordable price of no more than (USD 1cts per MB) .... through a smart device manufactured in the continent at the price of no more than (100 USD) to benefit from all basic e-services and content of which at least 30% is developed and hosted in Africa."*

This guides the starting point when creating a vision and goals for connectivity to HEIs in the continent. Based on the Vision, targets are set for 2025 and 2030.

3.2 The Vision

A Vision needs to be an aspirational and inspirational statement of the future. Therefore, the Vision here is not limited to the capabilities or funding from any initiative: it is focused entirely on where Africa desires to be. From interviews with various key stakeholders, there is a common aspiration that African higher education institutions should, as a minimum, be at levels comparable with the rest of the world in terms of connectivity if parity at a global level in both intellectual property output and development benefits is to be achieved. Based on this, the following Vision was developed:

> *An African continent where all higher education institutions achieve global parity in intellectual output and development impact through access to, and exploitation of broadband connectivity at capacities, quality, and costs comparable to the rest of the world.*

9 https://au.int/sites/default/files/documents/38507-doc-dts-english.pdf

To link this to benefit requires that these African institutions simultaneously develop the necessary pre-conditions to ensure that sufficiency and affordability of broadband can be seized as opportunities to improve learning and research outcomes, as well as employability in the context of the fourth industrial revolution.

3.3 Setting the Progressive Targets

Setting progressive targets is a balancing challenge that needs to take into account the following factors as well as regional and global comparatives.

i. In most African countries, education generally and HEIs specifically are currently severely underfunded. While the WBG, governments and other development partners can support Capex, beneficiaries must be responsible for future Opex and Capex: initial investment without future sustainability assurance would be a waste. Moreover, lessons from development learning and experience suggest that beneficiaries have a major stake in project sustainability through contribution.

ii. Experience through the establishment and development of the university, national, and regional research and education networks indicates that the following factors come into play, often in a “chicken and egg” situation:

    a) Due to high costs, demand is severely suppressed, which is specially compounded by the perennial shortage of funds in most government institutions. The determining factor of how much bandwidth an institution buys is cost, not sufficiency for the planned applications and desired outputs and outcomes. Any significant reduction in price leads to sharp rises in demand.

    b) As bandwidth improves, convenience improves due to faster access. This, in turn, leads to usage rising rapidly, which creates a habit and higher expectation. This behavioural change generates the pull factors for more bandwidth in institutions, the higher priority placed on the sufficiency of bandwidth, and a greater willingness to increase the expenditure envelope.

    c) The push for more bandwidth leads to a supply-side lowering of prices, especially if the market is competitive. This brings policy, regulation, and investment climate into the equation as a key enabling or disabling factors in any country. This challenge of policy, regulation, and investment climate is especially acute for land-locked countries because the transit countries can severely impact the cost. A case in point is Malawi, where the shortest route to marine fibre is Mozambique: the cheapest routing when the first link was set up during 2019 by the UbuntuNet Alliance was the much longer route from Dar es Salaam (Tanzania) to Lusaka (Zambia) and then into Malawi.

    d) Next generation technologies are being used increasingly around the world. As an example, CENIC CEO Louis Fox was quoted in a news release[10] during August 2020: *"Next-generation infrastructure ensures CENIC can easily meet today's networking demands while remaining flexible to meet the needs of tomorrow"*. The same news release stated that *"to develop the new 400G coastal route, CENIC staff upgraded the existing backbone network from fixed-grid technology to flex-grid spectrum Reconfigurable Optical Add-Drop Multiplexers (ROADMs)"*. Technologies like these provide an opportunity for Africa to leapfrog the last decade's fibre capability to Nextgen technologies provided there is a concerted drive across all fronts for this to happen. Even if the initial investment could be significantly higher, the vision of parity in terms of volume, quality, and cost could become a medium-term target instead of a long-term aspiration: African HEIs could move straight from the current affordability constrained definition of bandwidth to ports that can eliminate sufficiency of bandwidth from being a recurring challenge.

It is evident that high cost, itself a result of many factors as will be discussed later in this report, is at the heart of the broadband connectivity challenge. As an illustration, Makerere University, the largest in Uganda, has spent about $40,000 per month on broadband for the last 20 years. This provided 10Mbps in the early 2000s, which increased to about 30 Mbps during the life of the African Bandwidth Consortium a few years later. It is now at 2Gbps through the Research and Education Network of Uganda, RENU, and the UbuntuNet Alliance. Were the price to go down to $0.1 per Mbps/month, Makerere University would afford 400Gbps.

iii. The desire of the beneficiaries as well as regional and global comparators are key factors in setting targets. We note, in connection with this, that there is no uniform approach to defining broadband, or sufficient bandwidth, across the world. We have noted the following major approaches:

a) Setting the minimum bandwidth according to the size of the campus (small, medium, large – SML) in terms of student number. Across the Americas for example, the categorisations of small (<5,000 students), medium (5,000 – 15,000 students) and large (>15,000 students) are generally accepted. It should however be noted that size does not necessarily translate to bandwidth demand: small research-intensive institutions can have a much higher demand for bandwidth than large teaching-intensive universities.

b) Normalising using bandwidth per student (which appears to have the disadvantage of using the same diversity factor for widely varying total numbers of students) or per 1000 students (which makes better provision for diversity than BW/student). The Kenya NREN KENET, and the Federal Communications Commission of the USA, for example, both normalise capacity to bandwidth per 1,000 students.

c) Using an approach that ensures overabundance so that sufficiency or insufficiency of bandwidth is never a factor in trying to achieve learning and research outcomes. The South Africa NREN, TENET, for example provides port sizes that ensure average

10 *https://cenic.org/news/cenic-extends-400g-capabilities-to-coastal-path-between-los-angeles-and-sunnyvale*

demand at any campus never exceeds 50% of available capacity.

To guide the aspirational target for African HEIs, Table 2 gives current, and for some comparators, planned bandwidth for institutions of different sizes covering the North America, South America, Europe and the Asia-Pacific region.

It is immediately evident that even among the more developed regions, there is internal disparity, especially among countries. This is not to globalise and therefore accept the status quo, but rather to recognise that the solutions developed for Africa could well be applicable to other regions.

Table 2: Bandwidth comparison for higher education around the world

NREN/Country	Details of what is available	Remarks
UbuntuNet Alliance	Normalised designation: UA Recommendation is 2Gbps/1000 students for 2020, rising to 5 Gbps/1000 students by 2025, all at 50% congestion	Recommendation is that no campus should have less than 10Gbps in 2025, rising to 100Gbps minimum by 2030
KENET (Kenya)	Normalised designations: 40 Mbps @1,000 students. Projection: 100 – 200Mbps @1,000 students in five years	2020 data from CEO
TENET (South Africa)	Uses port sizes that ensure normal usage on campuses does not exceed 50% of the capacity	2020 data from CEO Defines broadband as "sufficient bandwidth to be able to use the prevailing applications of the day"[11]
RNP (Brazil) (Current)	They use the SML categorisation. Ranges from 100Mbps for small institutions, to 3 – 100 Gbps for large institutions	2020 data from CEO
Red CEDIA (Ecuador)	They use the SML categorisation. Ranges from 1Gbps for small to 5Gbps for large institutions	2020 data from CEO
CENIC (California)	They use the SML categorisation. Ranges from 1 – 10Gbps for small institutions to 100 – 200Gbps for large ones. Projection: 1 Gbps for small and >400Gbps for large in 3 years	2020 data from CEO States that Technology evolution makes prediction beyond 3 years tough
FCC (USA) e-rate	Normalised designation: 1Gbps@ 1,000 students recommended for e-rate	Note that this is defined for schools
AARNet (Australia)	Ranges from 10 to 100 Gbps	2018 TEIN Compendium
SingAREN (Singapore)	Ranges from 1 to 10 Gbps	2018 TEIN Compendium
CAMREN (Cambodia)	Ranges from 12 to 300 Mbps	2018 TEIN Compendium

11 *Discussions with Duncan Greaves, CEO of TENET*

GÉANT region (Europe)	"The capacities range between 1 Mbps and 100G, with over half of the respondents indicating 1G as the typical capacity for connected universities and research institutions. These two institution types are the best connected and some boast connectivity well above the typical 1G, 10G or even higher speeds being the rule in several countries"[12]	2018 GÉANT Compendium. Note that the GÉANT Network carries purely what is categorised as research and education, with the rest handled by commercial service providers. African NRENs tend to carry all traffic from campuses.
GRENA, Georgia (Small GÉANT member NREN)	Using the SML categorisation: Small - approx. 100 Mbps; Medium, 100 – 300 Mbps; and Large, 500 – 1000 Mbps	"We made a very rough estimation of GRENA international traffic increase during next five years, and it was approximately 100%"
AMRES, Serbia (Medium GÉANT member NREN)	Dark fiber technology is used for Universities (e.g., faculties, institutes and the biggest schools) Dark fibre locations are connected by 1Gbps and 10Gbps throughput.	"We typically make our estimations with traffic increase factor of the 25% per year. It means that for the 5-year period we expect a threefold traffic increase"
JISC, UK (Large GÉANT Member)	Current indicative approximations: 1G for <5,000; 10-20G for 5,000-15,000; and 20G+ for over 15,000. (There are some smaller institutions on 10G, larger ones with a smaller capacity). 2025 projection: 10G for the first category; multiples of 10G for the second category; and 100-200G for the third category.	"It varies quite a bit for a number of reasons - for example the type of institution, and the type of funding it receives"
SETDA Recommendation[13]	Small School District (fewer than 1,000 students) – >4.3Mbps per user Medium School District Size – > 3Gbps/1000 Large School District(more than 10,000 students) – > 2.0 Gbps/1,000 users	

What is evident from Table 2 is that typically, the lowest capacity for a small campus during 2020 should have been 1Gbps or, assuming 5,000 students, 0.2 Gbps/1,000 students. We must recognise however that demand is still highly suppressed in most African countries, and that next generation technologies will create new opportunities for faster growth. We note for example that at constant expenditure, Makerere University increased bandwidth from 10Mbps in 2000 to 50 Mbps in 2006, a factor of 5 in 6 years; and from 50Mbps to 2, 000Mbps in 2019, a factor of 40 in 12 years. We believe, therefore, that it is reasonable to set the future

12 *See https://www.geant.org/Resources/Pages/Compendium.aspx.*

13 *State Educational Technology Directors Association (2012, May). The Broadband Imperative II: Equitable Access for Learning, http://www.setda.org.*

projections as proposed by UbuntuNet Alliance. It is however evident that the overwhelming number of campuses are well below the UbuntuNet Alliance recommended target of 2Gbps/1000 students at 50% congestion for 2020: we therefore recommend this as the minimum for 2025. We can also expect next generation technologies to have kicked in fully by 2030, making 100 Gbps minimum for any campus – the same as the UbuntuNet Alliance recommendation – a routine expectation.

Based on these arguments, we recommend the targets as given in Table 3 starting with what is desirable as current, and projections for 2025 and 2030. An initial approach based on normalised bandwidth is used, moving progressively to pots whose capacity should be at least twice the normal link utilisation.

Table 3: Recommended progressive bandwidth targets for African HEIs

Year	Minimum Bandwidth	Remarks
2021 (targeted minimum)	0.2 Gbps @1,000	Translates to 1Gbps for a campus of 5,000; and 10 Gbps for a campus of 50,000
2021-2025	2 Gbps @1,000	Translates to 10 Gbps for a campus of 5,000; and 100 Gbps for a campus of 50,000. *This should be the minimum entry level for the WBG intervention*. It should be noted that the general aspirational target of most African NRENs by 2025 or earlier is 1Gbps per 1000 students, but this is heavily influenced by current challenges and limitations.
2025-2030	20 Gbps @1,000	Translates to 100 Gbps for a campus of 5,000. Actual size for any campus to be based on the TENET approach: *“sufficient bandwidth to be able to use the prevailing applications of the day” with port sizes twice the normal usage.*

Source: KCL.

4. Defining the Universe of Target Institutions in Africa

4.1 The Target Institutions

Higher education in Africa has expanded from a handful of public institutions in the 1980s to thousands of public and private institutions that offer post-secondary education in 2020. The dynamic growth and diversity mean that there is limited data on the number and characteristics of these institutions. There are two groups of institutions that require connectivity:

i. Higher education institutions, and
ii. Other institutions that are closely allied with such and play a critical direct or collaborative role in promoting research and education as well as their direct benefit to national development outcomes. These include research centres, training hospitals used by the schools of medicine, and establishments like libraries whose resources support TVET and/or university level training and research.

Some institutions are responsible for policy, regulation, standards, and sector management – making them critical players to be considered for broadband connectivity. Other institutions to take into account in estimating gross bandwidth needs but are not a direct target in terms of connectivity under this initiative include early childhood, primary, and secondary education providers. Non-tertiary post-secondary education would also be part of this.

There is no universal agreement on what constitutes higher education across Africa. In English-speaking countries, higher education comprises all the post-senior secondary school institutions including universities, colleges (teachers, nursing and agricultural), technical and vocational education and training institutions (TVETs). In French-speaking countries, the classification parallels the French higher education system of university and the Grandes Écoles. The Licence Master Doctorate (LMD) reform currently underway in Francophone countries is intended to improve harmonisation between the English and French systems of education, fostering coordination opportunities for connecting higher education in Africa.

The private higher education institutions, which are growing fast and catering for about a third of higher education students and faculty, are also becoming increasingly important. Higher education in this document covers all post-secondary education, including public and private universities, colleges, technical training institutes, and vocational schools.

UNESCO's International Standard Classification of Education (ISCED)[14] provides useful

14 http://uis.unesco.org/en/topic/international-standard-classification-education-isced

guidance on which institutions to consider as part of higher education by mapping national education systems in a way that facilitates comparison of programmes across countries.[15] Connectivity is considered crucial for all institutions above the third level—UNESCO ISCED3. An example of the mapping of the South African education system shows the kind of institutions within this category in Figure 1.

Source: Adapted from UNESCO

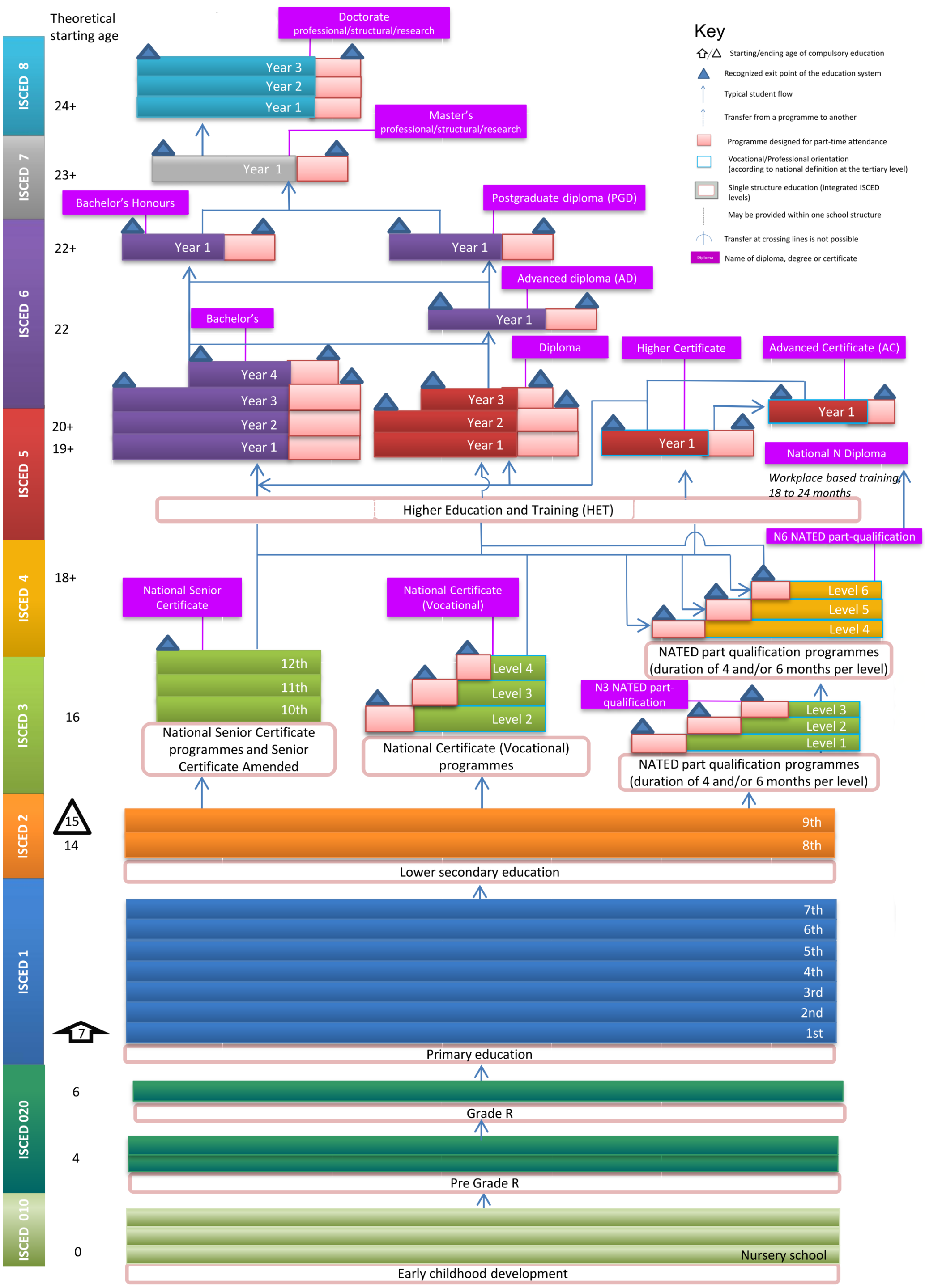

Figure 1: ISCED classification for the South African education system

15 http://uis.unesco.org/en/isced-mappings.

4.2 Student Numbers in Tertiary Institutions

Table 4 shows the student population based on the UNESCO Institute of Statistics' 2020 report (derived from data collected during the COVID-19 school lock-downs).[16] Coupled with 650,000 staff, higher education represented 1.4% of the African population in 2019.

Table 4: Higher education student population in Africa (rounded to nearest 100)

Country	Tertiary students (number)	Country	Tertiary students (number)	Country	Tertiary students (number)
Algeria	1,600,700	Eswatini	8,100	Namibia	56,000
Angola	253,300	Ethiopia	757,200	Niger	80,100
Benin	126,200	Gabon	10,100	Nigeria	1,513,400
Botswana	49,400	Gambia	5,000	Rwanda	80,800
Burkina Faso	117,800	Ghana	443,700	São Tomé and Príncipe	2,300
Burundi	61,700	Guinea	118,000	Senegal	184,900
Cabo Verde	11,700	Guinea-Bissau	3,700	Seychelles	1,300
Cameroon	290,300	Kenya	562,500	Sierra Leone	9,000
Central African Republic	12,600	Lesotho	22,600	Somalia	196,800
Chad	42,500	Liberia	43,900	South Africa	1,116,000
Comoros	6,500	Libya	375,000	South Sudan	11,300
Congo	54,800	Madagascar	143,800	Sudan	204,100
Congo, Dem. Rep.	464,700	Malawi	12,200	Tanzania	178,600
Côte d'Ivoire	217,900	Mali	72,600	Togo	101,900
Djibouti	4,700	Mauritania	19,400	Tunisia	282,200
Egypt	2,914,500	Mauritius	38,900	Uganda	258,500
Equatorial Guinea	1,000	Morocco	1,056,300	Zambia	56,700
Eritrea	10,200	Mozambique	213,900	Zimbabwe	135,600

Source: UNESCO Institute for Statistics, 2020.

16 *https://en.unesco.org/covid19/educationresponse.*

4.3 Diversity of Higher Education—The Rwanda Case

African research institutions are as diverse as the number of countries in the region. Apart from HEIs, some countries host well-endowed regional research centres of excellence; others have standalone domestic research centres or those affiliated with their main universities. The areas of focus of the research centres vary widely, covering social and economic development fields such as agriculture, biodiversity, biotechnology, climate, health, marine biology, material sciences and water resources. Rwanda is used here as an example to show a typology of higher education institutions (see Figure 2) showing also that centres of excellence could be international.

Figure 2: Universe of HEIs in Rwanda

Source: Higher Education Council, Rwanda.

Table 5 shows the number of higher education institutions, students and staff in Rwanda for academic year 2018/19 that highlights the increasing relevance of private higher education institutions and research centres, which has further implications for connectivity.

Rwanda has about 100,000 higher education students, with half of them in private sector institutions. The TVET population, which has been growing fast in the recent years represents 17% of the total student population. The University of Rwanda, which has close to 30,000 students in 2020, is the main public higher education institution in the country. Rwanda also presents an example of a mix of international and local centres of excellence, some of which provide advanced training in emerging technologies like the Internet of Things (IoTs) and Big Data Analytics.

Table 5: Number of HEIs, students and staff (both nearest 100) in Rwanda 2018/19

	Universities		TVETs		
Status	**Public**	**Private**	**Public**	**Private**	**Total**
Institutions (number)	2	28	1	9	40
Students (number)	26,300	45,800	9,400	4,700	86,200
Staff (number)	2,100	3,100	1,000	400	6,600
Total Users	**28,400**	**48,900**	**10,400**	**5,100**	**92,800**

Source: Ministry of Education, Rwanda, 2020.

The situation in Rwanda indicates the importance of African higher education having access to similar bandwidth with their counterparts in developed countries, as discussed in the vision.

5. Connectivity Status and Gaps in African Higher Education Institutions

5.1 Introduction

Broadband connectivity is mission-critical for the education and research community. It provides high-speed and high-quality access to learning resources - essential for active learning, teaching, research, and innovation. Broadband enables administrative efficiency and effectiveness. The COVID-19 pandemic has amplified demands for broadband infrastructure to support blended and ongoing learning. UNESCO's data shows that 14 million African higher education students were experiencing disruptions in their studies due to the closure of higher education institutions in 2020.[17] In addition, a new connectivity dynamic has been highlighted: the overwhelming majority of students in very many HEIs are non-resident and, because of poor or expensive off-campus commercial networks and limited national eduroam coverage,[18] were unable to access university learning and research resources online, leading to idle campus bandwidth in the middle of scarcity. While it is still the exception rather than the general case, it should however be noted that some African NRENs, for example KENET, MoRENet, RENU, and TENET have come up with solutions, working with commercial service providers, to enable off-campus connectivity within the metro areas.

Further, it is important to note that infrastructure is just one part of the equation: there are other non-tangible aspects that are critical to the presence or absence of sufficient and reasonably-priced bandwidth. This chapter discusses broadband opportunities and gaps for higher education at the global, regional, national, campus and individual levels. While we have sectioned the challenge into these five levels, we recognise that barriers to connectivity are multi-dimensional. Figure 3 summarises the key barriers that create divides at each of these levels.

17 *https://en.unesco.org/covid19/educationresponse.*

18 *https://www.eduroam.org/ eduroam (education roaming) is an international roaming service for users in research and higher education that is currently available in 18 African countries and piloting in 5.*

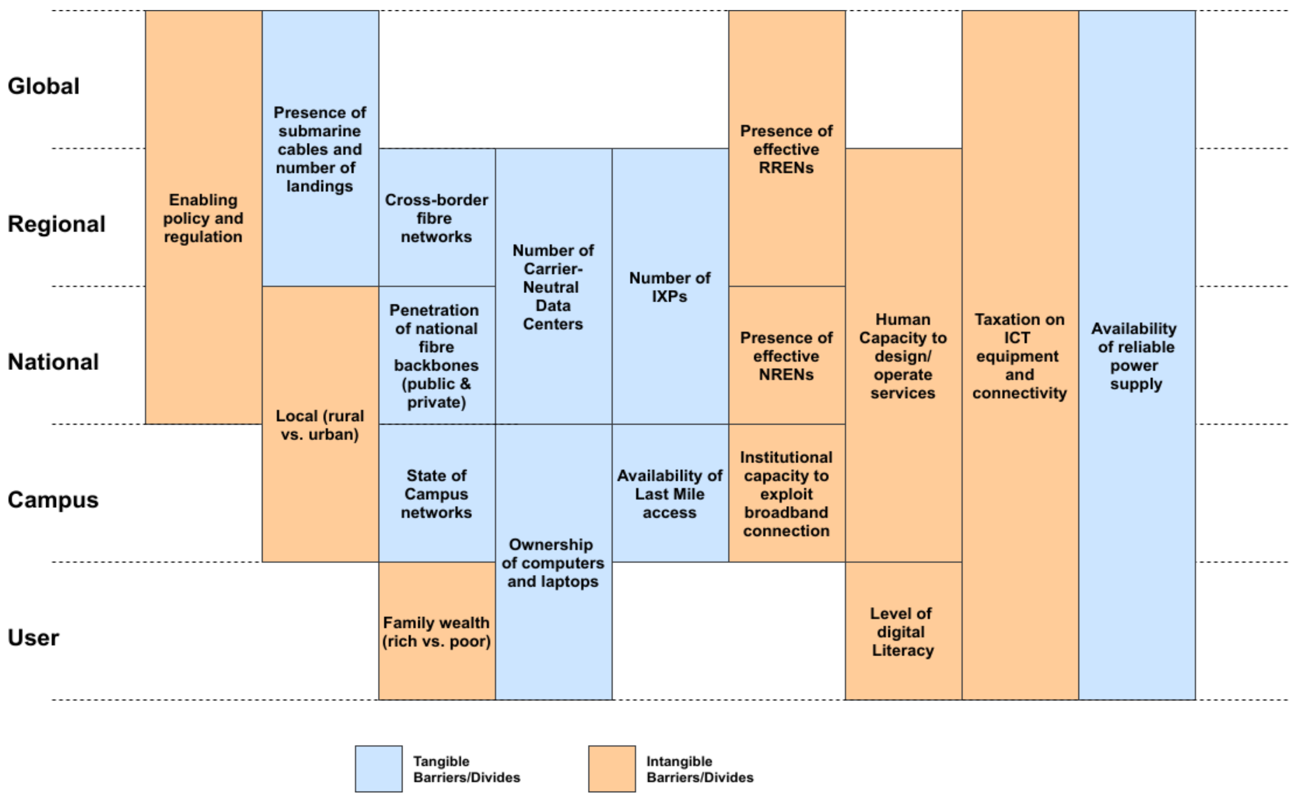

Figure 3: Tangible and intangible barriers for connecting HEIs

Source: KCL.

5.2 Status of and Connectivity Gaps at the Regional Level

5.2.1 Availability and Sufficiency of Global Connectivity

The extent of sufficient and competitive global connectivity influences the lowest price that users can get. Outside exceptional circumstances created by sound policy and regulation, effective competition requires that there are at least three providers and that the total available capacity is much higher than what is needed by the market to avoid scarcity effects on pricing.

Africa has seen substantial growth of international connectivity in recent years with the landing and upgrading of eight submarine cables (ACE, WACS, Main One, GLO-1, AST3, NCSIS, SAIL and SACS) constituting 127 Tbps in the West Coast, and five cables (EASSy, SEACOM, LION, TEAMS and SEAS) that brought 25 Tbps capacity to the East Coast of the region. Figure 4 shows the different undersea cables that currently serve Africa (grey shows under construction and planned). The availability of landing stations in all coastal countries (except Eritrea) has spurred fibre-optic links between undersea cable landing stations and the capital cities, and national fibre-optic backbones connecting major towns. Non-coastal countries are also able to connect to submarine cables, albeit at often much higher cost.

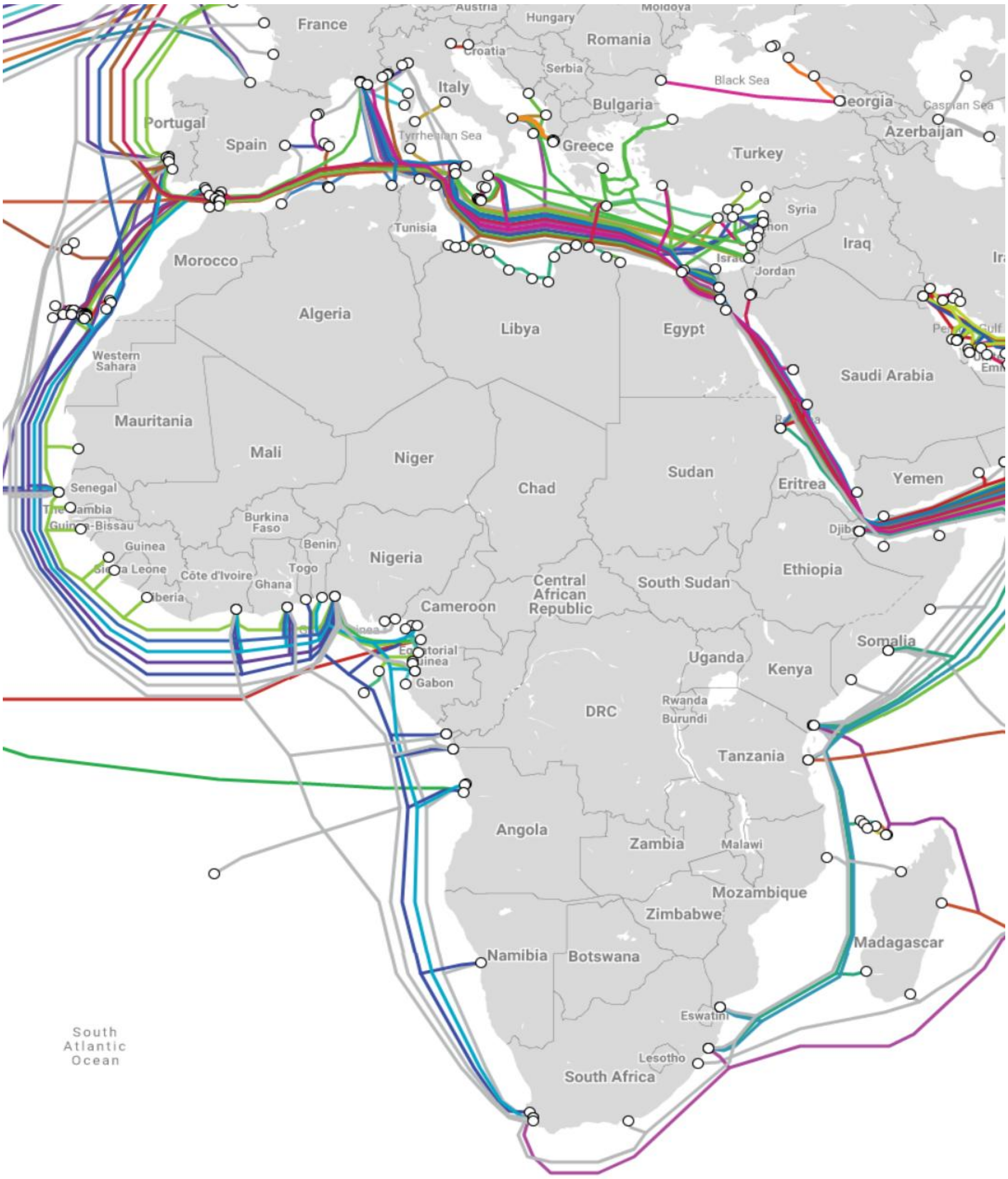

Figure 4: Map of active undersea cables around Africa (proposed in grey)

Source: Submarine Cable Map, Telegeography, 2020.

Additional capacity is expected to be available in subsequent years through Ellalink, Equiano and SHARE that are expected to double the international bandwidth in Western Africa; and METISS, DARE1 and PEACE, that are expected to increase the available bandwidth five-fold in Eastern and Southern Africa. The second wave of submarine cable links to Africa coupled with a proposed Facebook 2Africa project (180 Tbps) are expected to address bandwidth requirements for social and economic growth in general and higher education connectivity in particular.

The growth looks impressive only because it started from a very low base: Africa's present global bandwidth is very low compared to other regions. Figure 5 shows the global inter-regional bandwidth. While, on the face of it, Oceania (with 5,563 Gbps) has an inter-regional bandwidth that is less than Africa (with 12,240 Gbps), the population of the two is currently estimated as 42.1 million and 1.31 billion respectively,[19] resulting in 132.1 Mbps per 1000 people in Oceania compared to a meagre 9.4 Mbps per 1000 people in Africa. On a comparative global basis, the African continent is severely underserved in terms of available global capacity. Additionally, the continent faces a challenge of effectively utilising available bandwidth due to limitations in regional and national networks as well as last mile and last inch access, combined with prohibitive pricing that is caused by weak, poor, or poorly enforced policy and regulatory environments, limited competition, and geographic and trans-border access limitations among others. The Gambia is a case in point where operators use only 5% of the available international capacity. The country has been pursuing a strategy to sell spare capacity to neighbouring countries.[20]

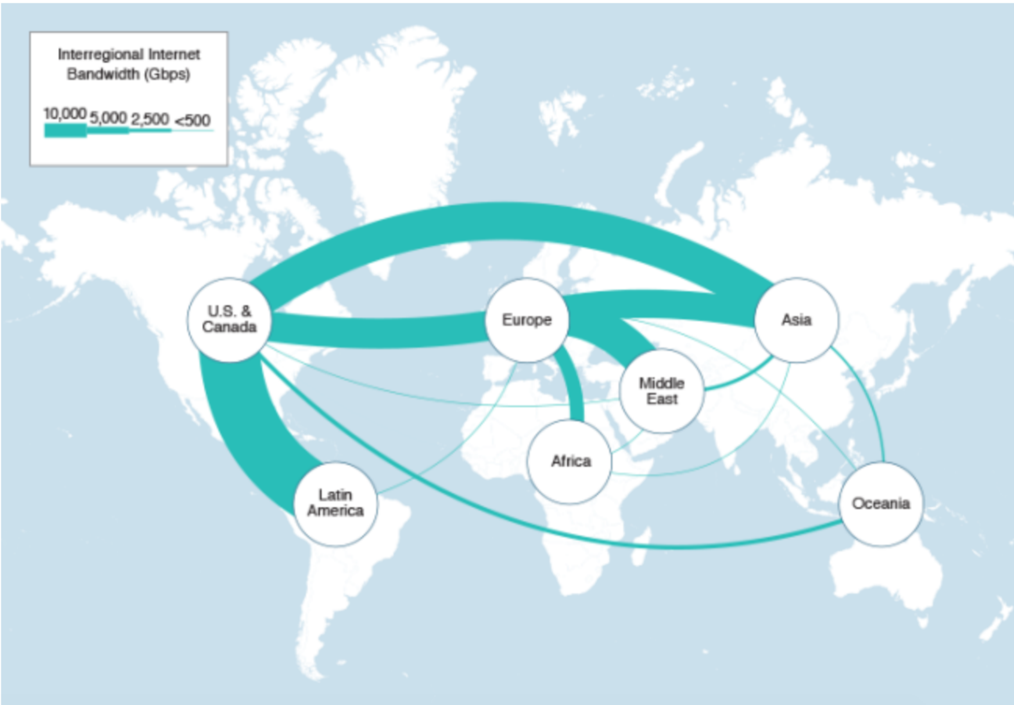

Figure 5: Global Inter-regional Internet Bandwidth

Source: Telegeography, 2019.

Among the 54 African countries recognized by the United Nations, 38 have access to the sea while 16 are land-locked. Of the 38 countries with access to the sea, 37 had at least one submarine cable landing by the end of 2019, Eritrea being the only exception. Eleven countries have one cable landing, ten countries have two cable landings, six have three cable landings, and 10 have more than three cable landings. The presence and number of such landing stations introduces the first global connectivity divide.

Table 6 shows available international Internet bandwidth for each African country and ranking by ratio of international Internet bandwidth to size of population (Mbps/1000 people). It is

19 *UN data population estimates 2019*

20 *Information based on a KCL assignment in the Gambia.*

evident from the data that Djibouti, Seychelles, Mauritius, South Africa, Gabon, Tunisia, Morocco, Algeria, Namibia and Botswana, have a relatively large bandwidth offering to the population, but the overwhelming majority of the countries have yet to provide adequate international bandwidth to citizens. The other observations that can be drawn include:

i. Although the cost of bandwidth has come down, Internet access in Africa is still more expensive compared to other regions of the world, and often less reliable, as one moves inland from the coast.

ii. Africa still largely consumes Internet content produced in other parts of the world, which requires expensive international transit often borne by end-users. Big content and cloud service providers have started to move to Africa, given the potential for more consumers and hence data and some like Facebook have started to invest in Infrastructure, but Africa is yet to start reaping the benefits.

iii. The limited regional/local exchange of Internet traffic due to the still limited penetration of IXPs means that many countries must rely on expensive transit capacity to Europe to exchange traffic abroad that would have otherwise been exchanged on the continent.

iv. In 2019, the 5 largest carriers operated 41% of all international connectivity to Africa compared to a World average of 29%. This highlights the high degree of market concentration that persists compared to other parts of the world.[21]

Table 6: International internet bandwidth (ranked by Mbps/1000 people) 2019

Country	Int'l Internet bandwidth (Gbps)	Int'l Internet bandwidth (Mbps/1000 people)	Country	Int'l Internet bandwidth (Gbps)	Int'l Internet bandwidth (Mbps/1000 people)
Djibouti	532.1	546.5	Somalia	134.2	8.7
Seychelles	13.5	137.6	Benin	96.5	8.2
Mauritius	108.5	85.5	Sierra Leone	53.0	6.8
South Africa	4,142.3	70.7	Liberia	32.9	6.7
Gabon	124.2	57.2	Nigeria	1,308.0	6.5
Tunisia	627.3	53.6	Uganda	261.6	5.9
Morocco	1,898.7	52.1	Tanzania	335.7	5.8
Algeria	1,529.9	35.5	Mozambique	164.9	5.4
Namibia	84.5	33.9	Comoros	4.5	5.3
Botswana	69.0	29.9	Congo (Rep. of the)	26.4	4.9
Zimbabwe	418.1	28.5	Guinea	58.6	4.6

21 *Telegeography, Global Internet Analysis, 2019.*

Sao Tome and Principe	5.5	25.6	Cameroon	110.3	4.3
Kenya	1,314.5	25.0	Angola	118.2	3.7
Libya	153.8	22.7	Sudan	133.2	3.1
Egypt	2,002.7	19.9	Guinea-Bissau	5.5	2.8
Eswatini	22.6	19.7	Burkina Faso	45.7	2.2
Senegal	310.2	19.0	Mali	35.2	1.8
Ghana	501.1	16.5	Malawi	32.0	1.7
Lesotho	33.9	16.0	Burundi	16.6	1.4
Mauritania	68.7	15.2	Madagascar	34.1	1.3
Côte d'Ivoire	337.5	13.1	Ethiopia	78.0	0.7
Equatorial Guinea	17.4	12.9	Niger	13.7	0.6
Gambia	29.7	12.6	Dem. Rep. of the Congo	46.8	0.5
Cabo Verde	6.6	12.0	Central African Rep.	0.9	0.2
Togo	91.0	11.3	Chad	2.7	0.2
Rwanda	133.0	10.5	Eritrea	0.5	0.1
Zambia	182.0	10.2	South Sudan	1.5	0.1

Sources: Telegeography, ITU and AfricaBandwidthMap.

5.2.2 Availability and Sufficiency of Regional Connectivity

The existence of competitive regional connectivity is vital for all countries in three respects:

i. It enables access to global connectivity for those countries that have no direct access to submarine cables;
ii. It allows regional research and education collaboration that sits above connectivity;
iii. It facilitates the development of infrastructure to exchange Internet traffic regionally and on the continent, improving performance and saving expensive international bandwidth.

Africa has seen an increase in the amount of terrestrial backbone coverage. By June 2020, the amount of operational fibre-optic network reached 1,072,649 km compared to 622,930 km in 2015. By the same date, there was a further 119,496 km of fibre optic network under construction, 95,057 km of planned fibre and 69,702 km of proposed fibre.[22] However, there are a series of challenges in regional connectivity. These range from different legal and commercial conditions to diversity of the quality of terrestrial fibre optics connections, ongoing vandalism, and fibre cuts during other construction works—especially roads.

22 *Fibre route analysis by AfricaBandwidthMaps, June 2020*

Figure 6 shows terrestrial fibre (both operational and under construction) around Africa. A close examination shows that while some countries, for example Rwanda, Ethiopia, Zimbabwe, Nigeria, and Ghana, have a fairly extensive coverage at the national level, the number of regional links, especially east to west, is very limited. Regional connectivity is therefore one of the significant macro-level gaps that will need to be addressed if the objective of high-quality broadband to each institution is to be achieved.

Various factors contribute to the gaps in terrestrial connectivity across Africa that have implications for the current topology of regional connectivity between higher education institutions:

i. Despite multiple efforts in harmonisation,[23,24,25] countries in Africa, even within the same economic blocks, still tend to have different ICT-sector policy and regulatory environments and various financial and taxation policies with which operators must be compliant. This means that even if a commercial operator owns a cross-border cable, the price offered to users can change sharply when the cable crosses a border. The challenges of regional transit and cost were especially raised by ISOC, Liquid Telecom, and SEACOM as a top priority for inland prices to come down - referencing the delays in getting the African Continental Free Trade Area fully ratified and operationalised. More than 10 expensive licences, for example, are required for marine cable to deliver connectivity starting from a cable at Mombasa, Kenya to Kigali, Rwanda. This route transits countries that are all in the East African Community. Another challenge raised by the three was the absence of significant inland data centres that would have both attracted carriers to roll out major capacity inland and would maximise keeping traffic local (also reducing transit times).

ii. Limited competition in backbone infrastructure (de facto monopoly, either private or public) in any of the countries through which a cable must transit, leading to high transit costs. An illustration of the impact of this was when UbuntuNet Alliance was connecting the Malawi Research and Education Network, MAREN in Malawi: the first connection that should have logically been routed through Mozambique to the UbuntuNet Alliance Point of Presence (PoP) in Maputo, had to be routed through Lusaka to Dar es Salaam, transiting two instead of one country over a much longer route because it was much cheaper.[26]

iii. As a result of either the absence of, and/or the high costs of terrestrial east-west and north-south cables, routing of traffic from east to west or south to north has tended to rely on marine fibre that, while being much cheaper, also introduces high levels of latency due to the much longer paths.

23 *African Information Society Initiative (AISI), https://www.uneca.org/publications/african-information-society-initiative-aisi-decade%E2%80%99s-perspective.*

24 *Programme for Harmonisation of ICT Policies in Sub Saharan Africa (HIPSSA), supported by ITU and European Commission, https://www.itu.int/en/ITU-D/Projects/ITU-EC-ACP/HIPSSA/Pages/default.aspx.*

25 *Revised AU/NEPAD African Action Plan, https://nepad.org/.*

26 *MAREN is implementing a second route that goes to Maputo, the determining objective being resilience rather than cost.*

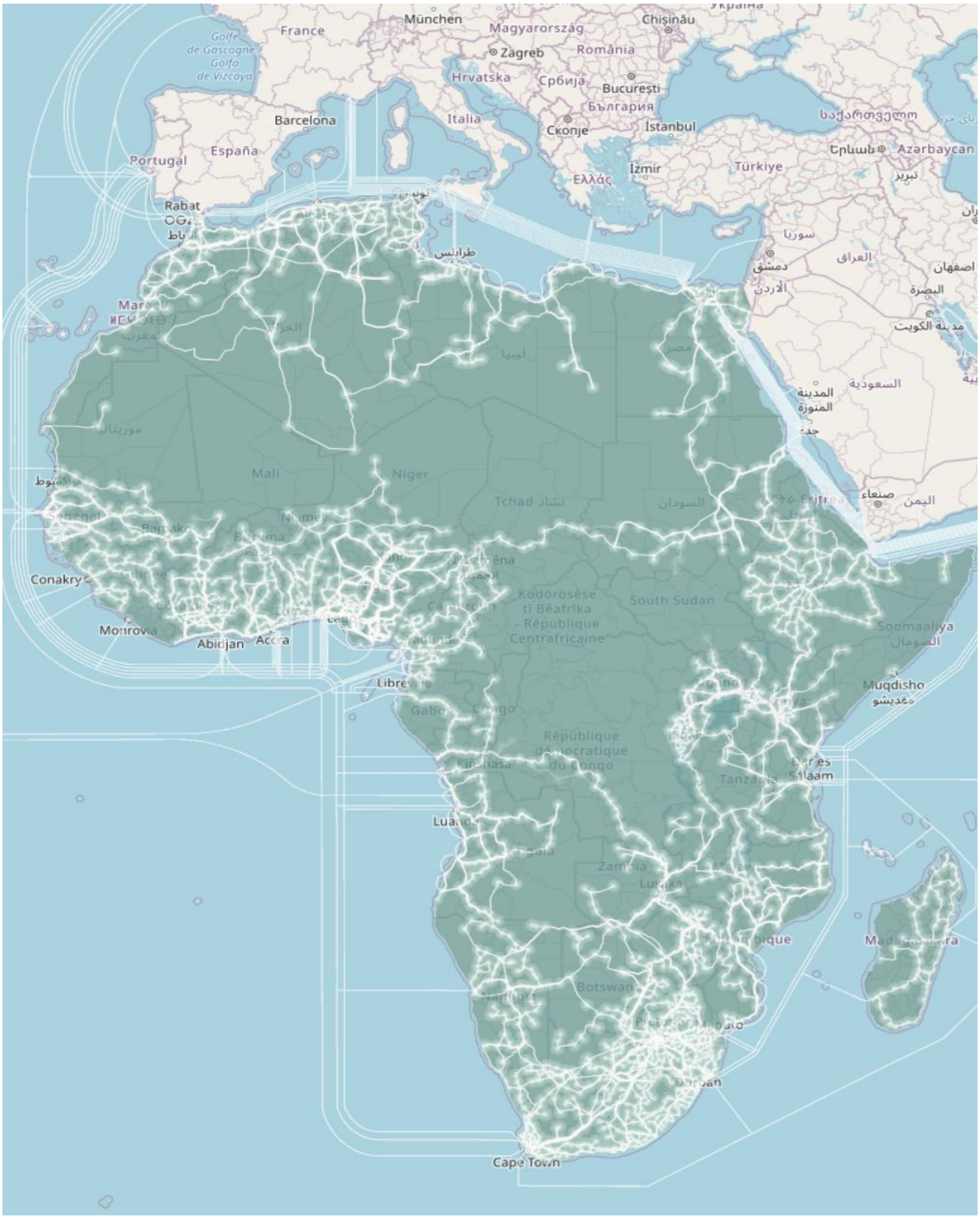

Figure 6: Terrestrial fibre within and around Africa

Source: www.africabandwidthmaps.com/fibrereach.

There are, however, companies, the largest being Liquid Telecom, that have based their business model on rolling out an expanding terrestrial network, and should over time, stimulate greater interest and investment. Liquid Telecom now has an operational overland Cape to Cairo link and recently launched an east-west route, shown in Figure 7 that should especially reduce latency. This is achieved by working with different operators in each of the transit countries.

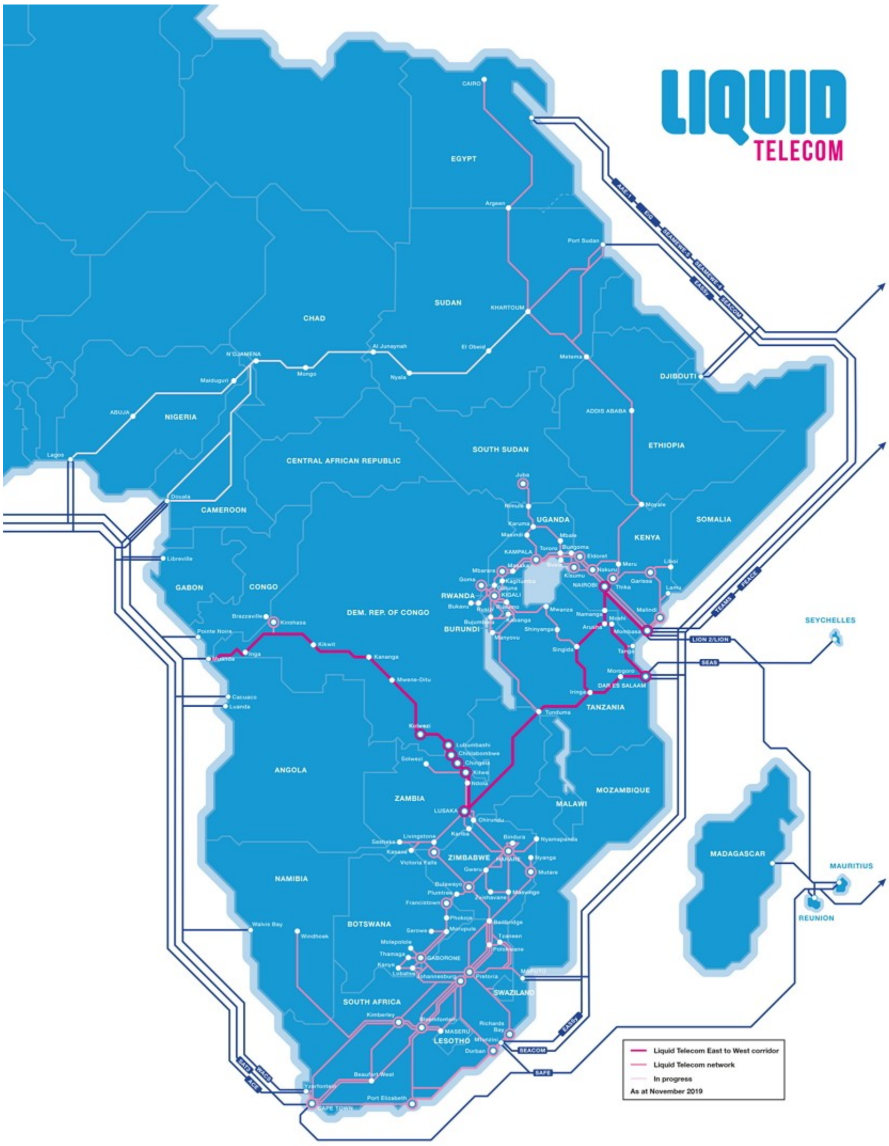

Figure 7: Liquid Telecom's fibre network showing east to west and north to south links

Source: Liquid Telecom, 2020.

Some countries have developed policies and regulations and/or licences that permit cable operators to offer IP transit through carrier Points of Presence (PoPs), facilitating local traffic exchange. This provides competitive global access that reduces the divide introduced by high costs of overland regional connectivity. Some cable operators with such PoPs across the continent include:

- SEACOM with PoPs in Botswana (Gaborone), Kenya (Nairobi and Mombasa), South Africa (Cape Town and Johannesburg), Mozambique (Maputo), Rwanda (Kigali), Tanzania (Dar es Salaam), and Uganda (Kampala).

- WIOCC with PoPs in Kenya (Nairobi and Mombasa), Mozambique (Maputo), Nigeria, South Africa (Cape Town and Johannesburg) and Tanzania (Dar es Salaam)
- Hurricane Electric with PoPs in Djibouti (Djibouti), Kenya (Nairobi and Mombasa) and South Africa (Cape Town, Durban and Johannesburg)
- MainOne with PoPs in Nigeria (Lagos) and Ghana (Accra) and Cote d'Ivoire (Abidjan)
- Orange with a PoP in Cote d'Ivoire (Abidjan).

5.2.3 Existence and Effectiveness of Regional Research and Education Networks

Connectivity of higher education institutions to international submarine cables is in most cases coordinated through regional research and education networks (RRENs). With the possible exception of TENET in South Africa where the government for a long time has had a significant focus on research funding, all NRENs that have made substantial progress in Africa have benefited from working through the regional models.[27] RRENs have made access to lower-cost international and regional bandwidth possible because they leverage demand aggregation both at national and regional levels.

Africa is covered by three major RRENs: the Arab States Research and Education Network (ASREN)[28] that connects North Africa but whose core members are outside Africa; the West and Central African Research and Education Network (WACREN)[29], and the UbuntuNet Alliance (UA).[30]

Table 7 gives the NREN membership in each of these Regional RENs, and also shows countries in each region that do not have any NREN. ASREN, WACREN and UA aggregate traffic from over 20 countries across Africa, as shown in as shown in Figure 8, and interconnect with GEÁNT to reach Europe as well as RRENs in other parts of the world.

27 *The African Bandwidth Consortium (http://www.foundation-partnership.org/pubs/pdf/more_bandwidth.pdf) that was funded by the Partnership for Higher Education in Africa (https://www.iie.org/en/Programs/PHEA) was the first functional regional aggregation model.*

28 *ASREN website, http://asrenorg.net.*

29 *WACREN website, https://www.wacren.net.*

30 *UbuntuNet Alliance website, www.ubuntunet.net*

Table 7: NREN members of RRENs in Africa

ASREN members	UbuntuNet members	WACREN members
Algeria: **ARN**	Botswana: **BotsREN**	Benin: **RerBenin**
Comoros:	Burundi: **BERNET**	Burkina Faso: **FasoREN**
Djibouti:	Dem. Rep. of the Congo: **Eb@le**	Cameroun: **RIC**
Egypt: **EUN & ENSTINET**	Ethiopia: **EthERNet**	Chad: **TchadREN**
Libya: **LibREN**	Kenya: **KENET**	Côte d'Ivoire: **RITER**
Mauritania:	Madagascar: **iRENALA**	Gabon: **GabonREN**
Morocco: **MARWAN**	Malawi: **MAREN**	Ghana: **GARNET**
Somalia: **SomaliREN**	Mozambique: **MoRENet**	Guinea: **Gn-REN**
Sudan: **SudREN**	Namibia: **Xnet**	Liberia: **LRREN**
Tunisia: **RNU & RNRT**	Rwanda: **RwEdNet**	Mali: **MaliREN**
	Somalia: **SomaliREN**	Niger: **NigerREN**
	South Africa: **TENET**	Nigeria: **NgREN**
	Sudan: **SudREN**	Senegal: **SenRER**
	Tanzania: **TERNET**	Sierra Leone: **SLREN**
	Uganda: **RENU**	Togo: **TogoRER**
	Zambia: **ZAMREN**	
	Zimbabwe: **ZARNet**	
Countries without an NREN		
	Angola	Cape Verde
	Eswatini	Central African Republic
	Eritrea	Republic of Congo
	Lesotho	Equatorial Guinea
	Mauritius	Gambia
	South Sudan	Guinea-Bissau
	Seychelles	São Tomé and Príncipe

Source: KCL using data from ASREN, UbuntuNet and WACREN[31]

31 *Other Arab countries that are members of ASREN but not part of Africa have been omitted from this list.*

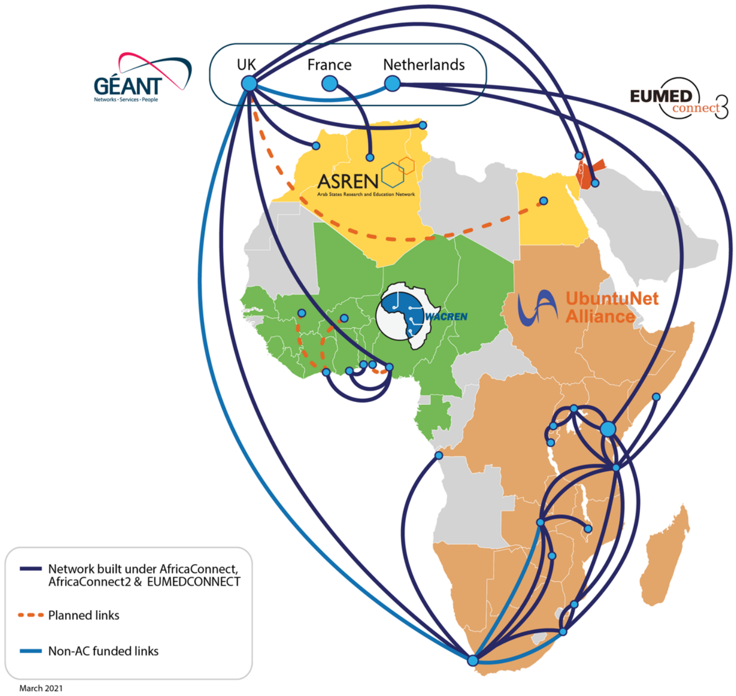

Figure 8: Coverage of African RRENs

Source: AfricaConnect3

Significant connectivity gaps in Africa are associated with the maturity and effectiveness of the Regional RENs. UA is the most advanced RREN in Africa, and it is not surprising that HEIs in this region (even with the exclusion of South Africa) generally have much higher bandwidths at much lower prices. Except for those countries that have connected directly through GEÁNT (several countries in North Africa connected directly to the GEÁNT network in Europe through the EUMEDConnect Projects[32]) and South Africa, countries that are not actively associated with one of the three RRENs face a significant challenge in getting cheap and high-capacity broadband connectivity to higher education institutions. RRENs or similar models must, therefore, be recognised as critical success factors for the availability of sufficient connectivity, especially in the early stages of NREN development.

The regional connectivity of research and education mirrors the maturity of RRENs and the density and availability of regional connections. Figure 9, for example, shows the absence of direct regional connection among most academic and research institutions in North Africa, as countries opted for connection to European Research and Education Network (GEANT) through the EUMEDConnect project. Saudi Arabia and Egypt however now serve as aggregation points for new research and education networks from Libya, Sudan, Somalia, Comoros and Djibouti.

32 https://www.eumedconnect3.net/Pages/Home.aspx.

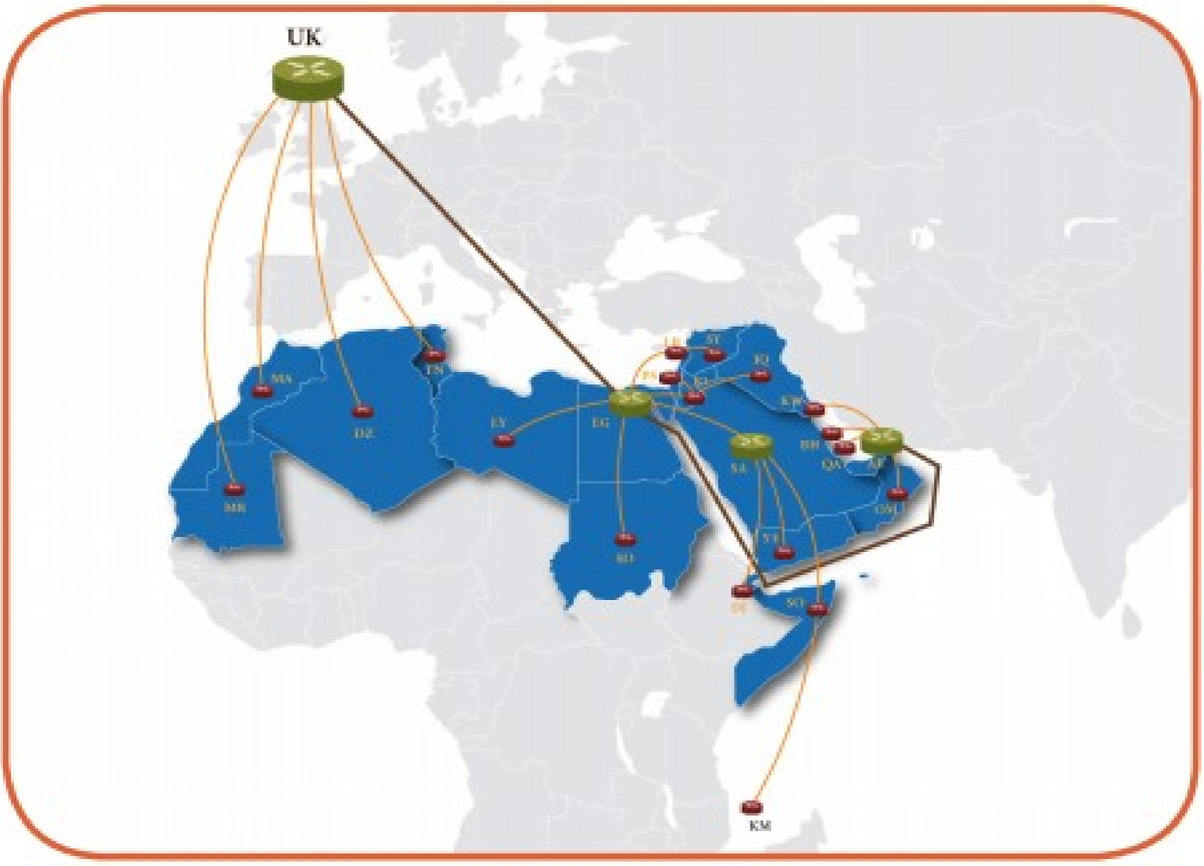

Figure 9: Regional connections among NRENs in North Africa

Source: ASREN.

Figure 10 shows the interconnection links between countries that NRENs in eastern and Southern Africa (UA region) and the West and Central Africa (WACREN region) leverage. South Africa serves as an aggregation point for most countries in the southern African region, while Ghana and Nigeria have become hubs for the western African region.

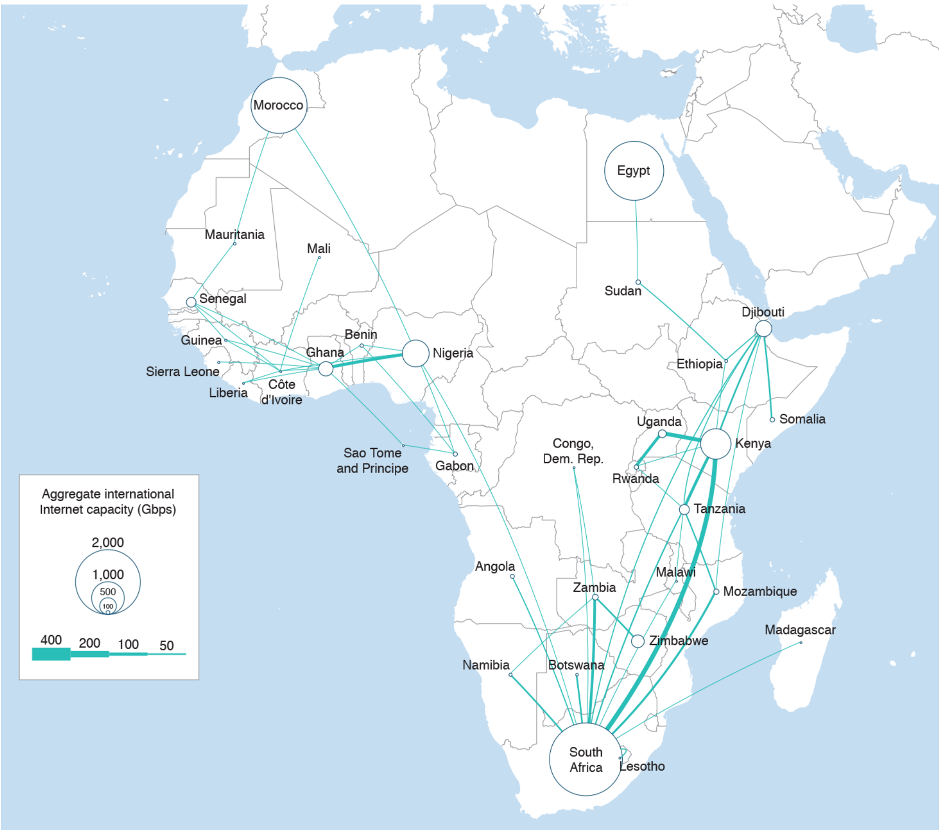

Figure 10: Intra-African routes, 2018

Source: Telegeography, 2019.

Notwithstanding these efforts, there are still substantial challenges in interconnecting countries across borders. Poor cross-border connectivity limits the potential for regional connectivity and network performance. It consumes valuable intercontinental bandwidth, creating a barrier to growth and innovation. Ongoing efforts to improve regional backbones and promote regulatory and policy harmonisation arrangements on cross-border interconnection will need to be pursued to facilitate competitive regional prices. A number of policy interventions are required to foster regional connectivity. It is essential to:

- Harmonise ICT policy and regulation across neighbouring countries or within regional blocks
- Ratify and operationalise the African Continental Free Trade Area
- Create incentives to attract investment in inland data centres, which will attract major carriers to roll out more inland capacity and facilitate more exchange of local traffic
- Minimise barriers for cross-border infrastructure, for example by eliminating need for national licenses to exchange traffic at IXPs to enable regional traffic exchange, or minimising licenses required for multi-country fibre projects.

5.3 Status of and Connectivity Gaps at the National Level

5.3.1 Availability and Sufficiency of National Backbone Connectivity, IXPs, and Data Centers

Whatever the cost estimates for connecting HEIs in any country, there needs to be sufficient national backbone coverage for national transport, and adequate network Points of Presence (PoPs) to enable last-mile connectivity. Associated with this are IXPs and Data Centers, all critical to keeping as much traffic as possible local.

While all African countries report having some form of fibre backbone with Eritrea having the shortest length with 74 km and South Africa having the most extensive fibre coverage with 278,000 km, national fibre coverage in Africa varies widely, again influenced by geography, level of competition and investment by public and private sector operators among others. Table 15 shows the number or marine fibre landing points where applicable (more than one cable landing point means that marine cable segments can be used as part of the national fibre infrastructure), and the number of Internet eXchange Points (IXPs)—also critical as part of the national backbone infrastructure. While many countries have seen significant deployment of their national backbones that have enabled connection to major cities, where most of the higher education institutions are located, interactions with NREN CEOs indicate that last-mile connections to institutions outside of major cities are still a big challenge.

The data indicates that small geographic-sized nations like Burundi, Cape Verde, Mauritius, Rwanda and São Tomé and Príncipe and digitally advanced countries like Morocco, South Africa and Tunisia have made good progress in building terrestrial backbone networks. A close examination of the fibre optics map and population density indicates that Angola, Algeria, Cameroon, Egypt, Gambia, Ghana, Kenya, Mozambique, Senegal, Tanzania, Uganda, Zambia and Zimbabwe have networks that could support most of their higher education connectivity needs. Some of these countries, like Egypt, have a very high concentration of the population in urban areas where fibre networks are well-built. Over half of African countries still need substantial investment into their terrestrial fibre backbone networks to support their higher education connectivity.

Recent research by the World Bank explores the importance of different components of a country's data infrastructure.[33] The work looks beyond conventional availability of infrastructural components towards their openness and interaction in order to support a vibrant digital ecosystem. Low and Middle-Income Countries are categorised using a data infrastructure maturity ladder into 4 stages:

i. Stage 0 (No IXP, internet traffic exchanged overseas)
ii. Stage 1 (Domestic internet traffic between ISPs exchanged at IXP)
iii. Stage 2 (Diversity of participants at IXP, presence of global CDNs)

33 *World Bank Group, 2021. The Importance of National Data Infrastructure for Low and Middle-Income Countries.*

iv. Stage 3 (IXP located alongside carrier neutral co-location data centre)

Countries higher up the ladder tend to reap more benefits from their data infrastructure. Currently, 34 out of 54 African countries have at least one IXP in the country to help facilitate local traffic exchange and save expensive international transit.[34] Coverage of carrier-neutral data centres is still inadequate as indicated in Table 15. 13 out of 54 African countries have at least one carrier-neutral data centre with South Africa having 21, followed by Nigeria and Mauritius with 10 each and Kenya with 7 data centres.

Beyond sufficiency of national fibre connectivity is the need for sufficient supply-side competition: there are several examples of sufficiency, where either the cost of backbone transport remains very high or the bandwidth made available is very low. It also needs to be noted that the presence of an extensive public backbone of sufficient capacity does not necessarily lead to adequate broadband connectivity to institutions (Rwanda, Tanzania, and Ethiopia are examples).

Our survey results indicate that in 2020 the highest bandwidth available for higher education institutions ranged from 10 Mbps to 50 Gbps with some best-connected campuses in a sample of countries ranging from 155 Mbps (Gabon), 200 Mbps (Ethiopia), 300 Mbps (Nigeria) at the low end; to 1 Gbps (Senegal), 2 Gbps (Uganda), 3 Gbps (Kenya and Morocco), 10 Gbps (South Africa) at the higher end. The results further indicate that pricing of bandwidth plays a major role in limiting the amount of connectivity to higher education institutions.

Some of the policies that can help to increase competition and drive down prices by increasing investment in national infrastructure include:

i. Eliminating monopoly provisions from the market structure,
ii. Reducing the cost of operator and spectrum licences, hence the barriers to entry and costs to the end-user,
iii. Enforcing shared use of telecom infrastructure, civil-works and access to the alternative infrastructure provided by transport and energy operators,
iv. Legislating for the protection of critical infrastructure, including ensuring sufficient compensation for fibre cuts,
v. Eliminating or reducing taxes on communication and communication equipment, helping reduce end-user costs and driving up demand,
vi. Deploying universal access funds that have provided funds for infrastructure in remote and sparsely populated areas of the country.

5.3.2 Existence and Effectiveness of National Research and Education Networks

While this analysis is not about making a case for NRENs (which has been extensively addressed elsewhere[35]), it is important to note at the outset that the *"provision of connectivity"*

34 *Africa IXP Association, http://www.af-ix.net/*
35 *https://www.casefornrens.org/Resources_and_Tools/Document_Library/Pages/All_documents.aspx (has links to multiple publications)*

aspect often leads to the assumption that this is just an alternative to normal commercial connectivity resulting in a fallacious comparison of costs. There is a major distinction between REN and commercial connectivity. As discussed in another publication[36] *REN networks are dimensioned to be responsive to research and education needs, which are often characterized by intermittent very high bandwidth demands. Such networks therefore run at 50 – 60% of available capacity during normal operation. Commercial networks are on the other hand operated close to full capacity, and therefore cannot respond to the demands of research and education"*.

The ethos of operation of RENs is also different from that of commercial networks: *"While commercial ISPs are characterized by fierce competition; R&E networks typically are publicly funded not-for-profit organizations that thrive on collaboration. This collaborative spirit is at the heart of the global R&E network community, empowering research and education across the globe.[37]"* From another source: *"As the scientific community pushes the boundaries of our knowledge, researchers rely on dedicated data communications networks to provide greater speeds, timely delivery, seamless global reach and a very high level of resilience.[38]"* To illustrate the difference: tests conducted using large file transfers (100Terabytes) on NREN networks and two commercial ISPs – all without any advance notifications – resulted in transfer durations of 1.4 days for the NREN links, and 7.6 and 119.3 days via two different commercial ISPs.[39] NRENs mediate between higher education and the market with respect to connectivity. They additionally offer services such: as access to digital libraries, learning management systems, and scientific resources; capacity building; identity management, eduroam, and eduMEET. The NREN model is so successful and necessary that today there are over 120 countries[40] that have initiated NRENs, including those in Africa, Asia, Australia, Europe and North America.

NRENs are therefore considered a critical element in delivering sufficient and reasonably priced connectivity of the right quality to HEIs. NRENs:

i Mediate between higher education and the market, getting the best price offering for this closed user group through economies of scale and customer aggregation benefits for the commercial suppliers.

ii They provide direct connectivity with international research and education networks so as to foster research collaboration and scientific resource sharing.

iii They offer national and global services such as access to digital libraries, learning management systems, and scientific resources; capacity building; identity management; and eduroam.

iv Africa's sustainable development challenges, such as increasing urbanization, climate change-induced crises, environmental degradation, food insecurity, and a growing load of non-communicable disease, demand extensive research and collaboration,

36 *See GÉANT Policy Paper, "Breaking the Final Connectivity Barriers for Higher Education Institutions in Africa: The Next Steps and A Call to Action."*

37 *https://www.inthefieldstories.net/why-re-networks/*.

38 *https://sustainabledevelopment.un.org/content/documents/2106Feasibility-Study-for-a-United-Nations-Technology-Bank-for-the-Least-Developed-Countries.pdf*.

39 *https://connect.geant.org/2017/05/15/taking-it-to-the-limit-testing-the-performance-of-re-networking*.

40 *https://geant3plus.archive.geant.net/Network/Global-Connectivity/Pages/default.aspx*

requiring advanced research and education networks. NRENs facilitate the formation of communities of researchers in the areas of agriculture, bioinformatics, disaster mitigation, network development, and telemedicine, among others, which foster collaboration between researchers in the developing world.

v Research and education networks create platforms for experimentation with the various aspects of network technologies, such as protocols and security, which have spill-over effects in other networks. They not only serve as anchors for high-capacity bandwidth delivery but also as catalysts for communities' digital literacy, broadband deployment, and adoption.

vi The vast majority of users in higher education consume bandwidth for learning, teaching, and research, while administration and services staff rely on occasional access to the internet with intensive use of campus servers. Researchers constitute a third category of users. They often need sustained high volume and high quality bandwidth for short periods to handle vast volumes of data, either by the transfer of large files or, increasingly, via instruments. NRENs can increase capacity for short periods of time when usage is expected to spike (such as access to instruments and when uploading, downloading, or accessing large volumes of research data). NRENs connect to e-science resources such as telescopes, sensor networks, accelerators, and supercomputers. Thus, access to bandwidth through NRENs is the most appropriate approach for higher education.

The NREN model is so successful and necessary that today there are over 120 countries that have initiated NRENs, including those in Africa. In Latin America and the Caribbean, for example, cases were made for NRENs as "public good" organisations because of their far-reaching implications for learning, teaching, research, and many other scientific endeavors that have a positive impact on economic growth and social development.[41] Sustainable NRENs must therefore be recognized as critical elements in national development in Africa—supporting innovation, scientific progress, and growing the economy and creating jobs.

Out of 20 NRENs that responded to our survey, 16 are not-for-profit membership organisations, and 4 are owned and run as government departments or agencies. 15 of the 16 are recognised by government through a ministry or government agency. This recognition is important because it affects the kind of support that NRENs can receive from government as well as their ability to secure the necessary licences and permits to be able to offer services to higher education institutions across the country.

NRENs are at different levels of network development. 40% of NRENs have no network of their own as yet (although they may offer bandwidth through a consortium model), 25% have a network backbone with a capacity at less than 10 Gbps while 35% have a network backbone at a capacity of 10 Gbps or more. This indicates the need to invest in creating better infrastructure that can be used to distribute high speed connectivity to HEIs in various countries.

41 *See the RedCLARA white book, Advanced Networks in Latin America: Infrastructures for Regional Development in Science Technology and Innovation, http://www.redclara.net/index.php/en/noticias-y-eventos/publicaciones.*

Figure 11 shows the percentage of African NRENs among the 20 that responded to the survey that serve different categories of users, starting at 100% serving universities, and 5% serving for profit organisations. Other types of institutions NRENs can serve include institutions associated with the educational sector like examination bodies and education sector regulators.

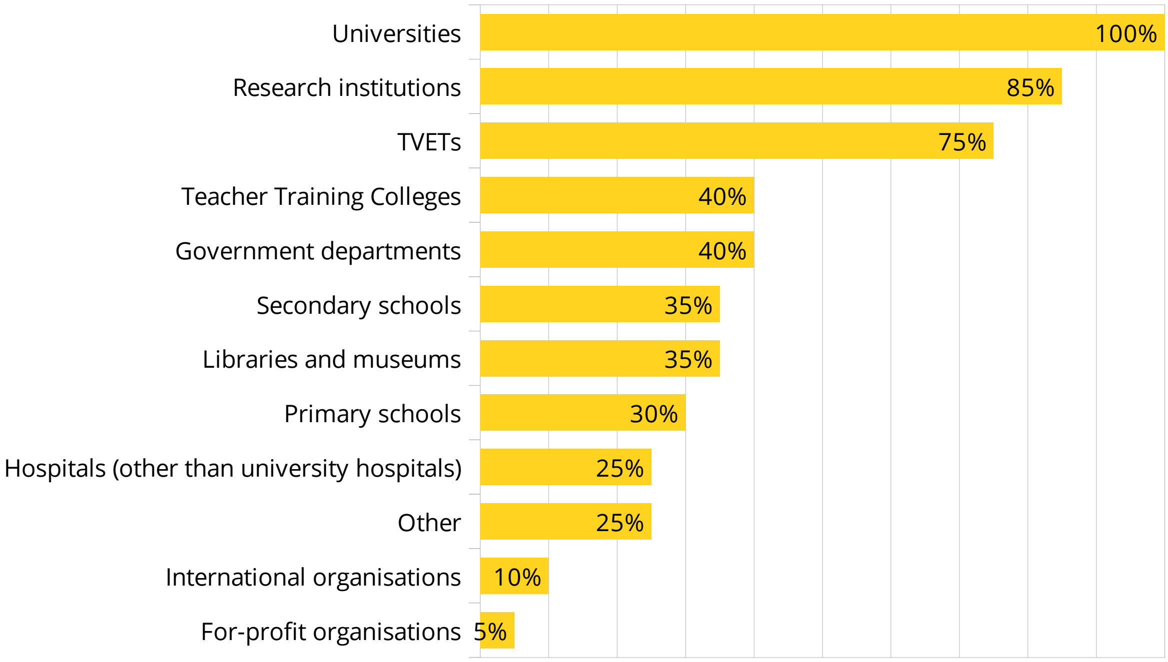

Figure 11: Types of member institutions NRENs are allowed to serve

Source: NREN survey

NRENs charge their members a wide range of prices across the continent from zero in countries like Côte d'Ivoire, Ethiopia, Gabon, Senegal and Tunisia where the government subsidises the cost of bandwidth to as high as $900 per Mbps/month in Chad due to market structures and regulatory environment in the country. Most NRENs (30%) charge between $25 – $99 per Mbps/month to account for the high cost of distributing bandwidth to members. Figure 12 summarises member pricing across responding NRENs. The missing 25% are those that do not currently provide connectivity. Most NRENs have implemented a tier system of pricing where member institutions that consume larger volumes of bandwidth pay lower cost per Mbps/month.

According to interviews with NREN CEOs, besides encouraging members to increase their bandwidth budgets and volumes to get better pricing for all members, the tier system is a tactic designed to fend off seeming competition from commercial providers who often attempt to lure away top consuming members to the commercial side: while the connectivity products offered by RENs and commercial providers are different, cash-strapped institutions where research is not yet highly developed focus only on pricing. Examples of tier pricing include MARWAN in Morocco, where for the minimum 100 Mbps, the price starts at $21 per Mbps/month while at the top-end, for 5 Gbps and above the price is $3 per Mbps/month. For RENU in Uganda, anything less than 100 Mbps costs $50 per Mbps/month, while 5 Gbps or more costs $10 per Mbps/month. TERNET in Tanzania also factors the location into pricing with an institution that can consume 1 Gbps or more at the top-end paying $15 per Mbps/month if they are within the Dar es Salaam metro area or $36 per Mbps/month if they are outside the capital.

Source: NREN survey

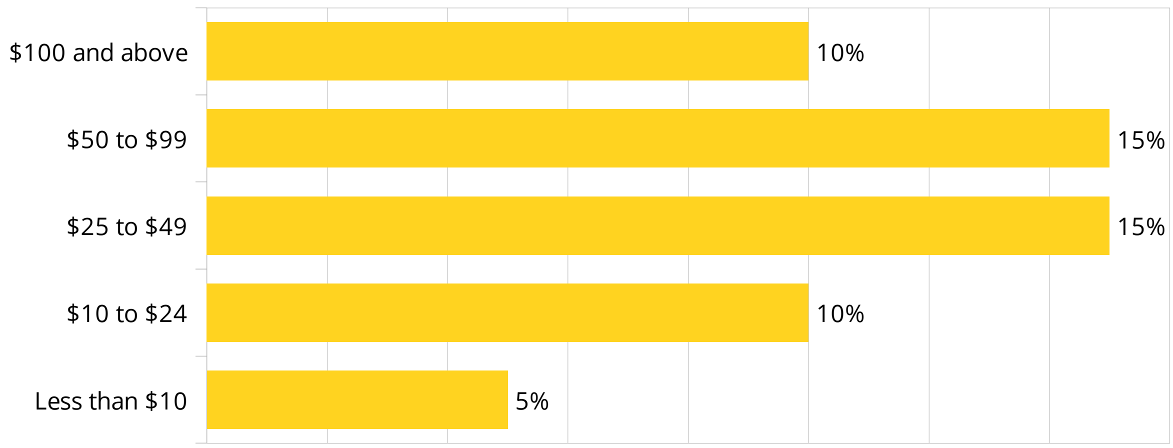

Figure 12: Proportion of NRENs charge varying amount for 1 Mbps/month

NRENs source their bandwidth from both RRENs and commercial providers. 35% of NRENs get their bandwidth exclusively from RRENs, 35% exclusively from commercial providers while 30% use both RRENs and commercial providers to source their bandwidth. This indicates the need for some upstream interventions either on the RREN-side, the commercial-side or both as WBG works to increase the amount of capacity available for higher education institutions.

Source: NREN survey

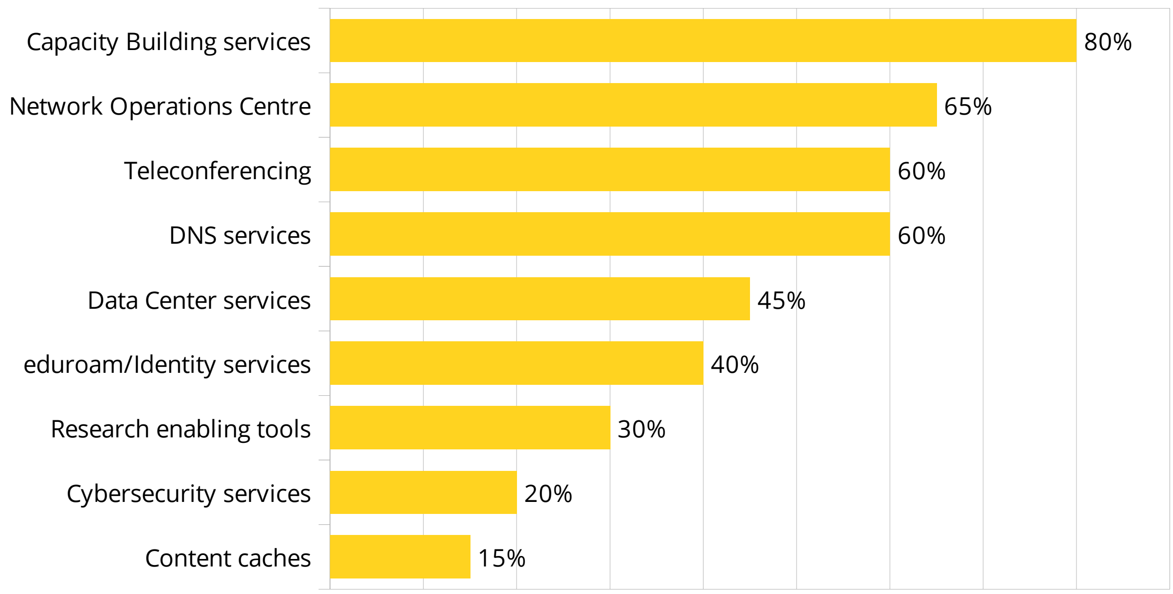

Figure 13: Proportion of NRENs offering middle-ware and advanced services

Figure 13 summarises the full range of services currently offered by NRENs in Africa. To address skill gaps among technical personnel, most NRENs offer capacity building services to their members. These range from organising technical workshops staff to offering direct engineering assistance at institutions on how to design and maintain campus networks. Other services include network operations and teleconferencing, the demand for which has increased due to travel restrictions necessitated by the COVID-19 pandemic. At the bottom end are two increasingly important services that reflect the nascent nature of Africa's Internet ecosystem—content caches reflect the level of local/regional traffic aggregation and exchange, saving the continent expensive international connectivity while Cybersecurity services reflect local capacity to mitigate and deal with Cyber incidents and attacks that inevitably accompany better connectivity.

In addition, the survey shows that NRENs face a lot of challenges including:

i. Lack of awareness among both members and other stakeholders about what an NREN is and how it contributes to improving ICT enabled teaching and learning;
ii. High cost for national and international bandwidth;
iii. Limited or no distribution network for last-mile access to peri-urban and rural institutions that are also likely to be more challenged in terms technical capacity and funding;
iv. Constraining policy and regulatory environment;
v. Competition with commercial service providers, some of whom have animosity towards NRENs and do not fully appreciate the role that NRENs play in nurturing digital natives that eventually end up as data-hungry customers of the same providers;
vi. Lack of sufficient funding among member institutions that also have many competing priorities. Insufficiency of funding leads to such institutions having very small budgets for ICT and connectivity, and late payments to NRENs for services provided;
vii. Poor campus networks at most member institutions so that even when members acquire more bandwidth it does not directly result in visible changes in speed or user experience for end-users; and
viii. Low levels of technical expertise among ICT staff at member institutions.

Sustainable NRENs must be recognised as a critical element in delivering sufficient and reasonably-priced connectivity to HEIs at the national level. NREN readiness is achieved when sufficient government commitment is secured, and an organisation that is recognised and supported by the public and private higher education institutions is created. The organisation needs to be properly staffed to handle both administrative and technical matters, and to have the capacity to negotiate connectivity deals on behalf of their members.

The survey shows that NRENs owned and operated by HEIs are the most successful. Such NRENs are responsive to the needs of the users, but still need support (in cash or in-kind) from government or governmental agencies.[42] Examples of NRENs that have this key combination include TENET of South Africa, ZamREN of Zambia, KENET of Kenya, and RENU of Uganda. It is not surprising that these are, to date, the NRENs in countries where HEIs have the best connectivity in sub-Saharan Africa. Despite the early start and better infrastructure, North Africa did not achieve the same level of NREN development and dynamism, because the process of university networking was driven by the government or government sponsored

42 *Foley, Michael. The Role and Status of National Research and Education Networks in Africa. World Bank, 2016.*

institutions.

The reality that only about twenty African countries have NRENs that deliver connectivity to HEIs, and of these, less than five (allowing for some progress since data was collected for this study) can be considered as mature NRENs, points to the urgency of addressing this institutional gap in the African development ecosystem.

5.4 Status of and Connectivity Gaps at the Campus Level

Several factors contribute to connectivity gaps at the campus levels. These include the number of staff and students, the intensity of applications and services, the available bandwidth, the quality of campus wireless and wired networks and competence staff in information technology and network management. How these are handled is determined by the ICT policy and support environment.

5.4.1 Sufficiency of Bandwidth Based on Number of Users

The number of users is a crucial indicator of connectivity requirements at campus and national levels. HEIs in most African countries tend to purchase bandwidth based on what is available from the market and through NRENs, but they lack the benchmark to ensure that the bandwidth they procure is sufficient for user population.

Based on the progressive targets given in Chapter 3 (see Table 3), we have calculated the current deficit based on 0.2 Gbps per 1,000 students during 2021; and the projections for 2025 and 2030 based on 2 Gbps per 1,000 students; and 20 Gbps per 1,000 students.

Based on a bandwidth need of 0.2 Gbps per 1,000 higher education students (or 200 Kbps per student) in 2021, Table 8 depicts higher education institutions collectively need 4.6 Tbps for international bandwidth in 2021, resulting in a bandwidth gap of 2.4 Tbps. In 2025, the projected bandwidth needs will increase to 54.8 Tbps while in 2030 this will be 507 Tbps. It should be noted that estimates are based on student population of higher education institutions per country (staff numbers are insignificant in comparison) as opposed to actual bandwidth delivered to these institutions (see Table 16 for details).

Table 8: Bandwidth gap for higher education institutions based on 0.2 Mbps per student in 2021

Country	Internet bandwidth Need (Gbps)	Current Bandwidth Gap (Gbps)	Country	Internet bandwidth Need (Gbps)	Current Bandwidth Gap (Gbps)
Algeria	320.1	286.6	Liberia	8.8	8.6
Angola	50.7	47.7	Libya	75.0	68.5
Benin	25.2	21.1	Madagascar	28.8	27.9
Botswana	9.9	8.7	Malawi	2.4	2.4
Burkina Faso	23.5	22.8	Mali	14.5	14.1
Burundi	12.3	11.1	Mauritania	3.9	3.6
Cabo Verde	2.3	2.1	Mauritius	7.8	2.4
Cameroon	58.1	57.3	Morocco	211.3	134.5
Central African Rep.	2.5	2.5	Mozambique	42.8	41.1
Chad	8.5	8.4	Namibia	11.2	10.5
Comoros	1.3	1.2	Niger	16.0	15.8
Congo	11.0	10.2	Nigeria	302.7	283.5
Congo, Dem. Rep.	92.9	92.7	Rwanda	16.2	15.4
Côte d'Ivoire	43.6	41.5	Sao Tome and Principe	0.5	0.4
Djibouti	0.9	0.9	Senegal	37.0	35.7
Egypt	582.9	504.6	Seychelles	0.3	0.2
Equatorial Guinea	0.2	0.2	Sierra Leone	1.8	1.8
Eritrea	2.0	1.9	Somalia	39.4	39.1
Eswatini	1.6	1.6	South Africa	223.2	0
Ethiopia	151.4	150.4	South Sudan	2.3	2.3
Gabon	2.0	1.9	Sudan	40.8	40.4
Gambia	1.0	0.9	Tanzania	35.7	35.5
Ghana	88.7	80.5	Togo	20.4	14.3
Guinea	23.6	22.9	Tunisia	56.4	38.9
Guinea-Bissau	0.7	0.6	Uganda	51.7	49.7
Kenya	112.5	0	Zambia	11.3	10.5
Lesotho	4.5	4.4	Zimbabwe	27.1	25.4

Source: Student data from UNESCO Institute for Statistics (UIS), connectivity data from ITU and Telegeography 2020

From a regional perspective, the proportion of the bandwidth gap to the actual need in 2020 is much higher for West & Central Africa compared to the other two regions as indicated in Table 9. This indicates that there is a need for more work to close the gap in West & Central

Africa compared to Northern Africa and East & South Africa.

Table 9: Bandwidth need and gap for higher education by region in 2021

WBG Region	Projected Bandwidth Need (Gbps)	Projected Bandwidth Gap (Gbps)	Ratio of Bandwidth Gap / Bandwidth Need
East & South Africa	1,076	723	67.2%
Northern Africa	1,247	1,034	82.9%
West & Central Africa	696	650	93.5%
TOTAL	**3,019**	**2,407**	

Source: Student data from UNESCO Institute for Statistics (UIS), connectivity data from ITU and Telegeography 2020

Country-by-country assessment of the above data indicates that only South Africa and Kenya meet the minimum of 200 Kbps per student bandwidth needed for research and education in 2020, while Mauritius and Morocco have made considerable strides towards meeting this minimum requirement in 2020. Gaps still remain across Africa in meeting the bare minimum bandwidth of 200 Kbps per higher education student in 2020.

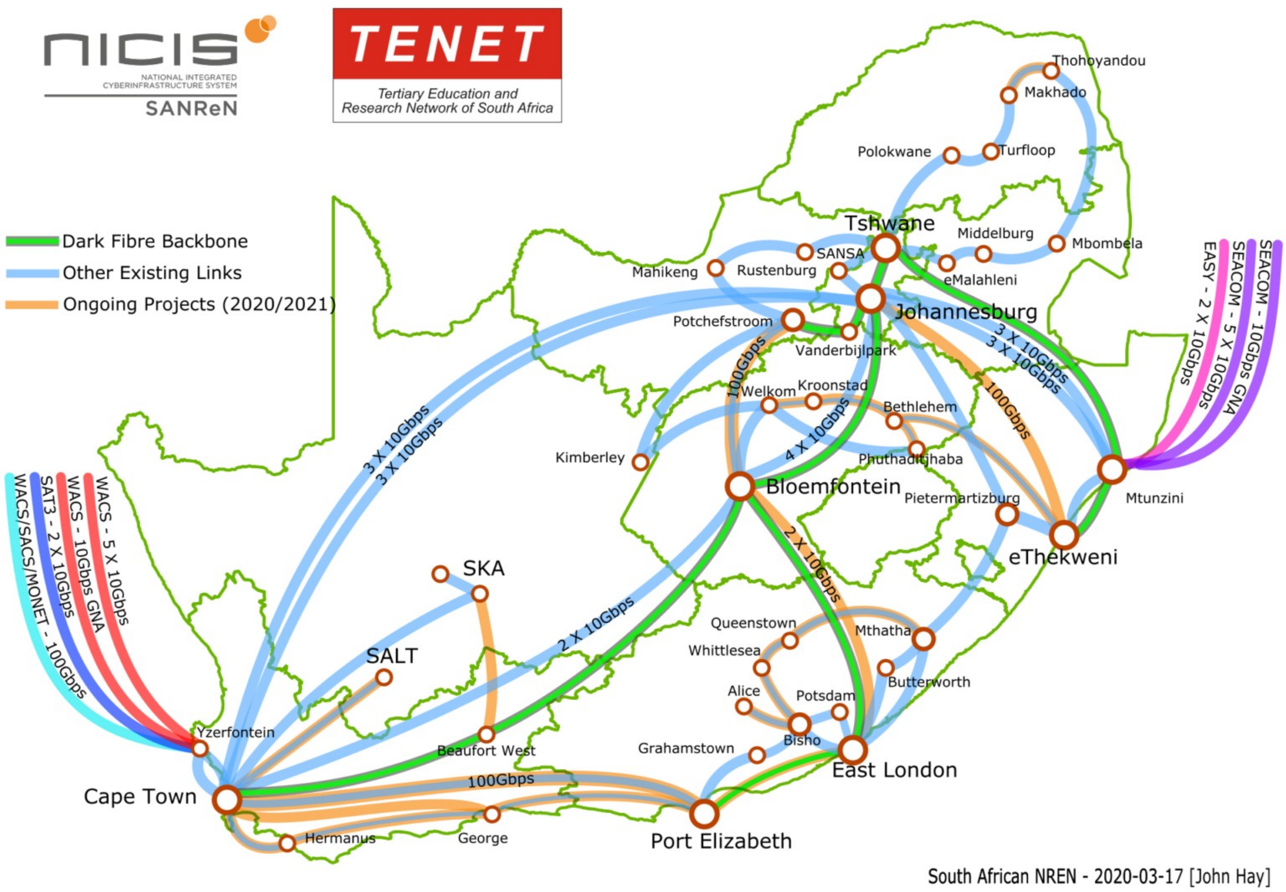

Figure 14: South African NREN backbone map showing terrestrial and undersea capacity

Source: SANReN.

The South African Research and Education Network (SANReN) depicted in Figure 14 and summarised in Box I[43] is jointly managed by the Council for Scientific and Industrial Research (CSIR) and the Tertiary Education and Research Network of South Africa (TENET).[44] The network connects over 500 sites across all nine South African provinces to the network that include universities, science/research councils, national facilities and institutions, academic hospitals and museums.

Box I: The South African Research and Education Network comprises:

i. A core national dark fibre backbone over 3,000 km and about 6,000 km of managed bandwidth links at speeds of up to 100Gbps,
ii. A network composed of multiple 10 Gbps links, with an upgrade to 100 Gbps underway,
iii. Eight metropolitan area networks at 10 Gbps each in Johannesburg, Pretoria, Cape Town Durban, Bloemfontein, East London, Pietermaritzburg, Vanderbijlpark and Polokwane. Three new metro networks currently under planning include Port Elizabeth, Nelspruit and George,
iv. High capacity long-haul circuits to the Hartebeesthoek Radio Astronomy Observatory (HartRAO), the South African Astronomical Observatory (SAAO) in Sutherland, the South African National Space Agency (SANSA)'s magnetic in Hermanus, and the developing Square Kilometre Array (SKA) site in Carnarvon,
v. Back-hauls from submarine cable landing stations at Yzerfontein and Mtunzini,
vi. Capacity on five undersea cables (SEACOM, EASSy, WACS, SAT-3 and WACS/SACS/MONET),
vii. Peering at all significant national Internet Exchange Points (NAPAfrica, CINX, JINX, DINX) and internationally at the UbuntuNet gateways at LINX in London and AMS-IX in Amsterdam, where SANReN exchanges traffic with other NRENs. Transit services are provided via Liquid Telecom in Cape Town and Johannesburg and via Cogent, NTT and GÉANT in London and Amsterdam,
viii. Currently, connects over 386 university and research sites and over 90 TVET sites through SABEN.

The assessment of campus connections shows that African countries need to ensure that abundant, inexpensive bandwidth is available locally, with massive connection to the rest of the world, along with redundancy in cities where higher education institutions are located. It is noted that even if it is for the lower levels of education, the EU broadband targets foresee that by 2025, all schools should have access to Gigabit internet connectivity.[45]

5.4.2 Quality and Sufficiency of Campus Networks

From both historical experience and current interviews with NREN CEOs around Africa, it is common to provide more bandwidth to higher education institutions, but have no positive change in user experience, which creates a pushback against increased funding for connectivity. Many NRENs, therefore, have had to dedicate a lot of their time to both technical

43 http://www.sanren.ac.za.
44 http://www.tenet.ac.za.
45 https://ec.europa.eu/education/education-in-the-eu/european-education-area/digital-education-action-plan-action-1-connectivity-in-schools_en.

capacity building and direct engineering assistance (DEA) to help improve campus networks.[46] They can reap the benefit of increased bandwidth to the campus – as assessed from user experience and satisfaction. Good campus networks, combined with sufficient high-quality bandwidth, generate the pull factors that will lead to increased willingness to spend and, therefore, sustainable access to adequate and high-quality bandwidth.

It is especially important to note that while there are multiple challenges that need to be addressed in connecting African HEIs to broadband, an emerging priority theme ahead of all other considerations is the quality of campus networks and the acute shortage of sustainable technical expertise at the campus level. The shortage of technical expertise is especially acute for rural campuses: people with such expertise tend to prefer major urban centers where they have easier access to extra sources of income through providing services to other organisations, and also have good schools and services within easier reach. This is one of the compounding factors of the rural-urban divide.

5.5 Status of and Connectivity Gaps at the Individual Level

The extent of utility of bandwidth delivered will be dictated by the utility to which individuals put it – the last inch—users need optimal bandwidth to run different applications and devices that connect to the network as summarised in Table 10.

Table 10: Example of optimal bandwidth requirement for teaching, learning and research

Teaching, learning and research needs	Optimal bandwidth requirement
Access to Open Educational Resources	1 Mbps
Learning Management System, Moodle, Canvas	1 Mbps
Online Public Access Catalogue, digital library access	500 Kbps
Video streaming	5 Mbps
Remote Instruction	1 Mbps
Video Conferencing	1.5 Mbps
Large files download	100 Mbps
Open science – access to lab and instruments	100 Mbps

Sources: various

Networks must therefore be designed with users' requirements in mind, including research and innovation needs. Optimal bandwidth is typically needed to conduct teaching, learning, research and administration. Researchers need intensely faster file transfer speeds for both uploads and downloads. Blended education requires the streaming of video and actual real-time collaboration and coordination with researchers and laboratories across the globe. This

46 *Discussions with NREN CEOs, July 2020, with specific comments about this from RENU (Uganda), TERNET (Tanzania), SomaliREN (Somalia)*

drives the optimal bandwidth higher and higher.

Various HEIs have tried establishing large computer labs to ensure that each student on campus can get sufficient online access, but this has faced the challenge of sufficiency of access and sustainability. A survey carried out for Sida,[47] for example, showed that the HEIs did not invest the resources required to maintain and replace desktops as they broke down or aged. The conclusion was that this final access needs to be addressed through individual ownership. The necessity for graduation from collective ICT access in colleges through computer labs towards one-to-one computing is more evident throughout the COVID-19 crisis. This highlights the massive efforts needed to avail devices to students and faculty in the coming years.

Access to devices is more acute in Africa, with just about 10% of the population having access to computers at home as shown in Figure 15. The percentage of students with access to computers is often much smaller. Thus, computer access will be an essential prerequisite to delivering connectivity to university end-users.

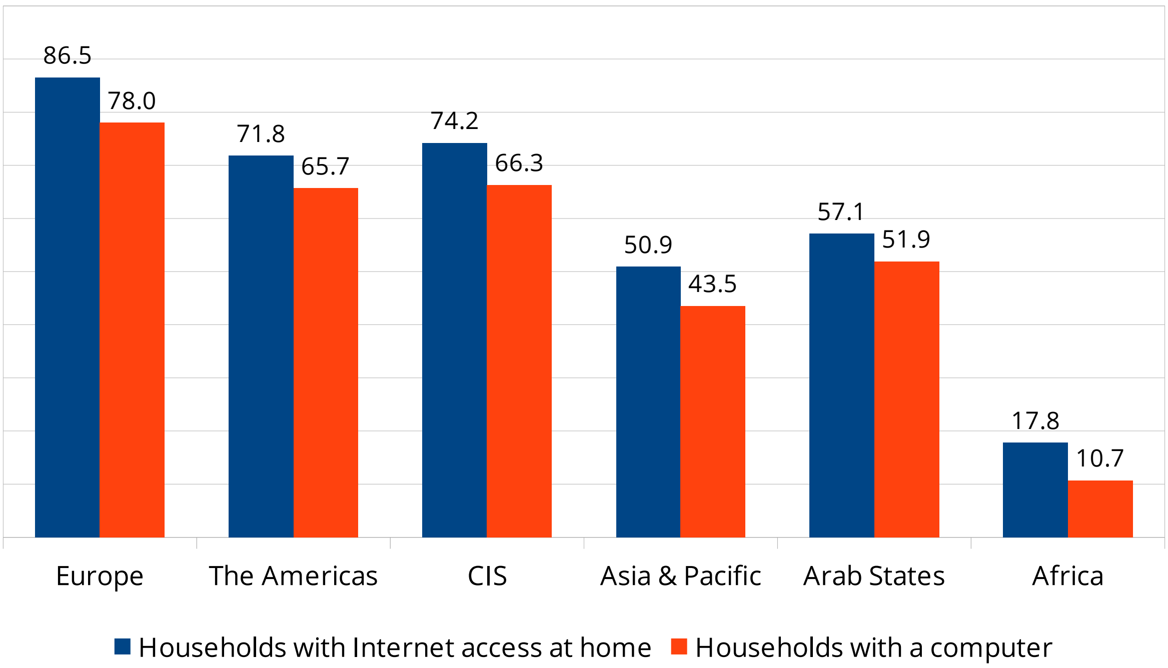

Figure 15: Percentage of households with internet access at home and with a computer

Source: ITU estimates, 2019.

The ability to own a decent laptop, which should be the minimum entry level for students at the higher education level in view of the applications they run and the work they do, is dictated by family wealth. This creates a rich-poor divide, regardless of whether it is a rural or urban campus, compounding the divide that exists among students throughout their educational life.

Another factor that has emerged and has been especially underscored by the COVID-19 pandemic is the need for off-campus access for students, which calls for negotiations with

47 *From assignments carried out for Sida by KCL*

service providers. TENET (South Africa), KENET (Kenya) and MoRENet (Mozambique) are examples of NRENs whose CEOs[48] indicated that they have taken specific steps to enable students to access campus and other online resources through mobile service providers. Outside the COVID-19 lock-downs, this approach has continuing relevance because many African HEIs now have the overwhelming majority of students as non-resident, leaving campus access idle most of the night.

5.6 Challenges and Gaps for Off-campus Online Learning

The uptake of off-campus online education will have significant implications to connectivity outside of HEI campuses. While HEIs in Africa have been offering blended and distance learning options to compliment the traditional in-class learning, during the ongoing Covid-19 pandemic, many governments have closed education institutions and ordered a shift towards virtual learning to limit public gatherings and maintain social distance in order to control the spread of the virus. This has led to substantial growth in e-learning and the use of digital technology to support remote education.[49]

Trends in developed countries indicate that while students opting for online courses are on the rise, those who took online courses also took other courses on campuses, because of the perception that online education may not have a similar level of quality compared to traditional Face to Face (F2F) classroom-based education. A benchmark of the OECD and Europe indicates that the proportion of students that opt for online education is low. In the United States where the uptake of online education is higher, 15% of the higher education students were online in 2017,[50] growing to 16.6% in 2018,[51] a substantial jump from 3.7% in 2007.[52]

In Africa, concerns such as rising costs of higher education and inadequate resources for government to build physical classroom infrastructure in remote places to improve access, point towards increased adoption of off-campus online education, but this alone will not spur uptake. Online education requires reliable connectivity outside HEI campuses, therefore access to reliable Internet connectivity and computing devices like laptops should be addressed.[53]

India provides an ideal location to understand the potential growth trajectory for online education in Africa. According to a recent report by KPMG and Google, the Indian online education market consists of five major categories—primary and secondary supplemental education, test preparation, reskilling and online certifications, higher education and language

48 *From interviews with the CEOs, July 2020.*
49 https://www.elearning-africa.com/reports_surveys_COVID19.php.
50 https://educationdata.org/online-education-statistics.
51 https://nces.ed.gov/fastfacts/display.asp?id=80.
52 https://www.bestcollegesonline.org/faq/how-many-students-take-online-college-courses.
53 *World Economic Forum, 2020. The COVID-19 pandemic has changed education forever. This is how* https://www.weforum.org/agenda/2020/04/coronavirus-education-global-covid19-online-digital-learning.

and casual learning.[54] Of these categories, higher education is the smallest and most nascent, accounting for about 3.5% of the estimated 1.6 million paid users across the Indian online market in 2016. The number of higher education students pursuing an online education in India was a mere 0.2% of the total higher education enrolment in 2016.[55] While this was projected to grow to about 1% of higher education enrolment in 2021, it is likely that Covid-19 has moved the process along a little faster.

Also, there is a growing trend towards Massive Open Online Course (MOOCs) Small Private Open Course (SPOC), but efforts to develop African MOOCs or SPOCs are yet to catch on.[56,57] The MOOCs space is currently dominated by the big four—Coursera, edX, Futurelearn and Udacity, but the proportion of African students signing up for these are expected to be low, particularly if studying for certificates, because individual students must meet their own costs. While efforts have started,[58] these are still limited to South Africa[59] and Northern African countries like Egypt, Morocco and Tunisia.

The development of Study Webs of Active Learning for Young Aspiring Minds' (SWAYAM) in India provides a great example of how such a MOOC can be launched and maintained with access, equity and quality in mind. SWAYAM is an initiative of the Ministry of Human Resource Development (MHRD) and All India Council for Technical Education (AICTE), and Government of India to provide an integral teaching learning platform in online mode.[60] SWAYAM shows the need for extensive coordination among different institutions in the preparation of the content, assessment, accreditation and quality control. Typical online courses involve the development of the syllabi, identification of content writers, enriching the content multimedia supplements (e.g., images, hand drawings, maps, graphs etc.), adding case studies, documentary, clear audio and video, as well as ensuring that the materials adhere to optimal curriculum and copyright requirements. The content should be evaluated and certified before it is widely available.

All of this experience indicates that multiple factors influence the uptake of online education. A well-developed online education system at higher education and national and regional MOOCs can accelerate the uptake of online education—a less than 1% online education uptake in Africa now can jump to at least 5% by 2030. Online education is dependent on the availability of robust a connection at national levels. The African countries where online education is expected to play a major role are therefore the same countries making the most progress in terms of building better digital ecosystems and Internet connectivity to become regional hubs—South Africa, Nigeria and Kenya. South Africa is projected to account for about one-fourth of the African online education market.[61] This implies the importance of meeting connectivity targets discussed above and extending connectivity beyond the confines of tertiary education institutions.

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54 *KPMG and Google, 2017. Online Education in India: 2021 https://home.kpmg/in/en/home/insights/2017/05/internet-online-education-india.html*

55 *Higher education enrolment data in India, 2016-2019 UIS UNESCO*

56 *MOOCs in Africa, https://blogs.worldbank.org/edutech/moocs-in-africa*

57 *https://en.unesco.org/news/unesco-supports-open-moocs-africa*

58 *https://www.atingi.org/en/tool*

59 *https://www.news.uct.ac.za/article/-2020-04-29-massive-uptake-in-mooc-participation*

60 *Majumder, C., 2019. SWAYAM: The Dream Initiative of India and its uses in Education.*

61 *Globe newswire, 2019 The Africa E-Learning Market: Industry Trends, Share, Size, Growth, Opportunity and Forecast 2019-2024*

6. Review of the Challenges

The environment in higher education connectivity is as diverse as the countries involved; therefore, the challenges are specific and contextual. However, it is possible to highlight the overall trends across countries. The survey of NREN stakeholders highlights the high cost of bandwidth, lack of enabling policy and regulatory, capacity and awareness of decision makers and technical personnel among the most critical challenges. Other issues that were raised by NREN stakeholders across Africa include:

- Inadequate campus networks
- Lack of adequate data centres and storage infrastructure
- Absence of IXPs
- Unreliable power supply
- Limited access to devices by students and staff of higher education institutions,
- Limited applications and services,
- Limited technical capacity of network engineers
- Lack of sustainable National Research and Education Networks
- Lack of sustainable funding, especially for National Research and Education Networks.

The regulatory environment is not clear-cut in all countries with regard to NRENs as closed user groups delivering connectivity to higher education institutions. The success of NRENs tends to depend on regulatory maturity and the effectiveness of the interaction between NREN champions, the concerned ministries of higher education, the ministries responsible for the ICT and the regulators.

Like the critical gaps identified earlier, the problems point to areas of potential strategic intervention to create an environment conducive to the achievement of the programme objectives.

In this section, we review the challenges under the two major categories:

i. The Supply Side

ii. The Demand Side

6.1 Supply Side Challenges

The supply side challenges are those issues outside the control of higher education institutions that create barriers or make it more expensive to roll out networks and services. These tend to generally fall under the ministries responsible for ICT (policy and regulation), and the ministries responsible for finance (tax and investment policies and laws).The supply side includes:

i. The large carriers who own marine fibre (that they have also extended to some inland fibre landing stations), for example WACS, EASSy, and SEACOM;

ii. Transnational inland carriers and service providers (Liquid Telecom, regional research and education networks—ASREN, UA, WACREN);

iii. National backbone owners/operators who provide transportation/backhaul services as well as last-mile connectivity (includes owners and/or operators of national backbones; private nationwide networks; utility companies—especially power transmission companies; and NRENs).

The desk study and current interactions with service providers show that the following are the principal supply-side issues that need to be addressed to accelerate connecting higher education in Africa:

i. Taxation
ii. National policy, laws, and regulation
iii. Regional barriers (also includes geospatial challenges)
iv. The shutdown of services by governments
v. Insecurity.

i. Taxation

Taxation impacts all segments of the delivery chain to different extents in different countries. Almost without exception, there is a perennial shortfall in government revenue across all African countries, compounded by heavy reliance on borrowing and substantial debt burdens. The average tax to GDP ratio is still below 18%, compared to that OECD average of about 34% and a Latin American and Caribbean average of about 23%.[62] Therefore, the tax laws use any commercial transaction as an opportunity for increasing revenue through taxation. It is not surprising that in many African countries, telecommunication service providers are routinely the most significant taxpayers. Heavy taxation leads to reduced investment capital availability for network improvement and expansion, higher prices to achieve good returns on investment and lower uptake of services.

Taxation impacts the entire supply-side chain. Based on interactions with NREN CEOs, many NRENs have to pay transactional taxes and have to continually negotiate about corporate tax as their exemption is not always assured. High taxes in any segment of the delivery chain will push up end-user prices and deter investment. What is needed in most African countries is a complete paradigm shift so that at the current stage of sector development, access to high-quality broadband is recognised as a critical input for growth in all sectors and whose cost should, therefore, be minimised: the tax should be imposed on the milk and beef, not on the grass the cow feeds on.

ii. Enabling National Policies, Laws, and Regulations

62 *Based on the OECD Publication, Revenue Statistics in Africa 1990 – 2017 https://www.oecd-ilibrary.org/docserver/5daa24c1-en-fr.pdf?expires=1594821308&id=id&accname=guest&checksum=36A78CC0CB28ECA148B18082EFEAC871*

National policy, laws, and regulations impact the national segments of the delivery chain. There are various aspects of the policy that will affect the supply side, the principal ones being:

i. Investment policy: Outside the ICT sector, all countries are making efforts in this direction with varying amounts of success. Good investment policy aims at eliminating or minimising barriers to investment and creating long-term assurances for investors. Unattractive investment climates will be a barrier to achieving programme objectives,
ii. ICT sector policy, laws, and regulation, especially regarding the availability of class licences that can be acquired through self-qualification and competition regulation (where not provided for as a cross-cutting issue for all sectors). There are still many African countries where individual licences are yet issued and sector policy limits competition. Even where ICT sector policy, laws and regulations are right on its face, regulatory failure, often due to shortage of skills and regulatory capture by the large providers, can make the environment de facto uncompetitive. Studies conducted by Research ICT Africa provide insights into the variation of quality of regulation across the continent.[63]
iii. Policy inconsistencies originate mainly from the desire to increase tax revenue, arising from the finance sector, and the desire to reduce the cost of devices and services from the ICT sector. In most cases, the winner in this tug-of-war is the finance sector, being under pressure to increase the ratio of tax to GDP to what is considered acceptable by multilateral lending agencies. Uganda is a good case in point. (This also relates to taxation discussed above).
iv. Finally, there is an ongoing competition between NREN and operators, especially in countries where the regulatory frameworks do not allow NRENs to operate as Closed User Groups dedicated only to research and education networking. Conventional legal and regulatory frameworks tend to specify licensing conditions for the operation of public networks only. Almost all laws and legal instruments were designed before the advent of research and education networks; therefore, they do not have provisions for closed user group networks like NRENs. The absence of a clear direction on the NREN status and limited provision for closed users' group status implies that emerging research and education networks need to steer the regulation to their advantage by raising the regulators' awareness and working with them.

iii. Regional barriers (also includes geospatial challenges)

Regional barriers originate from inconsistencies in policy, laws, and regulations across national borders, even within the same economic blocks. Each country takes national rather than regional approaches for maintaining independent regulation and maximising revenue from the sector. These barriers hit, especially the transnational operators responsible for rolling out the regional links, a critical element in achieving the programme objectives. As one of the large operators shared, they need about 10 different licences to move data from Mombasa to Kigali, some of them high annual fees, resulting in a high cost build up along the route. Liquid Telecom very specific in a recent presentation[64] about the interest they had in

63 *https://researchictafrica.net/research/research-papers-and-publications/*
64 *See "The African Internet in 2030" from Liquid Telecom*

the African Continent Free Trade Agreement (AfCFTA),[65] so far ratified by 31 countries, which was supposed to come into operation on 1st July 2020. This agreement should gradually reduce regional barriers associated with different aspects of the trade. During our interviews, both Liquid Telecom and SEACOM identified this as one of the major areas of challenges that warrants intervention of multi-lateral organisations like the World Bank.

The dependence of landlocked countries on transit countries for access to submarine cables remains the critical challenge in Africa, with commercial conditions favouring coastal countries. Research ICT Africa[66] and ITU figures indicate that prices in non-coastal downstream countries like Niger, South Sudan, Mali are higher than upstream countries. This is exacerbated by the lack of direct connection between neighbouring countries due to political and other commercial reasons. On the one hand, there is a need for regional solutions to establish fair interconnection and termination arrangements between countries. On the other hand, the competition among cross-border fibre companies will help bring the cost of access in landlocked down.

iv. The shutdown of services by governments

The partial or total shutdown of selected services and quite often the Internet severely disrupts operations and, where it occurs periodically, is a disincentive for investment: it leads to loss in revenue that cannot necessarily be recovered without taking governments to court. It is not correct to lump shutdowns in one common category, and indeed specific research is required for full characterisation[67] However, what is definitive is the increasing frequency and the fact that at least 22 African countries have ordered such shutdowns. This is therefore one of the challenges that needs to be recognised and addressed, challenging as that may be, to mitigate the likely negative impact on the achievement of programme objectives.

v. Insecurity[68]

Insecurity due to internal conflict, regional conflict, or terrorism, wherever it occurs on the continent, hinders or makes more expensive, or completely blocks the rollout of the high-capacity infrastructure, especially fibre, required to deliver universal broadband. There are therefore countries in the continent where achievement of the objectives will either take much longer, or will need to be deferred due to either absence of, or impossibility to roll out infrastructure. The Sahel region, the Horn of Africa, and parts of the Great Lakes region have been particularly prone to continuing armed conflict, terrorism, or both, and will pose a significant challenge in implementation.

65 *https://africa-eu-partnership.org/en/afcfta*

66 *https://researchictafrica.net/ramp_indices_portal/*

67 *See for example "Africa's Internet Shutdowns", http://pcmlp.socleg.ox.ac.uk/wp-content/uploads/2019/10/Internet-Shutdown-Workshop-Report-171019.pdf; and https://cipesa.org/2019/03/despots-and-disruptions-five-dimensions-of-internet-shutdowns-in-africa/*

68 *See for example https://www.nrc.no/shorthand/fr/sahel---the-worlds-most-neglected-and-conflict-ridden-region/index.html, and https://www.ukessays.com/essays/history/conflict-in-horn-of-africa-causes-and-solutions-history-essay.php*

6.2 Demand Side Challenges[69]

HEIs and their staff and students (the end-users) can be regarded as consumers, the point where the benefit of broadband connectivity is actualised. Demand side challenges tend to fall under the ambit of the ministries responsible for education, and the leaders of HEIs.

The challenges faced at this level fall among the following key categories:

- Absence of ICT policies and strategies that link investments in ICT to learning and research;
- Sustainability;
- Shortage of computers and laptops, compounded by limited digital literacy;
- Technical competence to implement, maintain and expand services and systems; and
- Inability to translate broadband to benefit through improved learning and research outputs and outcomes.

Translation of broadband into benefit through enhanced learning and research outputs and outcomes is addressed in a separate Report.

i. Absence of ICT policies and strategies that link investments in ICT to learning and research

There are many institutions where the approach to rolling out ICT services and systems is handled casually, and piecemeal without any overarching policy and strategy grounded in the why of learning and research. The required outlays and the expertise demand are not recognised in advance. Unfortunately, implementation is often approached as a technical matter in the hands of engineers instead of a business undertaking in the hands of those (academics and support units) who own the institutional business processes. The result is increasing disillusionment, and budget cutbacks as an increasing investment does not benefit the business of the universities, or as expensive systems simply fail. The participatory formulation of institutional ICT policies and strategies is a foundational gap that will need to be addressed for most institutions.

ii. Sustainability

Education generally and higher education in Africa, right from TVET levels, is severely underfunded, and institutions always struggle to meet costs. This is compounded by the contradiction of requiring especially public institutions to increase intakes to meet political targets with constant funding in the face of escalating costs. A consequence is that while many willing development partners have come in to help especially the larger national universities roll out campus networks along with ICT services and systems, and in many cases large computer labs for student use, such infrastructure is often neither maintained nor

69 *The assertions here are based on the Consultant's experience in evaluating and guiding on the implementation of ICT services and systems in universities within Africa, Asia, the Caribbean, and South America.*

replaced and is left to degrade over time until it is unusable. Sufficiency of funding maintenance and expansion is, therefore, an aspect that needs to be carefully examined before interventions are implemented.

Unfortunately, it is not just insufficiency of funding that leads to neglect of ICT infrastructure: many institutions still suffer from limited high-level awareness of the potential benefits of excellent ICT services and systems, which places these among the bottom priorities. A positive factor is that students are generally willing to pay user fees to ensure access to connectivity to the Internet and to services if HEIs could develop a culture of ring-facing such contributions.

Sustainability also brings in the structure of price in the market. Most service providers, especially where there is monopoly or oligopoly of infrastructure refuse to offer Indefeasible Rights of Use (IRUs), instead preferring a retail basis. Negotiation of an IRU will bring the cost of access down, making it cheaper for research and education institutions in the long term than the direct purchase of bandwidth from operators.

iii. Shortage of computers and laptops, compounded by limited digital literacy;

As discussed in Chapter 5, the only sustainable solution to end user access is universal personal ownership of laptops that have the capability to handle the applications used and the work done at higher education level. Tertiary institutions, especially the private ones, are increasingly making it a requirement for students to have laptops, which marginalises those from poor families but at the same time has pushed up ability to access services at the personal level. Political considerations make it difficult to apply this to government institutions. It is therefore evident that this is one of the key areas to be addressed if all the upstream investments are to achieve the desired outcomes.

Related to the shortage of computers and laptops is digital literacy. Due to limitations in facilities at the secondary school level, a large of students who enter higher education institutions, and likely the majority, have at best just basic computer skills, and at worst, no previous exposure to computers. This calls for interventions within the first six months to move everyone ton basic computer skills to digital literacy and over time to digital fluency. The challenges around this and how it should be addressed are discussed in another Report.

iv. Lack of technical competence to implement, maintain, and expand services and systems

A major underlying cause for the absence of a competent human resource is the lack of appreciation for ICT expertise. There are many institutions where technical skills, regardless of area of competence, are lumped at the same level, meaning that HEIs pay scales well below what the growing private ICT sector pays, meaning that they cannot recruit competent personnel; and that even if they invest in training, such people leave for the private sector at the earliest opportunity. This is compounded by insufficient budgets as discussed under sustainability, but insufficiency of budgets is not the underlying cause.

7. A Review of Previous and Existing Programmes on University Connectivity Agenda

There have been, and there are different higher education connectivity projects sponsored by the government, private sector, bilateral and multilateral institutions. Historically, multilateral development organizations, foundations or multinational companies were actively engaged in supporting the advancement of higher education connectivity in Africa. These include, among others, the Partnership for Higher Education in Africa which supported the African Bandwidth Consortium; The Leland Initiative, funded through USAID, which provided wireless backbones to campuses in selected countries; Fostering Research and Education Networking in Africa (FRENIA) funded by the Andrew W. Mellon Foundation which provided funding for the start-up of NRENs in Africa; and the International Development Research Centre which provided initial funding for NREN development and fostered the creation of Regional Research and Education Networks including the UbuntuNet Alliance and the West and Central African Research and Education Network. The World Bank and the Open Society Foundations have also been supporting connectivity for higher education institutions. Burundi, Mozambique, Tanzania, Somalia, Malawi, and Nigerian NRENs[70] are among the beneficiaries from the World Bank support. While not planned directly for university connectivity, the World Bank Regional Communications Infrastructure Project[71] (RCIP) has benefited HEIs in Rwanda, and much earlier on, Kenya. The Open Society Foundation and Open Society Initiative of South Africa have provided support to the UbuntuNet Alliance.

Foundations such as the Bill & Melinda Gates Foundation, Carnegie Corporation, Rockefeller Foundation, Ford Foundation, John D. and Catherine T. MacArthur Foundation, William and Flora Hewlett Foundation and Andrew W. Mellon Foundation have been playing roles in the development of the capacity of higher education institutions in Africa. These foundations did not only provide funding but also carried out considerable analysis into the problems of connectivity, content and knowledge sharing between academic and research institutions and libraries in Africa.

Other partners of higher education connectivity include:

- Multinational companies including CISCO, Google, Intel, Juniper Networks and Microsoft that provided tools,
- Research networks that provide technical assistance – GEANT Association, Red CLARA and Internet 2 that provided technical support,
- The Network Startup Resource Centre at the University of Oregon that played a major role in training NREN engineers on network management,

70 *The support to Tanzanian universities was directed through a government Ministry. It subsequently ran into challenges of sustainability.*

71 *https://www.worldbank.org/en/search?q=Regional+Communications+Infrastructure+Program*

- The African Internet Registry (AfriNIC) in the delivery of IP numbers and other resources

Table 11: Major partners for university connectivity projects in Africa

Focus area	Major Partners	Support	Remarks/Lessons
Capacity building	NSRC, ISOC, GÉANT (DANTE, TERENA), Red CLARA, OSI, CISCO, European Union	Direct technical training and support, financial support for capacity building, sponsorship for participants, equipment to roll out networks	While NSRC, ISOC, and CISCO provide direct training opportunities, GÉANT and more advanced NRENs open opportunities for bilateral collaboration or twinning that have been a major source of learning at the management and operational levels, especially through attachments and secondments that are needs driven. The Cisco academies established around Africa have provided a lot of training (CCNA and CCNP) for networking professionals. A sizeable portion of EU funding is dedicated to capacity building
Content	Foundations such as Carnegie, Hewlett, Bill and Melinda Gates, Ford Foundation, PHEA Other institutions such as: INASP	Support to specific research institutions	It should be noted that the initial major drive for connectivity was driven by the need for easier access to global information resources, and the Carnegie Corporation of New York was a major player in driving the formation of the Partnership for Higher Education in Africa.
Internet resources	AfriNIC	ASN, IP Numbers	AfriNIC, through negotiations led by the Research and Education Networking Unit of the Association of African Universities, agreed on a discount of 50% on the costs of ASNs and IP addresses for the REN community in Africa.
NREN development	Andrew W. Mellon Foundation, European Commission, World Bank, Canada (IDRC)	Bilateral funding	Development partner funding normally covers costs of travel and board. The actual knowledge and experience support has been donated by more advanced NRENs or RREN through discussions; attachments; and secondments. While a significant of this has been from outside Africa, the major part has been intra-Africa.
Regional network development	European Commission	Financial resources for	Until the funding of AfricaConnect, EC had never funded IRUs. Earlier

		capacity building and IRU for fibre	initiatives to support REN growth and connectivity (South America, Asia, Northern Africa and the Middle-East) focused on recurrent payment for bandwidth, which meant that funds were exhausted without creating sustainability. The UbuntuNet insisted on IRUs, leading to a delay of almost 2 years before EC gave consent. IRUs are now a common feature of GÉANT connectivity procurements.

Sources: various

The number of donor agencies and the scope of support has been dwindling in recent years. The European Commission, NSRC and the World Bank remain the most active space in the academic and research connectivity space.

7.1 European Commission (AfricaConnect)

The AfricaConnect project is in its third phase is by far the most active project in the continent for connecting HEIs in Africa. AfricaConnect that run between 2011 and 2015 began when most of the research and education networking activity was just starting. The focus of the first phase was building connectivity and development of NREN capacity in the eastern and southern African sub-region. To participate in the project, NRENs were required to pay a partner contribution that started at 20% of the total budget. The EC policy is for this to increase subsequent new support (AfricaConnect—20%; AfricaConnect2—25% ; AfricaConnect 3—variable, averaging 20%) of the access cost, register in the European Commission database, and sign a bilateral contract, service confirmation form and a “Principle of Good Membership” agreement. AfricaConnect2 that was run between 2015 and 2019 built on the connectivity in eastern and Southern Africa, as well as Northern Africa to extend high-capacity links in Western and Central Africa. Through capacity building and advanced network connectivity and services, AfricaConnect2's mission was to contribute to sustainable development and a more inclusive Information Society across the whole African continent.

The third phase, AfricaConnect3, that began in 2020, builds onto the predecessor projects in supporting the creation, development and use of advanced, reliable internet connectivity for the teaching, learning and research communities of Africa. AfricaConnect3 is co-funded by the European Union and delivered locally by RRENs—UbuntuNet Alliance, WACREN and ASREN, together with GÉANT.

Source: https://www.africaconnect3.net/?page_id=112

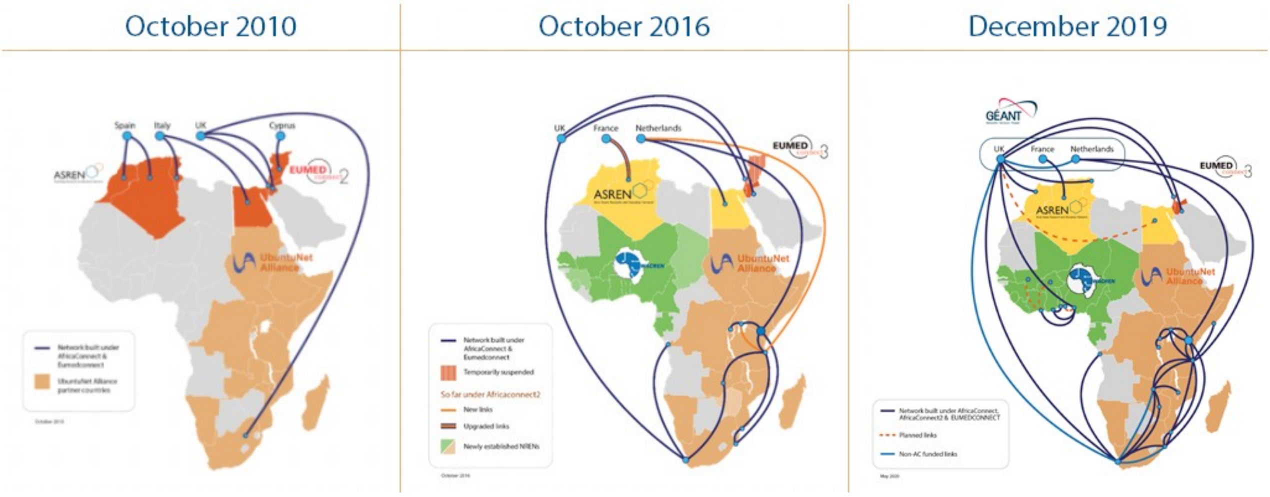

Figure 16: Progression in NREN development over AfricaConnect Period

7.2 African Development Bank

The African Development Bank (AfDB) has funded a number of higher education projects to improve Science, Technology and Innovation (STI). Guided by the New Education Model in Africa (NEMA), that emphasises ICT-based delivery as a central component that is adapted to different country contexts, the AfDB has funded ICT infrastructure (networks and computers) and training to help improve the delivery and quality of STI programs in higher education institutions. These include:

- Malawi: Support to Higher Education, Science and Technology (HEST) that also developed network infrastructure to interconnect beneficiary higher education institutions to facilitate the sharing of digital learning resources
- Uganda: Support to Higher Education, Science and Technology (HEST) Project that invested in network infrastructure and setup of computer laboratories to increase access and quality of training in science and technology programmes in six public universities and two degree-awarding higher education institutions in Uganda
- Kenya: Support to the enhancement of quality and relevance in Higher Education, Science and Technology (HEST) project provided investments in computing labs, video conferencing facilities and the integration of ICT to support learning and networking among beneficiary universities across the country
- Rwanda: Building Rwanda’s Regional ICT Center for Excellence, a tripartite partnership between AfDB, the Government of Rwanda and Carnegie Mellon University to develop critical technical skills in ICT
- Capacity building in Open and Distance Learning (ODL) to develop and deploy ODL content across SADC region through centres of specialisation in Malawi and Tanzania
- The African Virtual University (Phase II) that invested resources to improve ICT infrastructure and capacity in beneficiary higher education institutions in 22 participating African countries.

7.3 Network Startup Resource Center

The Network Startup Resource Center (NSRC) at the University of Oregon which is funded by the NSF's International Research Network Connections (IRNC) program has also been active in building human resource capacity, with emphasis focused on collaborations with African NRENs and universities. The NSRC assists African HEIs to develop their campus network infrastructure in a manner that allows the university to connect to Internet Service Providers, local Internet Exchange Points, and National Research and Education Networks (NRENs).

Some of the critical lessons that are drawn from the AfricaConnect project and the NSRC support include:

i. **NRENs are the primary model of higher education connectivity. Still, their readiness takes time.** The AfricaConnect programme's experience shows that several ingredients such as government support, internal commitment, and availability of resources need to fall in place before NRENs become ready. Having NREN champions is an important step, but the actual breakthrough often comes when a high-level government's support is secured, and university administrators commit to developing collaborative research and education networking.

ii. **The infrastructure and commercial conditions dictate connectivity.** Regional interconnection between NRENs and HEIs largely depends on available infrastructure from the operators and the ability of higher education institutions to band together and negotiate for better prices collectively. The experience of the AfricaConnect suggests that the presence of regional carriers of carriers like the WIOCC, Liquid telecom and extensive and iterative negotiation with service providers is essential for the evolution of a viable regional network. The ultimate regional backbone network that connects to GÉANT depends on the options available from service providers.

iii. **Capacity-building should go hand in hand with NREN development.** The AfricaConnect and NSRC promote capacity building for engineers and NREN partners as a critical aspect of regional connectivity. In addition to direct training provided at NREN levels, the UbuntuNet Alliance and WACREN's annual meeting offers a platform for training the trainer workshops on internetworking technologies that have increased the critical mass of NREN technical experts in the region. The training of a critical mass of experts has been the most crucial outcome for extensive NRENs growth in the WACREN and UA regions.

7.4 Key Lessons

A review of the different initiatives brings out the following key lessons:

i. The need for collaboration: all the efforts around access, capacity, and content focus on the same end beneficiaries. Most of them are however isolated from each other, losing potential synergy. The WBG initiative should make an effort to bring all stakeholder around an integrated plan of intervention. The PHEA is noteworthy for bringing key American private foundations together around common causes; and the AfricaConnect programmes have had collaboration involving DANTE and TERENA (later GÉANT Ltd) with NSRC and ISOC. It should be noted that this collaboration is driven from the African NRENs and RRENs.

ii. The need for beneficiary contribution and driving direction: The AfricaConnect initiatives have demonstrated beneficiary contribution as a key aspect of sustainability. They have also been responsive to beneficiary needs and direction, with outside expertise bringing on board especially procurement and communication skills. The procurement of IRU is a good case in point. Networks, certainly in the Alliance region, have been implemented and are operated by the owners.

iii. Government support: Many of the NRENs are challenged by the need to contribute to any initiative, and the smaller ones much more so. This does not reduce the necessity of such contribution, but rather points to the need to get government commitment to counterpart contribution before any intervention. Where governments are not interested, investments will not be sustainable.

8. Summary and Conclusion

The WBG initiative is an opportunity to address the perennial challenge of connectivity to African institutions of higher learning in a sustainable fashion. This Chapter presents a summary of the key findings and recommendations to achieve the objectives.

i. The Vision was formulated based on the aspirations and recommendations of key stakeholders:

   "An African continent where all higher education institutions achieve global parity in intellectual output and development impact through access to, and exploitation of broadband connectivity at capacities, quality, and costs comparable to the rest of the world."

   To link this to benefit requires that these African institutions simultaneously develop the necessary pre-conditions to ensure that sufficiency and affordability of broadband can be seized as opportunities to improve learning and research outcomes, as well as employability in the context of the fourth industrial revolution.

ii. While the connectivity initiative targets primarily HEIs, the beneficiaries should be extended to include research centres; teaching hospitals; libraries that serve the higher education sector; and the policy, regulatory, and standards agencies.

iii. Taking 200 Mbps per 1,000 users as a lifeline minimum during 2020, rising to 2 Gbps per 1,000 users by 2025, and to 20 Gbps per 1,000 users by 2030 provides, the progressive estimates for global connectivity for higher education are 3.0 Tbps in 2020, 39.6 Tbps in 2025 and 565 Tbps in 2030. The estimated bandwidth gap in 2020 is 2.4 Tbps.

iv. There are challenges and gaps at the five levels of connectivity: global; regional; national; campus; and user.

   a) **Global level:** Although the cost of bandwidth has come down, Internet access in Africa is still more expensive compared to other regions of the world, and often less reliable, as one moves inland from the coast. In 2019, the 5 largest carriers operated 41% of all international connectivity to Africa compared to a World average of 29%, highlighting the high degree of market concentration.

   Africa's global connectivity has achieved tremendous growth over the last 15 years only because it started from almost nothing The reality that is that with a continental average 9 Mbps per 1,000 users, compared to say Oceania's 130 Mbps per 1000 users, Africa is still in a very depraved position. The limited penetration of large data centers means that Africa still largely imports content from other parts of the world, which requires expensive international transit. This is compounded by the limited penetration of IXPs.

b) **The Regional Level:** By June 2020, the amount of operational fibre-optic network reached 1,072,649 km compared to 622,930 km in 2015. By the same date, there was a further 119,496 km of fibre optic network under construction, 95,057 km of planned fibre and 69,702 km of proposed fibre. What is visibly limited is cross-border fibre.

Despite multiple harmonisation efforts, countries in Africa, even within the same economic blocks, still have different ICT-sector policy and regulatory environments and varying financial and taxation policies with which operators must be compliant. The challenges of regional transit and cost were especially raised as a top priority for inland prices to come down, the key to this being the African Continental Free Trade Area being fully ratified and operationalised. Limited competition in backbone infrastructure (de facto monopoly, either private or public) in any of the countries through which a cable must transit also leads to high transit costs.

As a result of either the near absence of competitive terrestrial east-west and north-south cables, routing of traffic from east to west or south to north has tended to rely on marine fibre that, while being much cheaper, also introduces high levels of latency due to the much longer paths.

RRENs are also key players at the regional level. Africa is covered by three major RRENs: the Arab States Research and Education Network (ASREN) that connects North Africa but whose core members are outside Africa; the West and Central African Research and Education Network (WACREN), and the UbuntuNet Alliance (UA). With the possible exception of TENET in South Africa, where the government for a long time has had a significant focus on research funding, all NRENs that have made substantial progress in Africa have benefited from working through the regional models through which they initially aggregate bandwidth. Significant connectivity gaps in Africa are associated with the maturity and effectiveness of the RRENs. UA is the most advanced RREN in Africa. It is not surprising that HEIs in this region (even with the exclusion of South Africa) generally have much higher bandwidths at much lower prices.

c) **National level:** Whatever cost estimate is used for connecting in any country, there needs to be sufficient national backbone coverage for national transport, and adequate network Points of Presence (PoPs) to enable last-mile connectivity. While many countries have seen significant deployment of their national backbones that have enabled connection to major cities—where most higher education institutions are located, last-mile connections to institutions outside of major cities are still a big challenge.

34 out of 54 African countries have at least one IXP in the country to help facilitate local traffic exchange and save expensive international transit. In 2010, the Internet Society's team in Africa set a target endorsed by the African IXP Association to localise 80% of Internet traffic at both national and regional levels by 2020. At a country level, this has only been achieved by South Africa, with Nigeria and Kenya at about 70% of their traffic exchanged locally. Coverage of other important components of the infrastructure ecosystem that support connectivity like fibre backbone networks and carrier-neutral data centres is also still inadequate. All African countries report having some form of fibre backbone with Eritrea having the shortest length with 74 km and South Africa having the most extensive fibre coverage with 278,000 km. In terms of carrier-neutral data centres, 13 out of 54 African countries have at least one carrier-neutral data centre with South Africa having 21 of these followed by Nigeria and Mauritius with 10 each and Kenya with 7 data centres.

Some of the policies that can help to increase competition and drive down costs at the national level include: eliminating monopolies; reducing the cost of licences; enforcing shared use of telecom infrastructure; civil-works and access to the alternative infrastructure provided by transport and energy operators; legislating for the protection of critical infrastructure, including ensuring sufficient compensation for fibre cuts; eliminating or reducing taxes on communication and communication equipment; and deploying universal access funds to enable broadband in remote and sparsely populated areas.

The importance of NRENs, especially in the early stages of connectivity development is evidenced by the fact that countries with the best-connected HEIs also have the strongest NRENs. Strong NRENs tend to be those owned and managed by university consortia while receiving major funding support from the government or government agencies. TENET of South Africa is easily the best example of this. The absence of an effective NREN in any country is, therefore a major gap. It should be noted that REN connectivity is so different from commercial internet connectivity that any price comparison is fallacious: the approaches to capacity dimensioning; cooperation and collaboration across the globe; seamless national and global roaming centred around identity federation; and services that ride on top of all this place REN connectivity in a category of its own.

From 2020 (current) data, the best-connected campuses in a sample of countries range from 155 Mbps (Gabon), 200 Mbps (Ethiopia), 300 Mbps (Nigeria) at the low end; to 1 Gbps (Senegal), 2 Gbps (Uganda), 3 Gbps (Morocco and Kenya), and 50 Gbps (South Africa) at the higher end.

d) **The Campus and User levels**: The need to improve and strengthen all infrastructure associated with campus networks, and increasing technical competence of the human resource was acknowledged by all respondents as the key priority, with most putting it as the top priority, and a small number as a second priority. Closely related to this are the other priorities of ensuring that end-users have owned laptops that they can use on or off-campus; ensuring that off-campus coverage is provided to address the large numbers of non-resident students as well as addressing periods when, either due to regular closure or emergencies like COVID-19, campuses are closed; developing institutional policies and strategies that ensure that services can be exploited for improved learning and research outcomes; and ensuring sustainability of infrastructure and services.

v. There have been multiple connectivity initiatives over the last twenty years. The current major initiatives include the European Union through the AfricaConnect3 programme (whole of Africa); the World Bank through the RCIP programme that has enabled university connectivity as a benefit of networks rolled out, and specific programmes to support NRENs (Benin, Burkina Faso, Egypt, Ethiopia, Gabon, Ghana, Kenya, Nigeria, Malawi, Mozambique, Somalia, Tanzania and Uganda); the Network Startup Resource Center which is a key capacity building partner to all African RRENs and NRENs; and ISOC, working in and often together with NSRC on capacity building. The following key lessons from previous and current initiatives are noteworthy:

a) The need for collaboration: all the efforts around access, capacity, and content focus on the same end beneficiaries. Most of them were however, isolated from each other, losing potential synergy. The WBG initiative should make an effort to bring all stakeholder around an integrated plan of intervention.

b) The need for beneficiary contribution and driving direction: The AfricaConnect initiatives have demonstrated beneficiary contribution as a key aspect of sustainability. They have also been responsive to beneficiary needs and direction, with outside expertise bringing on board, especially procurement and communication skills.

c) Government support: Many of the NRENs are challenged by the need to contribute to any initiative, and the smaller ones much more so. This does not reduce the necessity of such contribution, but rather points to the need to get government commitment to counterpart contribution before any intervention. Where governments are not interested, investments will not be sustainable.

d) While the summary above is rich in areas for intervention, we emphasize the following challenges that the WB initiative should take up:

I. Supply Side Challenges (that affect all service providers including RRENs and NRENs)

Taxation: Taxation impacts all segments of the delivery chain. Heavy taxation leads to reduced investment capital for network improvement and expansion, higher prices to achieve good returns on investment and lower uptake of services.

Enabling National Policies, Laws, and Regulations: National policy, laws, and regulations impact the national segments of the delivery chain. This includes Investment policy; ICT sector policy, laws, and regulations, especially regarding the availability of class licences; Policy inconsistencies that originate mainly from the desire to increase tax revenue, arising from the finance sector, and the desire to reduce the cost of devices and services from the ICT sector; and the sometimes-aggressive competition between NREN and operators, which operators always win.

Regional barriers: Regional barriers originate from inconsistencies in policy, laws, and regulations across national borders, even within the same economic blocks. The African Continent Free Trade Agreement (AfCFTA) is a key piece in addressing this.

The shutdown of services by governments: The partial or total shutdown of selected services and quite often the Internet severely disrupts operations and, where it occurs periodically, is a disincentive for investment: it leads to loss in revenue that cannot necessarily be recovered without taking governments to court.

Insecurity: This is really just a reality to be recognised. Insecurity due to internal conflict, regional conflict, or terrorism, wherever it occurs on the continent, hinders or makes it more expensive, or completely blocks the rollout of the high-capacity infrastructure, especially fibre, required to deliver universal broadband. The Sahel region, the Horn of Africa, and parts of the Great Lakes region have been particularly prone to continuing armed conflict, terrorism, or both, and will pose a significant challenge in implementation.

II. Demand Side Challenges

Absence of ICT policies and strategies that link investments in ICT to learning and research: There are many institutions where the approach to rolling out ICT services and systems is handled casually, and piecemeal without any overarching policy and strategy grounded in the why of learning and research. The participatory formulation of institutional ICT policies and strategies is a foundational gap that will need to be addressed for most institutions.

Sustainability: Education generally and higher education in Africa, right from TVET levels, is severely underfunded, and institutions always struggle to meet costs. Sufficiency of funding maintenance and expansion is, therefore, an aspect that needs to be carefully examined before interventions are implemented. Unfortunately, it is not just insufficiency of funding that leads to neglect of ICT infrastructure: many institutions still suffer from limited high-level awareness of the potential benefits of excellent ICT services and systems, which places these among the bottom priorities.

Shortage of computers and laptops, compounded by limited digital literacy: The only sustainable solution to end user access is universal personal ownership of laptops that have the capability to handle the applications used and the work done at higher education level. It is therefore evident that this is one of the key areas to be addressed if all the upstream investments are to achieve the desired outcomes. Related to the shortage of computers and laptops is digital literacy. The challenges around this and how it should be addressed are discussed in another Report.

Lack of technical competence to implement, maintain, and expand services and systems: A major underlying cause for the absence of a competent human resource is the lack of appreciation for ICT expertise. This is compounded by insufficient budgets as discussed under sustainability to hire and retain competent personnel.

In conclusion, there must be initiatives to address the multiple gaps and challenges identified in this analysis if the desired outcomes are to be achieved. Since the challenges identified fall under different government ministries (ICT, Education, and Finance) as well as the leadership of HEIs, these should be recognised at the outset as key leaders and partners in the planning and implementation of any intervention. The required initiatives are discussed further in the second report under this study, **"Cost Model and Cost Estimates for Connecting All African HEIs to High-Speed Internet."**

Appendix A: Findings from Interviews with Stakeholders

As part of our data collection, we engaged mainly the CEOs of NRENs and RRENs at the thought level to get their views on various key aspects of the WBG initiative. The findings summarised here were derived from interviews with the CEOs of NRENs from 17 African countries; the 3 RRENs that cover Africa—Arab States Network (ASREN), West and Central African Research and Education Network(WACREN), and UbuntuNet Alliance(UA); two major backbone services providers—Liquid Telecom and SEACOM; the Internet Society (ISOC); and the Network Start-up Resource Center (NSRC); Many Possibilities. The full list is given at the end.

Two questions were put to each as part of a probing semi-structured discussion, the second one having three parts. All discussions were via an online platform, apart from one who responded to the questions, if full detail, in writing.

Question 1: Broadband is an elusive moving target. In your view, how should we define broadband for African universities—looking at the year 2025? What bandwidth do you currently recommend as bandwidth per 1,000 students, and what do you expect this to be by 2025?

There were both qualitative and quantitative approaches responses to this question. Four gave qualitative definitions:

- SLREN (Sierra Leone)—Ability of students to connect to their peers anywhere in the world;
- ISOC—Ability to have the same quality of internet access wherever you are in the world;
- Liquid—Broadband should be fast, affordable, and unlimited for any need;
- TENET—Sufficient bandwidth to be able to use the prevailing applications of the day.

Examples of the quantitative measure included:

- UbuntuNet Alliance—Current desirable should be 2Gbps/1000 increasing to 5 GB/1000 by 2025, with each university having at least 10Gbps.
- While there is an extensive variation in current connectivity, a general aspirational target by 2025 or earlier is 1Gbps per 1000 students, but some, like South Africa and Madagascar, are looking to 10Gbps/1000 by 2025. TENET currently connects universities at 10Gbps (and their smaller campuses at 1Gbps; research institutions are connected at 50Gbps and are working on their first 100Gbps connection).
- A minority of the NRENs had very modest aspirations, but these were generally the

ones that face current challenges in getting access. EthERNet, for example, has a 10Gb backbone and an aggregation router that can handle 40Gb—but they cannot provide external access to which Ethio Telecom has a monopoly. Addis Ababa University, with about 50,000 students now has 400Mbps and is upgrading to 1Gbps. Some countries had very modest projections.

Question 2: With your deep knowledge of your country and NREN, if opportunity through funding support were to be availed for connecting all universities and TVETs:

Part 1: What are the critical aspects that you would recommend addressing?

i The commonest priority raised was the quality of and access to campus networks, and the technical capacity at campuses – with 11 of the interviewees highlighted this as the major bottleneck. This also included, in a smaller number of responses where the challenge of last mile connectivity.

ii Closely related to the campus network bottleneck was the challenge of enabling access for the large population of students who do not reside on campus, now extending to all students because of the education lock-downs in response to COVID-19. TENET, MoRENet, KENET, and RENU have been creative for this and have implemented solutions. RENU for example has implemented a solution that works over the metro-networks of one on the service providers (see Country Case Study Report) to provide Eduroam.

iii Five respondents pointed to the challenges of limited or monopoly national providers and/or poor regulation.

iv Five NRENs pointed to the challenge of both capacity of NRENs in terms of human resource and funding. Only one, EthERNet raised the challenge of global connectivity where regulation gives Ethio Telecom a monopoly.

v The challenges of regional transit and cost were especially raised by ISOC, Liquid Telecom, and SEACOM as a top priority for inland prices to come down - referencing the delays in getting the African Continental Free Trade Area fully ratified and operationalised. Another challenge raised by the three was the absence of significant inland data centres that would have both attracted carriers to roll out major capacity inland and would maximise keeping traffic local (also reducing transit times).

Part 2: How would you recommend this initiative is handled in your country?

a) Many placed emphases on cultivating good relationships with government, and it is evident that almost all NRENs have invested a lot of effort in cultivating relationships with their governments—but the specific government entities to work with changed from country to country due to either formal government arrangement, or long-established relationships.

b) Several indicate the operators should be consulted as partners in any implementation initiative.

c) Only two—one RREN and the other a service provider, had a preference for implementation though the RREN and NRENs.

It is likely that the preference for government agencies founded on awareness that WBG works through governments.

Part 3: What major challenges to the initiative would you anticipate?

i. The commonest challenge that came up was sustainability after implementation, and this has to be considered during the business plan formulation.

ii. At the campus levels, the common challenges cited by many included university level acceptance and use of digital tools for teaching and learning in order to gain value from the connectivity; poor networks and lack of capacity, both technical and user; poor campus networks; and limited funding compounded by high costs of academic content as well as broadband, and taxation on equipment and connectivity.

iii. Another challenge was limited ownership of end-user devices and access off-campus, especially access by non-resident students (and during lock-downs, by all students) who have to use expensive mobile data. In other words, improved campus networks would be of little value if end-user access is not addressed.

iv. At the NREN level, technical capacity is a challenge for the younger NREN. NRENs in some countries also face the challenge of not being supported by government, which has in a few cases actually led to governments setting up government-owned NRENs or other arrangements.

v. Challenges at the national level often include poor or limited backbone infrastructure which marginalises especially institutions in rural settings; limited access to power in some locations; difficulty of establishing last mile connectivity; high cost of broadband caused by poor policy and regulations, conflicting government policies; and heavy focus on primary and secondary education with limited funding especially for university education.

vi. Major challenges cited by operators include the absence or weakness of policy and legal regimes to address destruction of their fibres dues to many civil works now happening in many countries. They also face the challenge of poor licensing regimes.

vii. At the implementation level through governments, worries were expressed about corruption, high cost (service providers see donor funded projects as an opportunity for making a lot of money), and difficulties in getting IRU pricing were cited.

Interviewees:

	NRENs	Interviewees
	African NRENs	
1	Burundi (BERNET)	Dr Grégoire Njejimana and Mr Pierre-Claver Rutomera
2	Côte d'Ivoire (RITER)	Dr Issa Traoré
3	Ethiopia (EthERNet)	Mr Zelalem Assefa
4	Gabon (GabonREN)	Prof Ousmane Balira Konfe and Mr Anicet Andjouat
5	Ghana (GhREN)	Mr Benjamin Eshun
6	Ghana (GARNET)	Mr Lucas Chigabatia and Mr Emmanuel Togo
7	Kenya (KENET)	Prof Meoli Kashorda
8	Madagascar (iRENALA)	Dr Harinaina Ravelomanantsoa
9	Malawi (MAREN)	Mr Solomon Dindi
10	Morocco (MARWAN)	Prof Redouane Merrouch
11	Mozambique (MoRENET)	Dr Lourino Chemane
12	Nigeria (NgREN)	Dr. Joshua Atah; Dr Patricia Eromosele and Mr Gaurav Gupta
13	Senegal (SnRER)	Prof. Ibrahima Niang
14	Sierra Leone (SLREN)	Mr Thomas Songu
15	Somalia (SomaliREN)	Mr Abdullahi Bihi Hussein
16	South Africa (TENET)	Dr Duncan Greave
17	Tanzania (TERNET)	Dr. Magreth Mushi
18	Uganda (RENU)	Mr Nicholas Mbonimpa
	Other NRENs	
1	GRENA (Georgia)	Dr Ramaz Kvatadze
2	AMRES (Serbia)	Dr Bojan Jakovljevic
3	JISC (UK)	Dr Rob Evans
4	RNP (Brazil)	Dr Eduardo Cezar Grizendi
5	Red CEDIA (Ecuador)	Dr Juan Pablo Carvallo
6	CENIC (California)	Dr Louis Fox
	RRENs	
1	UbuntuNet Alliance	Mr Tiwonge Banda and Mr J Kimaili
2	ASREN	Dr Yousef Torman

3	WACREN	Dr Boubakar Barry
4	GÉANT	Ms Cathrin Stöver
5	Red CLARA	Dr Luis Escadenas
	Major Backbone Services Providers	
1	SEACOM	Mr Michael Otieno
2	Liquid Telecom	Mr Ben Roberts
	Main Internet Actors	
1	NSRC	Dr Steve Huter and Mr Steve Song
2	ISOC	Mr Michuki Mwangi

Appendix B: NREN Survey

As part of the gap analysis, KCL conducted interviews and a survey with NRENs across the continent. In this section, we summarise responses from the survey.

Membership and Governance

NRENs in Africa serve a wide range of members, predominately composed of educational institutions. All NRENs (100%) serve universities, 85% serve research institutions while 75% serve TVETs as depicted in Figure 17. Other types of institutions include bodies associated with the educational sector like examination bodies and education regulators.

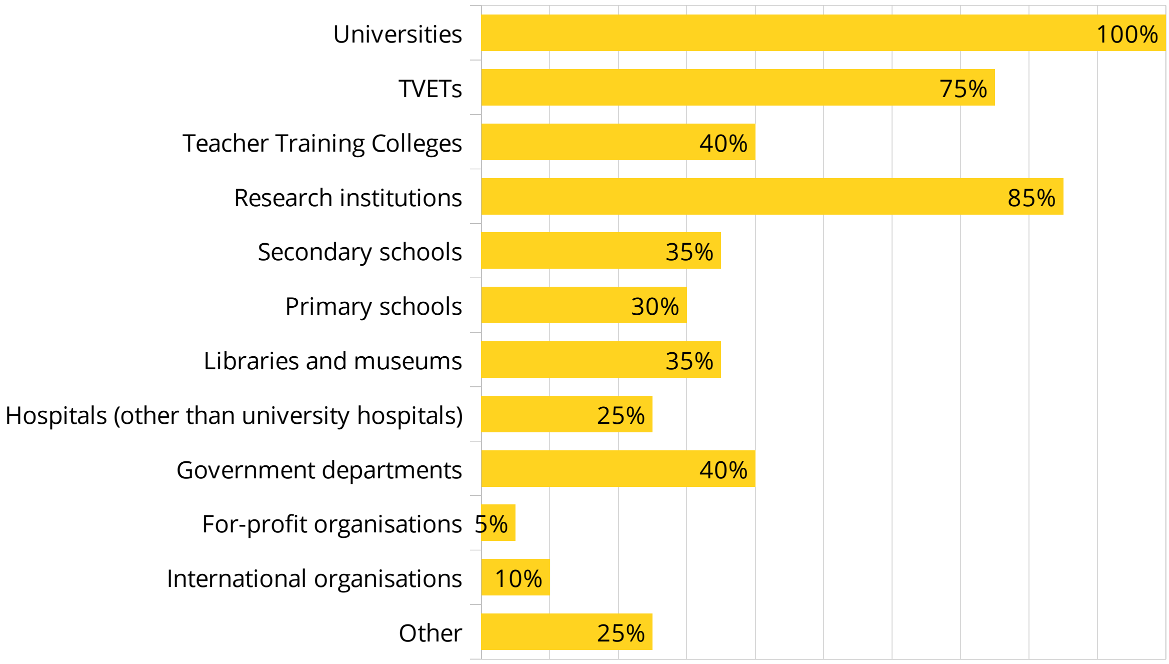

Figure 17: Types of institutions served by African NRENs

In terms of governance, most NRENs are set up as Not-for-profit membership organisations (60%) or some form of company (25%). The rest are a form of a government entity with the Sierra Leone Research and Education Network (SLREN) also legally recognised by the National Universities Act of 2005.

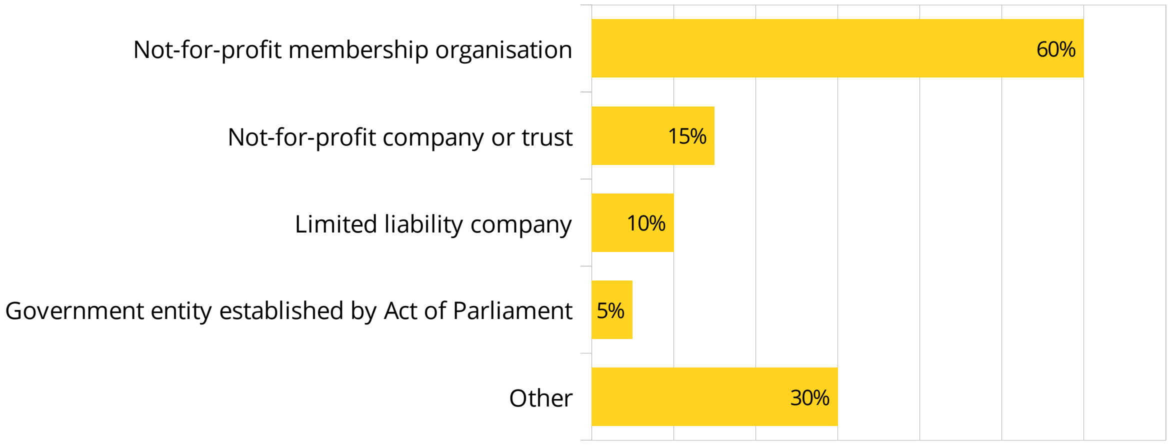

Figure 18: NREN governance structure (multiple select)

Most NRENs (70%) are recognised by the Ministry of Education/Higher Education as indicated in Figure 19. Only SnRER in Senegal and TERNET in Tanzania reported no form of relationship with the government. Still in TERNET's case the Board of Trustees is chaired by the Permanent Secretary of the Ministry of Education, Science and Technology.

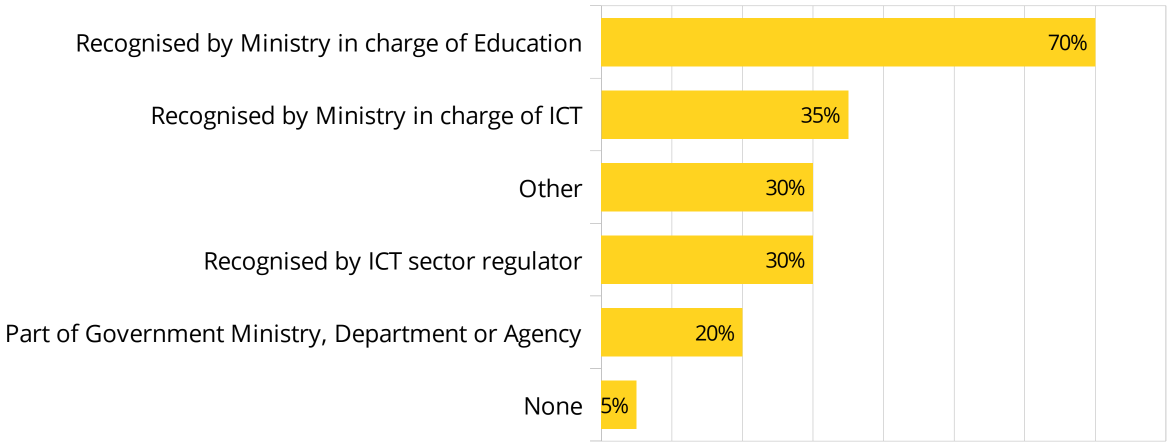

Figure 19: Relationship with government (multiple select)

Bandwidth and Networks

85% of all NRENs currently have less than 10 Gbps of capacity to distribute among member institutions as shown in Figure 20. While in some countries, universities do get connectivity from both NRENs and Commercial Service Providers (e.g., Ethiopia, Morocco and Nigeria), this nevertheless indicates the magnitude of the challenge of providing high speed connectivity to universities and TVETs. 35% of NRENs source their bandwidth exclusively from Regional RENs (RRENs), 35% exclusively from Commercial Service Providers (CSPs) while 30% use both RRENs and CSPs.

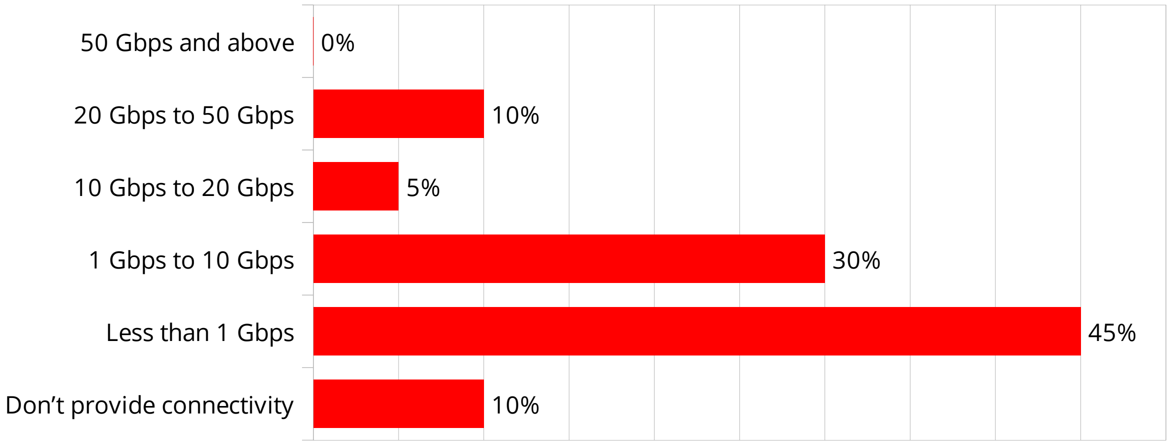

Figure 20: Amount of bandwidth procured by NRENs for members

The price paid by NREN members for connectivity varies from almost zero in countries like Benin, Côte d'Ivoire, Ethiopia, Gabon, Senegal and Tunisia) were the government subsidises the cost of bandwidth to as high as $900/Mbps/month in Chad. But even for countries where NREN members pay for connectivity, higher volumes of bandwidth often result in lower unit charges. For example, in Uganda, RENU charges an institution that can consume 5 Gbps or more $10/Mbps/month irrespective of location, an 80% reduction from the starting tier (see Table 12) while in Tanzania, TERNET charges an institution that can consume 1 Gbps or more $15/Mbps/month if they are within the Dar es Salaam metro area or $36/Mbps/month if they are outside (see Table 13).

Table 12: RENU's tier pricing system based on volume of bandwidth

Capacity (Mbps)	US$/Mbps/month
< 99 Mbps	50
100 – 399	40
400 – 999	30
1,000 – 4,999	20
5,000+	10
Shared Capacity (Minimum 2 – Maximum 10)	108 (total per month)

Source: RENU, 2020

The latter price factors in the high network distribution costs that TERNET needs to meet to service members outside of the Capital. About 6 out of 10 NRENs still lack backbone networks or have a network less than 10 Gbps that they can use to distribute connectivity to member institutions as highlighted in Figure 21. This indicates that there will be need to invest in creating better infrastructure that can be used to distribute high speed connectivity to universities and TVETs in various countries. Table 14 compares bandwidth pricing among selected African NRENs that participated in the survey.

Table 13: TERNET's tier pricing system based on volume of bandwidth and location

Capacity (Mbps)	Dar es Salaam Metro US$/Mbps/month	Outside Dar es Salaam US$/Mbps/month
1 – 10	84	110
11 – 30	71	82
31 – 50	47	76
51 – 100	37	66
101 – 500	28	52
501 +	15	37

Source: TERNET, 2020

Table 14: Comparison of bandwidth prices across NRENs

NREN/Country	Cheapest (USD)	Bandwidth (Mbps)	Most Expensive (USD)	Bandwidth (Mbps)
KENET (Kenya)	5	≥ 4,000	80	≤ 5
MAREN (Malawi)			85	Does not vary with amount
MoRENet (Mozambique)			60	Does not vary with amount
MARWAN (Morocco)	3	≥ 5,000	21	≤ 100
NgREN (Nigeria)			25.5	Varies with amount
RENU (Uganda)	10	≥ 5,000	50	≤ 99
SomaliREN (Somalia)	92	≥ 50	115	≤ 10
TERNET (Tanzania)	15 (in capital) 35 (outside capital)	≥ 1,000	85 (in capital) 100 (outside capital)	≤ 5

Source: NREN CEOs, 2020

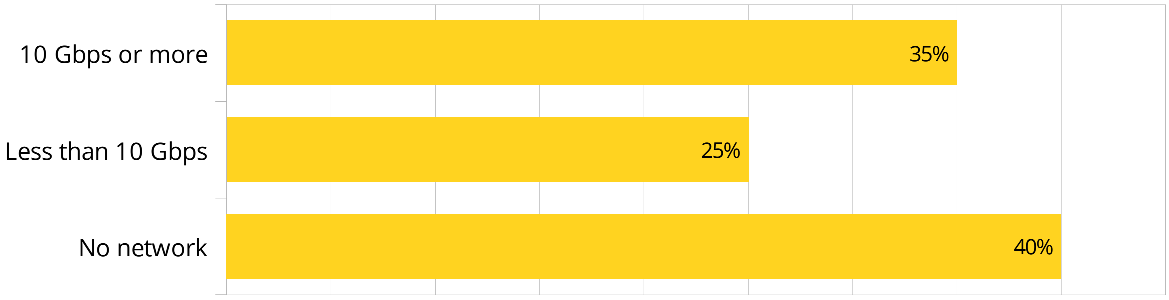

Figure 21: Capacity of NREN networks

NREN Services to Members

Besides basic connectivity, NRENs offer a wide range of services to their members. To address skill gaps among technical personnel, most NRENs (80%) offer capacity building services to their members. These do range from organising technical workshops staff to offering direct engineering assistance at institutions on how to design and maintain better campus networks. Other services include network operations (65%) and teleconferencing (60%), which has increased in demand due to travel restrictions necessitated by the Covid-19 pandemic. At the bottom end are two increasingly important services that reflect the nascent nature of Africa's Internet ecosystem—content caches (18%) reflect the low level of local/regional traffic aggregation and exchange that can save the continent expensive international connectivity while Cybersecurity services (20%) reflect local capacity to mitigate and deal with Cyber incidents and attacks that inevitably accompany better connectivity. Figure 22 summarises the full range of services currently offered by NRENs.

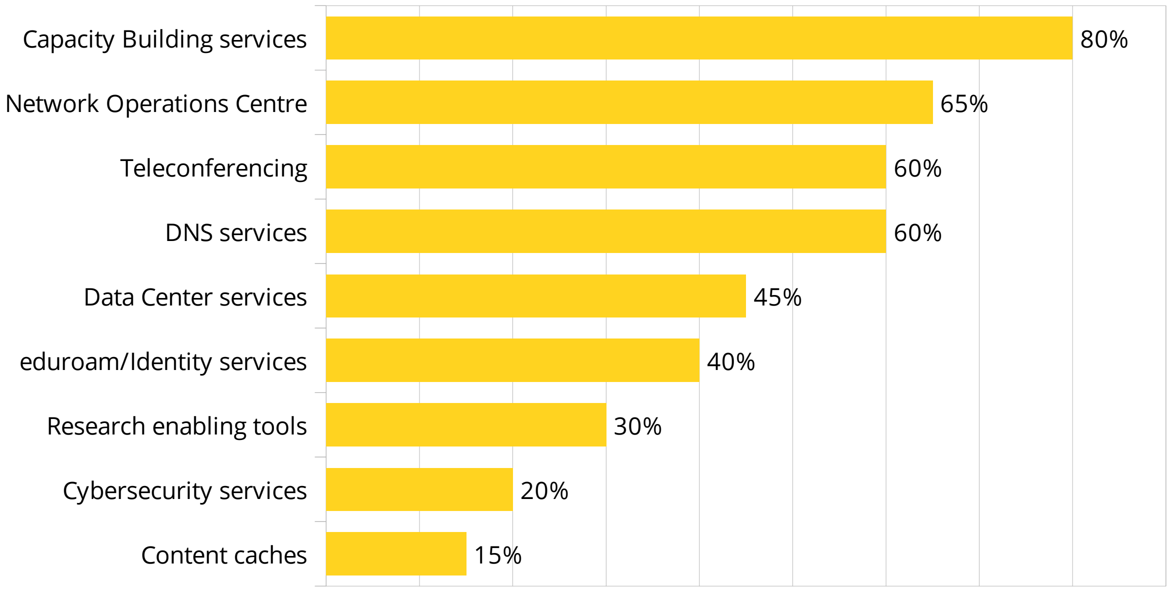

Figure 22: Services offered by African NRENs

Funding and Sustainability

Every 7 out of 10 African NRENs rely on government grants as a regular funding source. 45% of all NRENs relied fully on government grants for connectivity and operations. Only one in four NRENs relies on the sale of bandwidth as a funding source while 35% also collect some form of membership fee.

Given the trends in government funding for higher education in Africa, this portends issues of sustainability for efforts geared towards improving connectivity for universities and TVETs where they do not make any form of financial contribution from the onset.

Challenges and Obstacles

NRENs reported a number of challenges with regard to connectivity, as presented in Figure 23. Perhaps unsurprisingly, most NRENs (80%) complained about the high costs of bandwidth within each of their countries. This is exacerbated by the high cost that they need to pay for back-haul and last-mile access to distribute this bandwidth to different members across the country. The result is that in some countries like Tanzania, upcountry/rural members pay more than twice the cost that a member in the capital Dar es Salaam pays per Mbps/month because TERNET has to spend much more to back haul traffic from the peri-urban towns to the capital where TERNET's Point of Presence (PoP) is located.

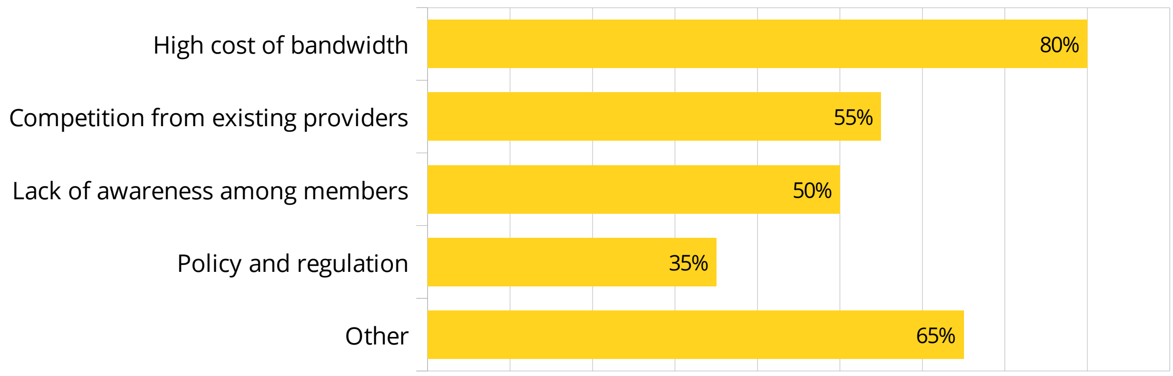

Figure 23: Internal obstacles that hinder NREN performance

Besides the connectivity, NRENs are troubled by many of the same challenges facing the rest of the ICT sector like constraining policy and regulatory environment (35%), low investment in country-wide and metro fibre network infrastructure, deficient and unstable power supplies, poor taxation regimes that result in high ICT equipment costs as well as the lack of local digital content. Other challenges are intrinsic to the nature of NRENs and some of these include:

i. Competition from commercial service providers (55%), some of whom have animosity towards NRENs and do not fully appreciate the role that NRENs play in nurturing digital natives that eventually end up as data-hungry customers of the same providers in a few years

ii. Lack of awareness among both members and other stakeholders (50%) about what an NREN is and how it contributes to improving ICT enabled teaching and learning directly and the greater digital economy indirectly. For those that depend on government for support this lack of awareness manifests itself in different ways, from lack of recognition and the right licences to facilitate operations to lack of funding to participate in regional initiatives like the AfricaConnect programme.

iii. Poor campus networks and ICT infrastructure at most universities and TVETs so that that even when members acquire more bandwidth it does not directly result in visible changes in speed or user experience for end-users.

iv. Universities and TVETs have to compete with the private sector for skilled ICT personnel, who need to remunerated well. The result is that most educational institutions have insufficient numbers of technical staff, and they tend to have knowledge and capacity gaps. The absence of adequate capacity building programmes makes this a more pronounced challenge.

Appendix C: Tables

Table 15 shows important components of the infrastructure ecosystem that supports better connectivity. 38 out of 54 African countries have access to the sea. Of these, 37 had at least one submarine cable landing by the end of 2019, Eritrea being the only exception. All countries have some form of terrestrial fibre backbone with Eritrea having the shortest length with 74 km and South Africa having the most extensive fibre coverage with 278,000 km. 34 out of 54 African countries have at least one IXP in the country to help facilitate local traffic exchange and save expensive international transit. 13 out of 54 African countries have at least one carrier-neutral data centre with South Africa having 21 of these followed by Nigeria and Mauritius with 10 each and Kenya with 7 data centres.

Table 15: African coverage of infrastructure that impact connectivity

Country	Landing stations (number)	Length of national fibre network (km)	Geog. area (sq. km)	Fibre density (fibre length/geog. area) (1/km)	IXPs (number)	Carrier-Neutral Data Centres (number)
Algeria	3	169,352	2,381,741	0.071	0	2
Angola	4	21,752	1,246,700	0.017	2	4
Benin	2	5,659	112,622	0.050	1	0
Botswana	landlocked	10,077	581,726	0.017	1	0
Burkina Faso	landlocked	6,987	274,000	0.026	1	0
Burundi	landlocked	7,500	27,830	0.269	1	0
Cabo Verde	3	2,633	4,033	0.653	0	0

Cameroon	6	16,856	475,442	0.035	2	0
Central African Rep.	landlocked	1,050	622,984	0.002	0	0
Chad	landlocked	1,973	1,284,000	0.002	1	0
Comoros	2	826	2,235	0.369	0	0
Congo (Rep. of the)	1	2,951	342,000	0.009	1	0
Côte d'Ivoire	4	21,137	322,460	0.066	1	0
Dem. Rep. of the Congo	2	7,556	2,344,858	0.003	2	1
Djibouti	11	322	23,200	0.014	1	0
Egypt	15	34,000	1,001,449	0.034	2	0
Equatorial Guinea	2	1,539	28,051	0.055	0	0
Eritrea	0	74	117,600	0.001	0	0
Eswatini	landlocked	1,329	17,364	0.077	1	0
Ethiopia	landlocked	21,178	1,104,300	0.019	0	0
Gabon	2	1,760	267,668	0.007	1	0
Gambia	1	1,380	10,380	0.133	1	0
Ghana	5	14,485	238,534	0.061	1	2
Guinea	1	5,067	245,857	0.021	1	0
Guinea-Bissau	1	112	36,125	0.003	0	0
Kenya	6	28,880	580,367	0.050	3	7

Lesotho	landlocked	1,605	30,355	0.053	1	0
Liberia	1	620	111,369	0.006	0	0
Libya	3	32,529	1,759,540	0.018	0	0
Madagascar	4	11,000	587,041	0.019	1	0
Malawi	landlocked	4,805	118,484	0.041	1	0
Mali	landlocked	8,809	1,240,192	0.007	1	0
Mauritania	1	4,093	1,030,700	0.004	0	0
Mauritius	4	5,153	2,040	2.526	1	10
Morocco	3	80,760	446,550	0.181	1	5
Mozambique	2	51,981	801,590	0.065	1	0
Namibia	2	14,313	825,418	0.017	1	0
Niger	landlocked	3,967	1,267,000	0.003	0	0
Nigeria	6	95,236	923,768	0.103	4	10
Rwanda	landlocked	4,857	26,798	0.181	1	0
São Tomé and Principe	1	116	964	0.120	0	0
Senegal	4	14,353	196,723	0.073	1	0
Seychelles	2		451		0	0
Sierra Leone	1	1,450	71,740	0.020	0	0
Somalia	5	1,805	637,657	0.003	1	0

South Africa	11	277,588	1,221,037	0.227	6	21
South Sudan	landlocked	500	644,329	0.001	0	0
Sudan	5	23,960	1,861,484	0.013	1	0
Tanzania	3	40,371	945,203	0.043	5	1
Togo	1	2,790	56,785	0.049	1	0
Tunisia	4	29,942	163,610	0.183	2	2
Uganda	landlocked	23,094	236,040	0.098	1	1
Zambia	landlocked	14,215	752,614	0.019	1	0
Zimbabwe	landlocked	20,268	390,757	0.052	1	1

Sources: AfricaBandwidthMap, PeeringDB, Packet Clearing House, DataCentreMap, 2020

Table 16 shows that projected international bandwidth needs for higher education students will grow from 4.6 Tbps in 2021 to 54.8 Tbps in 2025 and 507 Tbps in 2030. Student enrolment numbers are calculated using the compound growth rate method. Projections for bandwidth need are based on the progressive targets given in Chapter 3 (Table 3) of 0.2 Gbps per 1,000 students during 2020; 2 Gbps per 1,000 students in 2025; and 20 Gbps per 1,000 students by 2030.

Table 16: Projected bandwidth needs for higher education by country

	Tertiary students (number)			**Projected bandwidth (Gbps)**		
Country	**2021**	**2025**	**2030**	**2021**	**2025**	**2030**
Algeria	1,729,000	1,965,000	2,261,000	346	3,930	45,220
Angola	339,000	410,000	498,000	68	820	9,960
Benin	155,000	185,000	223,000	31	370	4,460
Botswana	67,000	77,000	90,000	13	154	1,800
Burkina Faso	160,000	221,000	297,000	32	442	5,940
Burundi	53,000	62,000	73,000	11	124	1,460
Cabo Verde	18,000	21,000	25,000	4	42	500
Cameroon	420,000	497,000	594,000	84	994	11,880
Central African Republic	18,000	21,000	24,000	4	42	480
Chad	60,000	72,000	86,000	12	144	1,720
Comoros	11,000	13,000	16,000	2	26	320
Congo, Republic of	69,000	83,000	102,000	14	166	2,040

	Tertiary students (number)			Projected bandwidth (Gbps)		
Country	**2021**	**2025**	**2030**	**2021**	**2025**	**2030**
Congo, Democratic Republic of	579,000	655,000	750,000	116	1,310	15,000
Côte d'Ivoire	272,000	311,000	359,000	54	622	7,180
Djibouti	12,000	16,000	20,000	2	32	400
Egypt, Arab Republic of	2,907,000	3,066,000	3,264,000	581	6,132	65,280
Equatorial Guinea	17,000	21,000	26,000	3	42	520
Eritrea	10,000	9,000	9,000	2	18	180
Eswatini	18,000	21,000	27,000	4	42	540
Ethiopia	1,239,000	1,377,000	1,550,000	248	2,754	31,000
Gabon	19,000	21,000	24,000	4	42	480
Gambia, The	14,000	17,000	22,000	3	34	440
Ghana	560,000	676,000	820,000	112	1,352	16,400
Guinea	196,000	236,000	287,000	39	472	5,740
Guinea-Bissau	23,000	27,000	34,000	5	54	680
Kenya	1,081,000	1,367,000	1,740,000	216	2,734	34,800
Lesotho	32,000	37,000	41,000	6	74	820
Liberia	94,000	116,000	144,000	19	232	2,880

	Tertiary students (number)			Projected bandwidth (Gbps)		
Country	**2021**	**2025**	**2030**	**2021**	**2025**	**2030**
Libya	227,000	252,000	264,000	45	504	5,280
Madagascar	172,000	210,000	257,000	34	420	5,140
Malawi	45,000	60,000	79,000	9	120	1,580
Mali	106,000	117,000	130,000	21	234	2,600
Mauritania	22,000	26,000	30,000	4	52	600
Mauritius	48,000	55,000	64,000	10	110	1,280
Morocco	1,194,000	1,377,000	1,607,000	239	2,754	32,140
Mozambique	248,000	291,000	344,000	50	582	6,880
Namibia	69,000	81,000	97,000	14	162	1,940
Niger	88,000	102,000	120,000	18	204	2,400
Nigeria	2,234,000	2,786,000	3,485,000	447	5,572	69,700
Rwanda	100,000	117,000	138,000	20	234	2,760
São Tomé and Príncipe	4,000	5,000	6,000	1	10	120
Senegal	207,000	244,000	290,000	41	488	5,800
Seychelles	2,000	2,000	3,000	0	4	60
Sierra Leone	93,000	112,000	135,000	19	224	2,700
Somalia	250,000	314,000	407,000	50	628	8,140

	Tertiary students (number)			Projected bandwidth (Gbps)		
Country	**2021**	**2025**	**2030**	**2021**	**2025**	**2030**
South Africa	1,250,000	1,352,000	1,479,000	250	2,704	29,580
South Sudan	170,000	208,000	266,000	34	416	5,320
Sudan	829,000	944,000	1,087,000	166	1,888	21,740
Tanzania	200,000	222,000	250,000	40	444	5,000
Togo	112,000	134,000	162,000	22	268	3,240
Tunisia	257,000	237,000	212,000	51	474	4,240
Uganda	294,000	342,000	402,000	59	684	8,040
Zambia	248,000	357,000	357,000	496	7,140	7,140
Zimbabwe	221,000	265,000	265,000	442	5,300	5,300
TOTAL	**18,862,000**	**21,812,000**	**25,342,000**	**4,617**	**54,820**	**506,840**

Table 17 shows that projected international bandwidth needs for higher education students by Africa Country Regions. In 2021, East & South Africa needs 2.4 Tbps of international bandwidth connectivity for higher education compared to 1.3 Tbps for Northern Africa and 1 Tbps for West & Central Africa. These exponentially increase in 2025 and 2030 as summarised in Table 17.

Table 17: Projected bandwidth needs for higher education by WBG Africa Regions

	Tertiary students (number)			**Projected bandwidth (Gbps)**		
WBG Region	**2021**	**2025**	**2030**	**2020**	**2025**	**2030**
East & South Africa	7,591,000	8,869,000	10,315,000	2,362	28,934	206,300
West & Central Africa	4,957,000	6,046,000	7,419,000	991	12,092	148,380
Northern Africa	6,314,000	6,897,000	7,608,000	1,263	13,794	152,160
TOTAL	**18,862,000**	**21,812,000**	**25,342,000**	**4,617**	**54,820**	**506,840**