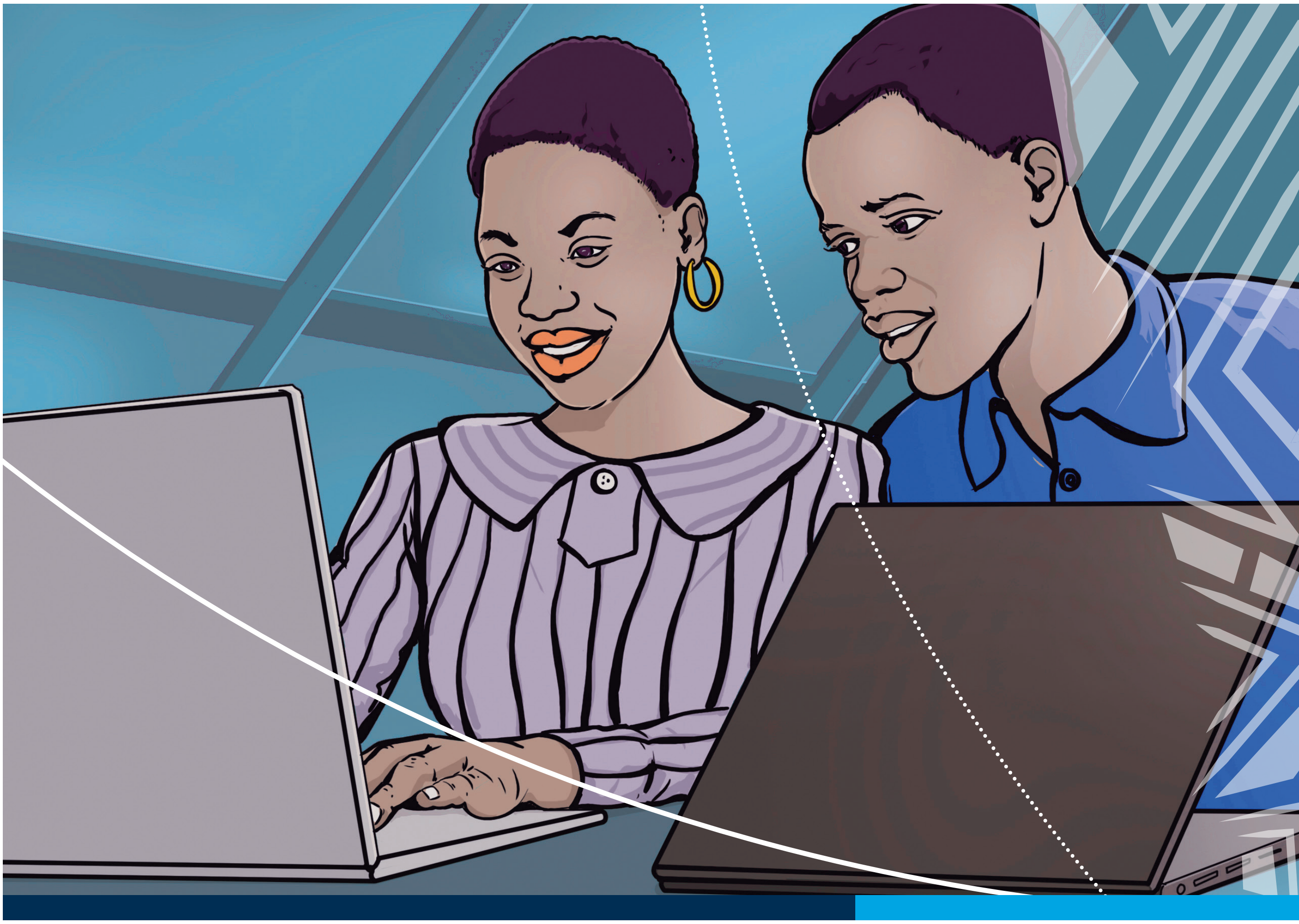

Feasibility Study to Connect all African Higher Education Institutions to High-speed Internet

DIGITAL DEVELOPMENT PARTNERSHIP

Administered by WORLD BANK GROUP

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Abbreviations

Term	Description
AfCFTA	African Continent Free Trade Agreement
AfDB	African Development Bank
AfriNIC	African Internet Registry
ASN	Autonomous System Number
ASREN	Arab States Research and Education Network
AUP	Acceptable Use Policy
BYOD	Bring Your Own Device
CAP	Country Action Plan
CapEx	Capital Expenditures
COVID-19	Coronavirus Disease 2019
CSP	Commercial Services Providers
DDP	Digital Development Partnership
DE4A	Digital Economy for Africa initiative
DEA	Direct Engineering Assistance
DNS	Domain Name System
DS4DE4A	Digital Skills for Digital Economy in Africa
EMIS	Education Management Information System
FTTX	Fiber to the X (home, office, school kerb etc.)
Gbps	Gigabits Per second
GER	Gross Enrollment Ratio
GIS	Geographical Information System
HEI	Higher Education Institution
ICT	Information and Communications Technology
IDRC	International Development Research Centre
IFC	International Finance Corporation
INASP	International Network for Availability of Scientific Publication
IRU	Indefeasible Right of Use
ISCED	International Standard Classification of Education
ISOC	Internet Society

Term	Description
ISP	Internet Service Provider
ITU	International Telecommunication Union
IXP	Internet Exchange Point
KCL	Knowledge Consulting Ltd
Mbps	Megabits per Second
MDAs	Ministries, Departments and Agencies of Government
MOOC	Massive Online Open Course
NREN	National Research and Education Network
NSRC	Network Startup Resource Center
O&M	Operations and Maintenance
OpEx	Operational Expenditure
OSI	Open Society Initiative
PoP	Point of Presence
RCIP	Regional Communications Infrastructure Program (World Bank)
RREN	Regional Research and Education Network
SDG	Sustainable Development Goal
SPOC	Small Private Online Course
Tbps	Terabits per Second
TVET	Technical and Vocational Education and Training
UA	UbuntuNet Alliance
UIS	UNESCO Institute of Statistics
UNESCO	United Nations Education Scientific and Cultural Organization
WACREN	West and Central African Research and Education Network
WBG	World Bank Group
Wi-Fi	Wireless – Fidelity – Local area wireless computer networking technology

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	Organization	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
	Other Key Informants	
1	ISOC	Michuki Mwangi
2	NSRC	Steve Huter and Steve Song

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Executive Summary

Broadband connectivity is a critical enabler for modernizing higher education institutions (HEIs) in their mission of teaching, research, and community outreach. Connecting African HEIs for improved learning, research collaboration, and access to global scientific resources has been on national and global development agendas for many years but has never achieved top priority policy consideration.[1] The higher education sector in Africa falls far behind the rest of the world in connecting to global research and education networks. The available bandwidth is generally expensive and limited in capacity and therefore cannot meet modern institutions' research and education requirements.

Significance of Broadband Connectivity for HEIs and Research and Education Networks in Africa

The COVID-19 pandemic highlighted the urgent need to extend broadband infrastructure even further to facilitate teaching, learning, research, access to educational resources, and the attainment of effective administration in higher education. The COVID-19 pandemic led to global lockdowns and made any physical face-to-face approach to learning difficult. Because of the many major gaps in broadband connectivity, and the limited preparedness across the continent, most African universities were not able to participate in online teaching, which immediately kicked in as an alternative form of educational delivery in developed countries. This underscored the urgency of enhanced connectivity for HEIs, placing immediate corrective action high on the agenda of governments, educators, and development partners.

Vision for Broadband Connectivity for Higher Education in Africa

As a first step toward achieving sufficiency of bandwidth, a process that combined consultation with African stakeholders and international benchmarking was conducted, leading to the formulation of a "vision for broadband connectivity" for HEIs in Africa:

vision

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

To translate this to national and regional development impact, African HEIs must develop the necessary pre-conditions to ensure that the 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.

Status of Higher Education Broadband Connectivity

Current gaps in broadband connectivity of higher education in Africa highlight the importance of connecting over 15 million students and about 500,000 staff in higher education. Needed improvement in broadband connectivity has to be carried out across the broadband value chain—at the international level where connectivity enters the country, at cross-border and regional levels, nationally, and at the campus level.The continent is in its second wave of submarine cable rollout on the western, eastern, and southern coasts, presenting tremendous opportunities for interconnecting the higher education sector.

1 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).

The main barriers to utilizing this connectivity are the limitations and inadequacies in national and regional backbone networks on the supply side; and the challenges related to poor campus networks as well as the very limited individual access to computers on the demand side.

The region has seen an increase in the amount of terrestrial backbone coverage. By June 2020, the size of the operational fiber-optic network had reached some 1,072,649 km compared to 622,930 km in 2015. By the same date, there was a further 119,496 km under construction, 95,057 km of planned, and at least 69,702 km of proposed fiber[2]. However, there are a series of challenges in cross-border connectivity. These range from different legal and commercial conditions to disparities in the quality of terrestrial fiber connections, ongoing vandalism, and fiber cuts during other construction works—especially for roads.

National fiber coverage in Africa varies widely, again influenced by geography and level of competition and investment by public and private sector operators. A close examination of the fiber-optics map and population density indicates that Angola, Algeria, Cameroon, Egypt, Gambia, Ghana, Kenya, Mozambique, Senegal, Tanzania, Uganda, Zambia, and Zimbabwe have better networks that align with the populations' geographic settlements and that could support their higher education connectivity needs. Yet, over half of African countries still need substantial investment in their terrestrial fiber backbone networks.

Still, the presence of an extensive public backbone of sufficient capacity does not necessarily lead to adequate broadband connectivity to universities (Rwanda, Tanzania, and Ethiopia are examples). Bandwidth availability should be accompanied by a policy and regulatory environment that would stimulate competitive broadband ecosystems along with the growth of Research and Education Networks (RENs).

2 Hamilton Research. 2 April 2021. Africa Bandwidth Map. http://www.africabandwidthmaps.com/?p=6440.

Role of Research and Education Networks as Enablers for Higher Education Broadband Connectivity

Regional research and education networks (RRENs) and national research and education networks (NRENs) have been coordinating the broadband connectivity for HEIs in Africa. Three major RRENs cover the African continent—the Arab States Research and Education Network (ASREN), which 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).

Some 40 of the 54 African countries are currently associated with these RRENs, but these countries' 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 the pan-European research and education network, GÉANT, to reach Europe and RRENs in other parts of the world.

There are also variations in the development of NRENs in Africa. NREN readiness is enabled when sufficient government commitment is secured, and an organization that is recognized and supported by both public and private HEIs is created. The organization 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 an even more significant challenge in getting cheap and high-capacity broadband connectivity to universities. The reality is that only about twenty African countries currently have NRENs that deliver connectivity to HEIs, and of these, fewer 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.

Models for Connecting Higher Education to Broadband

In general, there are four models for connecting higher education, as follows:

i. Model 1: Connecting exclusively via Commercial Services Providers (CSPs),
ii. Model 2: Connecting via either CSPs or NRENs,
iii. Model 3: Connecting exclusively via NRENs, and
iv. Model 4: A hybrid model, connecting to both CSPs for general internet access and to the NREN for REN traffic.

Model 1, exclusive connectivity via commercial service providers, is the common entry option for African countries without NRENs or those with emerging NRENs. This model allows only for connecting to the internet and will not facilitate access to scientific collaboration available through research and education networks or access to the tailored dimensioning available with REN connectivity. When countries establish NRENs, institutions will start connecting via these, and those HEIs not yet connected to an NREN will still connect through CSPs (Model 2). The third model works in countries where NRENs are mature and able to provide internet access and global research and education connectivity. This is the model recommended for connecting African HEIs to broadband. In Model 4, institutions connect to CSPs for general internet access and to NRENs for REN traffic. Model 4 works in very mature and highly competitive telecommunication markets with fully functioning internet exchange point(s) (IXP), data centers and data caches for popular content distribution networks, and where HEIs are research intensive and well resourced.

The different models and the widely varying states of the enabling environment and connectivity in African countries imply that there can be no one-size-fits-all approach to connecting HEIs. Each country needs to assemble a high-level team drawn from all relevant stakeholders, including the ministries of higher education and the information and communications technology (ICT) sector; sector regulators; HEIs; NRENs, where present; the ICT private sector; key development partners; and other stakeholders to map out these gaps and develop a unified plan for connecting HEIs, including approaches to developing and/or strengthening the national RENs.

Cost of Connecting HEIs to Broadband

The connectivity of higher education has the following four major components, all of which need to be addressed to complete the value chain: end-user access devices, high-quality campus networks to deliver a good broadband experience to the end-users, high-quality national networks to interconnect campuses, and regional and global networks to join national networks to the global environment.

Access to Devices

Access to devices is a critical enabler for higher education connectivity. Students need laptops to access learning materials around the clock and from any location; staff need devices to conduct research, teaching, and collaboration with their peers around the globe; and management and administrative staff need laptops to support the overall learning environment. The benefits of connectivity can only be maximized when faculty and students have one-to-one access to computing devices as shared access is difficult to manage and sustain. Laptops, rather than tablets or other devices, are recommended as they possess both the functionality and attributes to support teaching, learning, and research. Since affordability is still a challenge for many students, the recommended entry model is a combination of bring your own device (BYOD) and subsidies/loan schemes, with owner contribution emphasized in the latter model.

The recommended approach is a phasing in by providing devices for only first-year students each successive year and scaling this down year-on-year as institutions and countries take up the financing. Since most courses in HEIs have a duration of two years (TVETs) to three years (universities), this would ensure that all students have laptops within three years. All staff would be equipped with fully subsidized devices over the same period. Estimates based on the available data on the number of higher education students and staff indicate that African countries would need some USD 17.3 billion to roll out one-to-one computing devices between 2021 and 2025.

Upgrading Campus Networks

Campus networks are crucial because all student and staff devices must connect through a local wireless or wired network to access the internet and other academic and research resources. Campus networks have been found often to be the main bottleneck in the connectivity chain due to poor design. The design of campus networks is subject to multiple factors, which include physical characteristics such as the number of buildings, the distance between buildings, the skills of the engineers, and the number of end-users and network devices. Campus networks must be designed to meet the security, connectivity, and performance challenges while enabling the delivery of all critical IT applications and services. They must scale as needed and offer operational simplicity and flexibly to accommodate new computing trends. Emphasis should be placed on Wi-Fi access to create the flexibility required in modern learning environments. The capital and operating costs of campus digital infrastructure depend on campus size, the number of users, the quality of the pre-existing network, and the skillsets to design and upgrade the network. Estimates based on the available data on the number and size of HEIs indicate that African countries need some USD 27.3 billion to upgrade campus networks and maintain them over the next five years.

It should be noted that the gross estimate of USD 27.3 billion for campus networks is based on the broad categorizations of campuses as small (< 5,000 students), medium (> 5,000 and < 15,000 students), and large (> 15,000). Small campuses account for about 94% of all HEIs and about 83% of the total cost of upgrading campus networks. Where more detailed data on campus sizes is available, the small category can be refined further into micro, mini, small, medium, large, and very large campuses. The modeling of the case study countries at this level (as provided for in the Cost Model) led to reductions in the cost of campus upgrading by 37%, 6.7%, and 32.2%, respectively, for Côte d'Ivoire, Mozambique and Uganda. This potential reduction has not been factored into the gross estimated cost in the summary because the number of countries analyzed is too small to be used as a basis for a reliable generalization across the continent—but it does point to a significant potential reduction in the gross cost by taking a more detailed approach to campus size.

Connecting at the National and Regional Levels

The cost of interconnecting campus networks at the national level and further regionally and globally will depend on many factors, including NREN maturity, the level of broadband competition and market structure, and economic and geographic aspects. Data for various indicators were collected from various databases as part of the Gap Analysis phase. Duncan Greaves' NREN Capability Maturity Model[3] and Michael Foley's levels of NREN development[4] provide possible mechanisms to gauge the level of NREN maturity within a given country. NRENs in different African countries can be broadly categorized into "no NREN" (no NREN but varying levels of awareness about need and ongoing conversations); "emerging NREN" (legal entity established but without or with a physical network of varying coverage); "connected NREN" (physical network with regional/global connectivity to other NRENs and offering middle-ware services); and "mature NREN" (physical network with high-speed regional/global connectivity to other NRENs and offering advanced services).

3 D. Greaves, An NREN Capability Maturity Model (2009), https://repository.ubuntunet.net/bitstream/handle/10.20374/69/NREN_Capability_Maturity_Model.pdf?sequence=1&isAllowed=y.

4 M. Foley, The Role and Status of National Research and Education Networks in Africa (World Bank, 2016).

ICT indicators at the country level, with a direct bearing on connectivity, include landlocked-ness; number of cable landing stations; internet exchange ladder stage (reflects number of IXPs and carrier-neutral data centers and their interaction);[5] percent population within 10 km of fiber coverage (reflects fiber network coverage of the country); and a regulatory score, which reflects the maturity of the regulatory environment (based on country scores from ITU Global Regulatory Outlook 2020). Estimates to connect campuses upstream based on these factors indicate an aggregate cost of some USD 7.3 billion for upstream connection over the next five years.

Through negotiated procurement procedures, which benchmark the most competitive regional prices, this could be lowered even further by securing, where appropriate, long-term leases. The cost of USD 7.3 billion is based on final-deliver-to-campus prices, which factor in NREN and RREN costs and overhead as well as commercial service provider costs, overheads, and profits.

Supporting the Development and Sustainability of NRENs and RRENs

Nationally, a fully functional NREN can help aggregate traffic at the national level and in turn connect to regional RENs, such as the UA, WACREN, and ASREN and further to GÉANT (Europe), RedCLARA (South America), APAN (Asia-Pacific), or Internet2 (North America), so that there is full integration in the global research and education fabric. NREN member institutions typically cover connectivity-related expenses through payments for bandwidth, but NRENs often struggle to cover core costs as well as costs related to ongoing capacity building for both internal staff and especially member institutions where the value of connectivity is realized.

A shortage of funding also means NRENs fail to retain competent staff, who are attracted by the much higher pay within the ICT private sector; this is especially a challenge in the development and growth stage of five to 10 years.

As the cost of bandwidth falls, it will be especially important to provide for such support in order to reap the resulting value of the NREN to the delivery of high-speed connectivity in any given country. Countries will need an estimated USD 513 million to support NREN core costs over a five-year period. Support will be provided inversely proportional to the level of NREN maturity. That is, mature NREN countries receive the least support, while no NREN countries receive the most support.

Regionally, there is a need for strengthening the WACREN, UA, and ASREN, which provide regional connectivity as well as upward connectivity to other regional networks, such as GÉANT, RedCLARA, APAN and Internet2. RRENs play a critical role in NREN development and training in internetworking technologies, such as routing and campus network development. The three RRENs require USD 25 million to accelerate NREN development and capacity building.

Estimated cost of connecting all African HEIs to high speed internet

The estimated total cost of connecting African HEIs over the next five years (2021–2025) is thus USD 52 billion in total. This includes the expense of providing devices to students and staff (USD 17.3 billion), the expense of upgrading campus networks (USD 27.3 billion), bandwidth cost for upstream connectivity (USD 7.3 billion), and NREN and RREN development/support (USD 538 million).

All total costs assume regional demand aggregation, smart procurement strategies (e.g., benchmarking regional pricing), and, where applicable, the procurement of long-term leases for bandwidth to secure the best price advantages. Potential sources of funding include governments, development partners, students, and HEIs. Actual proportions will vary across countries depending on government funding priorities and policies as well as development partner funding guidelines.

5 World Bank Group, National Data Infrastructure: The Role of Internet Exchange Points, Content Delivery Networks, and Data Centers (draft WDR21 background paper, 2021).

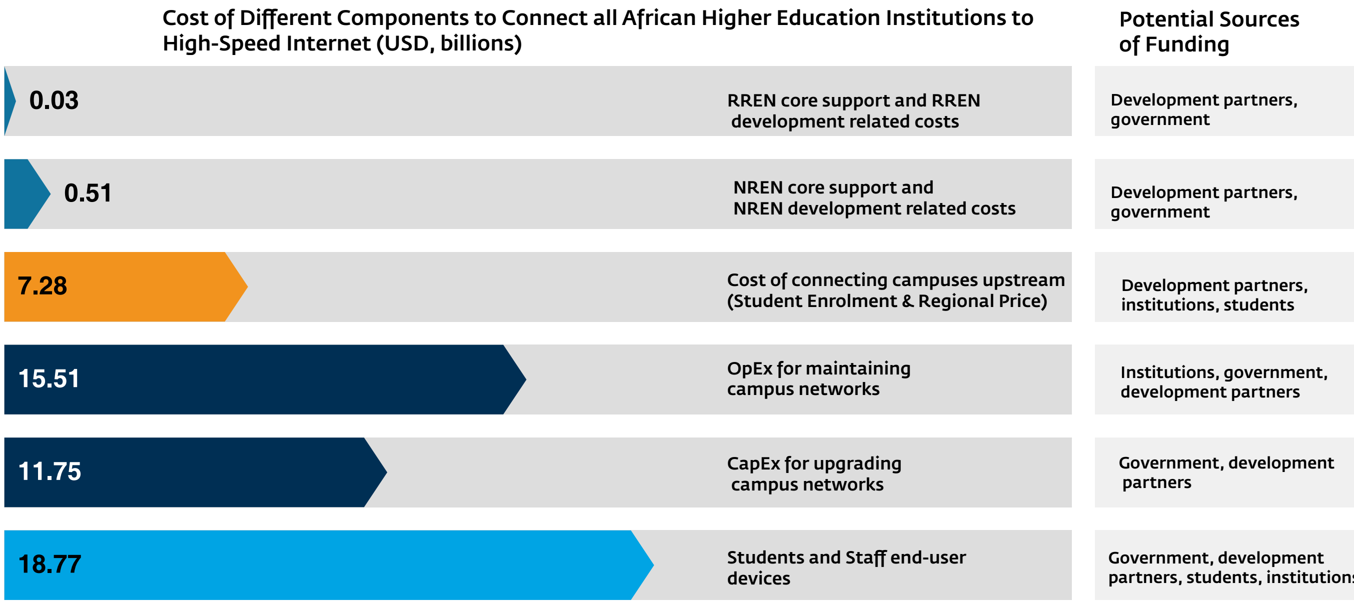

Figure 1: Summary of total cost (USD, billions) of connecting all African higher education institutions to high-speed internet
Source: KCL calculations

Leveraging Broadband Connectivity to Enhance Learning Outcomes

Connectivity is crucial for learning, research collaboration, and access to scientific resources, yet the real benefit only occurs if it is accompanied by other efforts that expand access, equity, learning outcomes, and employability in the emerging digital economy. While curriculum, pedagogy, and assessment are key elements of the solution, the focus here is on the key ICT-related impediments to the integration of technology into learning and research and recommending a roadmap for addressing them.

The integration of technology in higher education to enable better learning outcomes and academic excellence, foster research and innovation, and achieve greater operational efficiency needs to be accompanied by a digital technology integration vision, policies and strategies, a change in processes, and a shift of the mindsets of people—such as students, administrators, and faculty. A well-staffed corporate ICT department, with highly skilled engineers and a user support team, is as critical as is the presence of technology-savvy teachers and administrators that facilitate students' success in digital technology-enriched learning environments.

There are several well-known impediments to the integration of ICT in support of learning, research, and effective administration in HEIs. These include the following:

i. The absence of, or deficient, ICT policies and strategies, which often arises from lack of awareness of the role of higher education connectivity
ii. Limited ICT awareness and ICT literacy among faculty and administrators
iii. Limited competence of campus ICT personnel
iv. The poor quality of campus networks
v. Poor digital learning spaces
vi. Limitations in resource allocation and coordination
vii. Limited individual access
viii. Limited digital learning resources

All these have to be addressed if the opportunities of broadband connectivity are to be exploited for improved learning and research outcomes. Change at the infrastructure/technology level is relatively easy, but the changes required will not be sustainable unless they are accompanied by changes in people and processes. Intervention should also be carried out at the regional, national, and institutional levels. The following four recommended strategic interventions provide the framework under which detailed activities would be undertaken:

i. Establishing and sustaining regional partnerships with other agencies and organizations that are interested and active in digital technologies for improving research output, learning outcomes, and employability in Africa;
ii. Identifying leadership and catalyzing the formation of national-level coalitions that will be responsible for spearheading change in the integration of technology in higher education;
iii. Guiding national- and institutional-level approaches through toolkits; and
iv. Supporting specific quick-win demonstration projects.

The following key considerations are important when looking ahead at leveraging broadband connectivity to enhance learning outcomes :

i. First, there is a need for increasing awareness among decision makers about the different connectivity issues and challenges. This is especially important for those in the ministries of education, ministries responsible for digital technologies, ministries responsible for finance and investment, and HEI leaders. An awareness of the magnitude of the challenges (e.g., the need for access to computing devices, the importance of the upgrading of campus networks, NREN development) is critical to ensure that adequate resources are available for higher education connectivity.

ii. Second, there is a need for accelerating connectivity to facilitate teaching, research, learning, and administration in higher education in order to improve learning outcomes.

iii. Third, connectivity should be accompanied by the digitalization of campuses, building ICT literacy among staff and students and enabling the individual ownership of laptops to support reforms in learning and new ways of teaching digital and soft skills to meet the demands of 21st-century jobs.

iv. Fourth, coordination is an essential prerequisite for achieving higher education connectivity and attaining reforms in learning and digital skills.

Each country needs to assemble a high–level team drawn from the ministries responsible for higher education, the ICT sector, and finance; HEIs; NREN, where present; the ICT private sector; key development partners; and other stakeholders in order to develop a national plan for connecting its HEIs and accelerate learning and digital skills for the jobs of the future.

Governments and development partners need to work together to push the connectivity, learning, and digital-skills agenda forward, which demands engaging stakeholders, cost sharing at all levels, and adhering to a timeline for connecting HEIs in Africa. The five-year timeline proposed is ambitious, and an aggressive approach is required to achieve the objectives.

Action plan for connecting all African HEIs to high speed internet

A five-year action plan is proposed below for connecting all African HEIs to high speed internet. It is ambitious, and requires an aggressive approach to achieve the objectives.

Table 1: Prioritizing connectivity to African higher education

Timeline/ priorities/	Year 1	Year 2	Year 3	Year 4	Year 5
Devices	Individual ownership for all first-year students	Individual ownership for all first-year students	Individual ownership for all first-year student	Individual ownership for all first-year students	Individual ownership for all students and staff
Campus network	Build functioning campus networks across HEIs			Nationwide support for evolution of a world-class campus network	
Connectivity	All institutions progress to a goal of 2 Gbps per 1,000 students			Start work toward a goal of 20 Gbps per 1,000 students	
NREN development	Aggressive NREN development support to all countries; special focus on countries without sustainable NRENs		Intensive support to upgrade countries to the NREN Exclusive model		
RREN interconnections	Each African country is connected though at least one regional REN, and the RRENs are interconnected at multiple points throughout the continent				
Developing pre-conditions for leveraging connectivity for improved learning outcomes	Enabling policy environments related to the use of ICT in teaching, learning, and research; curriculum; pedagogy; assessment; quality management; and industry linkages developed and implemented in HEIs along with the necessary institutional arrangements				

Source: KCL.

The implementation of the above action plan requires coordinated actions of all stakeholders, in particular:

Government:

- Support the development of comprehensive higher education ICT policies that address device, connectivity, campus networking, and capacity issues
- Support the development of research and education networks
- Promote access to devices through national negotiation with suppliers and industry players
- Allocate resources for higher education connectivity through donor funding or universal access funds

Development Partners:

- Promote information exchange among countries on the different issues of connectivity
- Support projects that enhance the connectivity of higher education and those that leverage advanced networks to solve social and economic challenges

Leaders of HEIs:

- Support the development of NRENs
- Allocate resources to ensure sufficient bandwidth is available for higher education
- Sponsor projects that leverage connectivity to enhance teaching, learning, and research collaboration
- Serve as advocates for higher education connectivity

Private sector:

- Recognize the specific connectivity requirements of HEIs and engage in dialogue with NRENs to optimize service offerings, including through service level agreements
- Consider offering preferential rates or tailored service offerings for HEIs, in cooperation with REN.

1 Introduction

Overview

Higher Education Institutions (HEIs)—comprising public and private universities, colleges, technical training institutes, and vocational schools—play crucial roles in training skilled workforces, conducting research, and fostering innovation, all of which underpin social development, economic growth, and national competitiveness. However, most HEIs in Africa lack access to affordable and functional quality broadband connectivity. In addition, the available bandwidths are expensive and limited in capacity and are thus unable to meet the research and education requirements of modern institutions. Ultimately, this negatively affects national education goals and targets as detailed in the Sustainable Development Goals (SDGs) and various country-specific development plans.

The COVID-19 pandemic further highlighted the gaps in the connectivity of higher education throughout the continent. Countries began to transition to digital technologies to address the disruption in education, choosing various options based on their constraints in infrastructure and connectivity. Overall, the experience points to the acute need for investment in digital technologies and connectivity, along with reforms in the education systems, to accelerate digital skills and achieve better learning outcomes.

As part of the Digital Economy for Africa (DE4A[6]) initiative, the World Bank commissioned a 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)[7], aims to digitally enable every African individual, business, and government by 2030. Connecting universities and research institutions is crucial for expanding the opportunities for teaching, learning and innovation to foster relevant digital skills on the continent.

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

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

Connecting Africa's HEIs to Affordable High-Speed Internet

Higher education is instrumental in fostering long-term growth and boosting shared prosperity in all countries, whether high-, middle-, or low-income.[8] At the individual level, it provides unique opportunities for advanced and enhanced learning to nurture skills for immediate professional application. Economic returns for a tertiary graduate are the highest in the entire educational system – with higher employability and higher wages. At a societal level, tertiary education provides a highly skilled workforce which is a prerequisite for a country's innovation and long-term growth. Furthermore, as university-industry cooperation is becoming more and more important, HEIs are considered the "backbone of a country's innovation ecosystem." A research also finds that "Tertiary schooling can also have less direct benefits for economies. By producing well-trained teachers, it enhances the quality of primary and secondary education systems and gives secondary graduates greater opportunities for economic advancement. By training physicians and other health workers, it improves a society's health, raising productivity at work. And by nurturing governance and leadership skills, it provides countries with the talented individuals needed to establish a policy environment favorable to growth[9]."

> The university must become a primary tool for Africa's development in the new century. Universities can help develop African expertise; they can enhance the analysis of African problems; strengthen domestic institutions; serve as a model environment for the practice of good governance, conflict resolution, and respect for human rights, and enable African academics to play an active part in the global community of scholars.
>
> — Kofi Annan

8 WB Tertiary Education Position Paper: STEERing Tertiary Education – Toward Resilient Systems that Deliver for All (forthcoming)

9 Bloom, D. E., D. Canning, K. Chan, and D. L. Luca. 2014. "Higher Education and Economic Growth in Africa." International Journal of African Higher Education 1 (1): 23–57

With the growing significance of tertiary education in a country's economic growth, technology adaptation or digitalization of the sector is the present in accordance with the general trend of the digital transformation of the economy. COVID-19 has also reaffirmed that distance delivery for tertiary education should become a norm to sustain the core tertiary education functions during the emergency or disaster situations. In this context, broadband connectivity is a critical agenda for the African HEIs to ensure that they also keep up with the pace and depth of transformation in the rest of the world. According to Sajitha (2020)[10], the availability of bandwidth in HEIs determines:

- Whether efforts to improve internet access through supplying devices (laptops, tablets) are successful;
- The extent to which university faculty and students can
  - Access international knowledge (journals, papers, databases, courses, presentations on YouTube);
  - Collaborate with fellow academics worldwide (including uploading papers and large data sets) in research and teaching programs;
  - Access expensive instrumentation, such as supercomputers, virtual labs and so on;
- What online content and applications can be used for teaching and learning; whether online and blended learning approaches can be introduced;
- Whether personalized and differentiated learning (such as adaptive learning) can be used for students and also for faculty professional development;
- Whether "cloud" services can be used for administrative and teaching purposes;
- The ease of updating subscriptions, managing apps, maintaining content management, learning management and student information systems, as well as protection of the network by providing system updates and addressing vulnerabilities.

The implication of increased broadband connectivity on learning and research outcomes is significant. Greater use of technology and digital resources enhances the learning experience of students (improvements in pedagogy, assessment, access to open education resources, online courses, etc.) and the professional development of faculty.

10 https://openknowledge.worldbank.org/bitstream/handle/10986/34955/Connecting-Africa-s-Universities-to-Affordable-High-Speed-Broadband-Internet-What-Will-it-Take.pdf?sequence=1&isAllowed=y

Access to large databases, the sharing of computational resources, shared access to data analysis and visualization techniques further enhances the quality of research, enabling the participation of African HEIs into the global sciences, technology, and innovation space. The technology advancement and connectivity also allow tertiary education institutions to become a hub to equip students and staff with important digital skills – from foundational, intermediate, to advanced levels, accelerating the economy-wide digital transformation.

Role of Research and Education Networks

While high-speed internet is prerequisite to reach the goals of continued learning, collaborative research, and human capacity development in the tertiary education sector, research and education networks (RENs) has been a successful model in providing the necessary digital connectivity to HEIs. In particular, national research and education networks (NRENs) are considered a critical element in delivering sufficient and reasonably priced high-speed connectivity to HEIs in that they:

i. Mediate between HEIs 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. Provide direct connectivity with international research and education networks to foster research collaboration and scientific resource sharing.
iii. Offer access to digital libraries, learning management systems, and scientific resources; capacity building; identity management; and eduroam.
iv. Ensure high-capacity bandwidth with undisrupted connection to allow spikes in usage through dedicated bandwidth to each client. Connection to e-science resources such as telescopes, sensor networks, accelerators, and supercomputers requires sustained high volume and quality bandwidth for short periods of time to transfer large research data or enable access to instruments.
v. Create platforms for experimentation with the various aspects of network technologies, such as protocols and security, which have spill-over effects in other networks.
vi. Facilitate the formation of communities of researchers in the areas of agriculture, bioinformatics, disaster mitigation, network development, and telemedicine, among others, among researchers in the developing world. 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, requiring advanced research and education networks.

vii. Although in some cases, commercial connectivity pricing appears to be lower than NREN connectivity pricing, the above advanced qualities that NRENs offer verify that any price comparison is fallacious. Moreover, there has been "evidence that the availability of cost-effective and cutting edge NREN network services enables and encourages technological spillover into commercial sector, which ultimately benefits society as a whole[11]."

Approach

There have been efforts over the last decade to assess the main challenges and opportunities of connectivity for the African higher education system, especially within the context of the development of NRENs. Yet, there is limited understanding of the connectivity value chain among HEIs and at national levels. To fill the knowledge gaps and guide action, the feasibility study was carried out through the following three sub-activities, each of which is covered by a comprehensive report:

i. The production of a gap-analysis report addressing connectivity, ecosystem challenges (policy, regulation, institutions, human capacity, etc.), and funding.
ii. The development of a cost model. This also referenced in-depth country case study reports for Burkina Faso, Côte d'Ivoire, Mozambique, and Uganda.
iii. The development of a high-level strategy to leverage campus connectivity to achieve learning outcomes in higher education.

This report presents a summary of the feasibility study and establishes a roadmap for connecting all African HEIs to high-speed internet.

Structure of the Report

This report is organized as follows: after the Introduction in Chapter 1, Chapter 2 discusses the methodology used for gathering the data to conduct a baseline assessment for the gap analysis and to establish the business model for connecting HEIs to high-speed internet.

Chapter 3 begins with setting the context by defining the universe of the target institutions. Next, the chapter sets minimum connectivity targets for the target HEIs and presents an analysis of connectivity gaps at the regional, national, and campus levels. It concludes with lessons learned from existing projects on closing the connectivity gap.

Chapter 4 presents a business model for connecting all HEIs. It begins with the vision and targets for linking HEIs to the global networks. The chapter then presents different models of access to laptops for students and staff. Next, the chapter reviews the necessary upgrades to campus computing infrastructure. This is followed by a discussion of upstream connectivity options for campuses based on an aggregation model, after which it explores the necessary support to strengthen NRENS and regional RENs, which are important elements of aggregating demand across higher education. The last section brings all of these components together to present the estimated cost of connecting African HEIs.

Chapter 5 presents a summary of the country case studies of Burkina Faso, Cote d'Ivoire, Mozambique, and Uganda to illustrate the implementation of the business model in different contexts.

Chapter 6 proposes a high-level strategy and roadmap for leveraging connectivity to improve learning outcomes, with a specific focus on what needs to be done to ensure the full digitalization of campuses to support effective learning skills, including addressing the related technology, processes, and people challenges.

Chapter 7 concludes the report, providing a roadmap for addressing the gaps and identifying potential partners to the World Bank Group (WBG) Initiative for connecting all African HEIs to broadband.

11 https://www.casefornrens.org/Resources_and_Tools/Document_Library/Documents/Case%20for%20NRENs.pdf.

2 Methodological Summary

The Feasibility Study draws on extensive document analysis, and a wide range of data sources both within and outside the public domain. Surveys and interviews with key informants within and outside Africa were conducted. The study draws on extensive analysis, both qualitative and quantitative, to inform the findings and recommendations.

A survey of research and education networks, operators, and key informants was conducted to establish the current connectivity environment, gaps, and challenges in higher education. Data on enrollment rates were collected from the ministries of education and cross-checked with figures available from the UNESCO Institute of Statistics (UIS). In-depth country case studies were also conducted in Burkina Faso, Cote d'Ivoire, Mozambique, and Uganda to identify connectivity gaps and challenges specific to different contexts.

Table 2 provides a methodological summary of our analysis.

Table 2: Methodological Summary

	Output/data/ information required	Sources of data and information	Analytical methods
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	• Benchmarking • Comparative examination and projections taking into account the different views and perspectives as well as historical trends and technology projections
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
3	Current enrollment in TVETs and universities	Data from UIS, complemented with recent data from ministries of education/higher education and accreditation and quality assurance bodies where available	Estimation based on historical data and population growth for a few countries with data gaps

4	Projected student enrollment between 2021 and 2030	Data from UIS, complemented with recent data from ministries of education/higher education and accreditation and quality assurance bodies where available	• Forecasting student enrollment at a country level was based on historical figures from 2001 to date where available; model uses triple exponential smoothing forecasting technique to give more weight to recent data (less weight to older data) and take into account seasonality and trends in the data • The average gross enrollment ratio (GER) at the regional level was used to estimate enrollment for some countries that lacked historical student enrollment data but have population projections for the 20–24 age category; GER was derived from forecast of student enrollment and population in age category 20–24 at a country level
5	Projected staff numbers between 2021 and 2030	Data from UIS, complemented with recent data from ministries of education/higher education and accreditation and quality assurance bodies where available	• Forecasting student enrollment at a country level was based on historical figures from 2001 to date where available; model uses triple exponential smoothing forecasting technique to give more weight to recent data (less weight to older data) and take into account seasonality and trends in the data • Determined regional average for student-staff ratio; this was used to estimate number of staff for some countries that lacked data about the number of higher education staff
6	Quantifying bandwidth gaps	Desk study; data from multiple sources (Telegeography, ITU and UIS)	In Scenario 1, forecast student enrollment was multiplied by the progressive targets in Table 10 to estimate bandwidth requirements at the country-level. In Scenario 2, minimum connection port sizes for each campus size (small, medium & large) were used to multiply by the number of institutions in each campus size category to estimate bandwidth requirements
7	Determining the unit cost price of bandwidth	Desk study; data from Telegeography and other sources	• For the Local Price, the unit cost of bandwidth (per Mbps) was derived by adding the cost of IP transit for the cheapest provider and the cost of local access to deliver the bandwidth in a metro area for the cheapest provider in the country • For the regional price, the unit cost of bandwidth (per Mbps) was derived by adding the cost of IP transit for the cheapest provider and the cost of local access to deliver the bandwidth in a metro area for the cheapest provider in the region where the country is located • Calculated regional[12] averages to cater to countries that lack data

12 https://www.worldbank.org/en/region/afr.

8	Identifying savings that can accrue from aggregating bandwidth demand	i. Desk study; data from multiple sources (Telegeography, ITU, GSMA, etc.) ii. Questionnaires to NRENs	Derived aggregation savings from NREN maturity at the country level as well as the country's performance based on various national ICT indicators pertinent to connectivity
9	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	Qualitative analysis to identify key issues and common threads
10	Deep-dive country case	i. Desk study ii. Interviews with selected in-country stakeholders iii. Data collection guide for in-country team to facilitate data collection	• Qualitative and quantitative analysis to identify specific country issues • Testing the cost estimates using country-specific parameters

3 Context and Connectivity Gaps in Higher Education

The analysis summarized in this chapter looked at both the demand and supply sides. The demand side comprises the universe of target institutions, down to the users; and the supply side includes the entire bi-directional connectivity value chain, starting from the end-user and extending to the global research and education community (and vice versa). The gaps are the situational factors that impede or block the delivery of value along the supply chain.

Development partners are enablers, but they do not always act in harmony in order to create the synergy of interventions, and this also needs to be recognized as a gap. The chapter therefore concludes with a review of previous and current development partner interventions to address connectivity gaps in HEIs.

The Universe of Target Institutions and Student Numbers

There is no universal agreement on what constitutes higher education across Africa. 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)[13] maps national education systems in a way that facilitates a comparison of programs across countries.[14] All institutions from UNESCO–ISCED Level 5 and above are considered part of higher education and taken into account for this report. The private HEIs, which are growing fast and catering to about a third of higher education students and staff, are also included in the analysis and projections.

The universe of target institutions in this study comprises the following:

i. HEIs;
ii. Other institutions that are closely allied with HEIs 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 centers, the training hospitals used by the schools of medicine, and establishments such as libraries, whose resources support TVET and/or university-level training and research; and,
iii. Institutions that are responsible for policy, regulation, standards, and sector management—making them critical players that need to be considered for broadband connectivity.

While categories (ii) and (iii) have been included as part of the universe of target institutions in so far as connectivity is concerned, the relative numbers in each country compared to the main body of HEIs is very small and has no significant impact on bandwidth needs. They also have their independent budgets to fund networks within the buildings and computers and are therefore not included in the cost estimates for these elements.

Table 3 shows the student population based on the UIS 2020 report (derived from data collected during the COVID-19 school lockdowns).[15] Coupled with 500,000 staff, the higher education population totaling close to 16 million students, faculty, and researchers represented about 1.3% of the African population in 2019.

13 http://uis.unesco.org/en/topic/international-standard-classification-education-isced.
14 http://uis.unesco.org/en/isced-mappings.
15 https://en.unesco.org/covid19/educationresponse.

Table 3: Higher education student population in Africa (rounded to nearest 100)

Country	HEI students	Country	HEI students	Country	HEI students
Algeria	1,600,700	Eswatini	1,798,100	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.

Connectivity Gaps in Higher Education

The following major dimensions of the connectivity gaps are discussed in this section:

i. Availability and sufficiency of global connectivity
ii. Availability and sufficiency of regional connectivity
iii. Existence and effectiveness of regional RENs
iv. Availability and sufficiency of national connectivity
v. Existence and effectiveness of NRENs
vi. Existence and sufficiency of campus networksvxii.
vii. Availability and sufficiency of last-inch connectivity: individual access level

Availability and Sufficiency of Global Connectivity

The sufficiency and competitiveness of global connectivity influence 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 in 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 continent. Figure 2 shows the different undersea cables that currently serve Africa (gray indicates under construction and planned). The availability of landing stations in all coastal countries (except Eritrea) has spurred fiber-optic links between undersea cable landing stations and the capital cities and national fiber-optic backbones connecting major towns. Non-coastal countries are also able to connect to submarine cables albeit at often much higher cost.

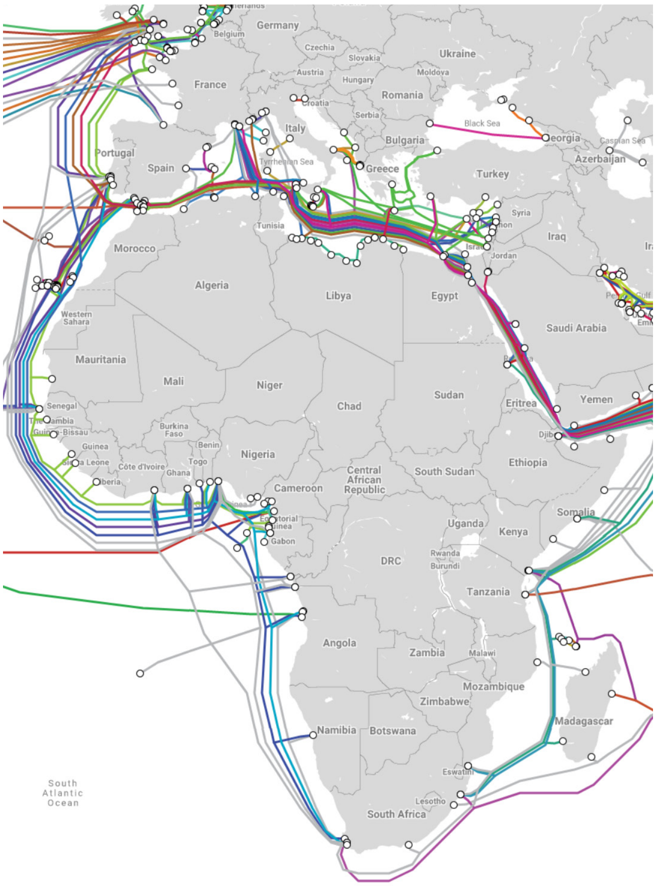

Figure 2: Map of active undersea cables around Africa (proposed indicated in gray)
Source: Submarine Cable Map, TeleGeography
https://www.submarinecablemap.com/

Figure 3 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,16 resulting in 132 Mbps per 1,000 people in Oceania compared to a meagre 9 Mbps per 1,000 people in Africa. On a comparative global basis, the African continent is clearly still severely underserved in terms of available global capacity.

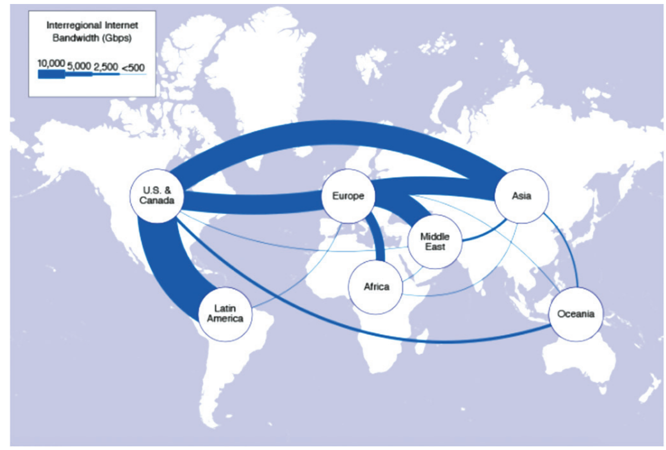

Figure 3: Global inter-regional internet bandwidth
Source: Telegeography, 2019

The absence or presence and number of cable landing stations in a country introduces the first global connectivity divide. 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, 10 countries have two cable landings, six have three cable landings, and 10 have more than three cable landings.

The study also established the following:

i. Although the cost of bandwidth has come down, internet access in Africa is still much more expensive compared to other regions of the world and often less reliable, especially inland.

ii. Africa still largely consumes internet content produced and/or hosted in other parts of the world, which requires expensive international transit. Big content and cloud service providers have started to move to Africa, and some, such as Facebook, have started to invest in infrastructure, but that is yet to have significant continental impact.

iii. The regional/local exchange of internet traffic due to the still-limited penetration of IXPs (34 out of 54 African countries have at least one in-country IXP) means that many countries must rely on expensive transit capacity to Europe to exchange traffic that would have otherwise been exchanged on the continent.

iv. In 2019, the five 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.[17]

16 UN Data Population Estimates (2019).

17 Telegeography, Global Internet Analysis (2019).

Availability and Sufficiency of Regional Connectivity

The existence of competitive regional connectivity is vital for all countries as it enables access to global connectivity for those countries that have no direct access to submarine cables, and it facilitates the development of infrastructure to exchange internet traffic regionally, improving performance and saving expensive international bandwidth. Specific to this study, it also allows regional research and education collaboration. Africa has also seen an increase in the amount of terrestrial backbone coverage. By June 2020, the size of the operational fiber-optic network had reached 1,072,649 km compared to 622,930 km in 2015. By the same date, there was a further 119,496 km under construction, 95,057 km of planned, and 69,702 km of proposed fiber.

Figure 4 shows the terrestrial fiber (both operational and under construction) around Africa. A close examination shows that while some countries, such as Rwanda, Ethiopia, Zimbabwe, Nigeria, and Ghana, have a fairly extensive fiber 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.

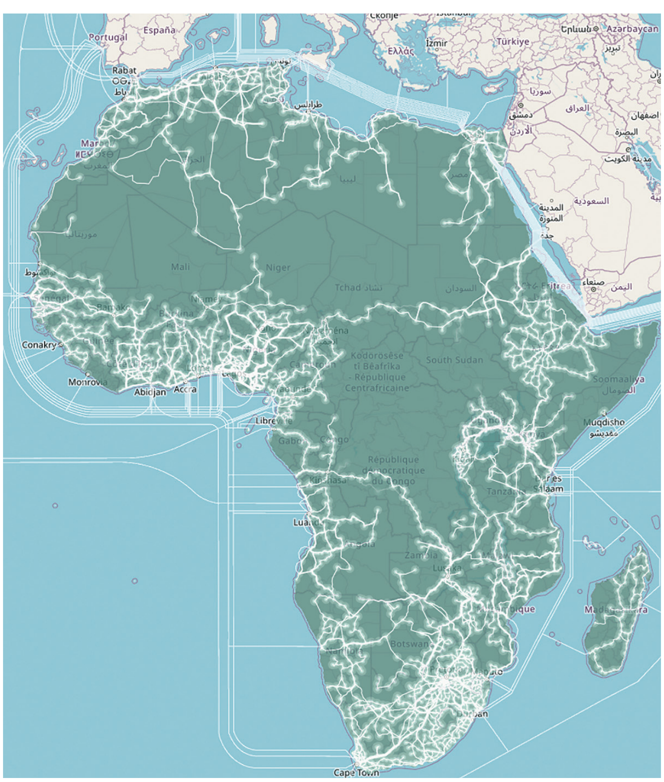

Figure 4: Terrestrial fibre within and around Africa
Source: www.africabandwidthmaps.com/fibrereach/

Various factors contribute to the gaps in terrestrial connectivity across Africa, as follows:

i. Despite multiple efforts at policy and regulatory harmonization,[18],[19],[20] countries in Africa, even within the same economic blocks, still have different ICT-sector policy and regulatory environments and various financial and taxation policies with which licensed providers must be compliant. This makes it difficult for providers to build and operate regional (multi-country) infrastructure and to offer similar prices across countries for the same service.

ii. Limited competition in backbone infrastructure (de facto monopoly, either private or public) in the countries through which a cable must transit, leading to high transit costs.

iii. Disparities in the quality of terrestrial fiber connections, ongoing vandalism, and fiber cuts during other construction works—especially roads.

As a result of the absence, and/or the high costs of terrestrial east-west and north-south cables, the routing of traffic from east to west or south to north has tended to rely on marine fiber, which, while much cheaper, also introduces high levels of latency.

Existence and Effectiveness of RRENs

The connectivity of HEIs to international submarine cables is in most cases coordinated through RRENs. With the possible exception of TENET in South Africa, which has been supported by the government for a long time through research funding, all other NRENs that have made substantial progress in Africa have benefited from working through the regional model.[21] RRENs have made access to lower-cost international and regional bandwidth possible because they leverage demand aggregation at both national and regional levels.

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

19 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

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

21 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.

Three major RRENs cover Africa: ASREN,[22] which connects North Africa but whose core members are outside Africa; WACREN,[23] and UA.[24]

Table 4 gives the NREN membership in each of these regional RENs and also shows countries in each region that do not have any NRENs. ASREN, WACREN, and UA aggregate traffic from over 20 countries across Africa, as shown in Figure 5, and interconnect with the pan-European GÉANT network to reach Europe as well as RRENs in other parts of the world.

Table 4: NREN members of RRENs in Africa

ASREN Members	UbuntuNet Members	WACREN Members
Algeria: ARN	Botswana: BotsREN	Benin: RBER
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[25]

22 ASREN website, http://asrenorg.net.
23 WACREN website, https://www.wacren.net.
24 UA website, https://www.ubuntunet.net.
25 Other Arab countries that are members of ASREN but not part of Africa have been omitted from this list.

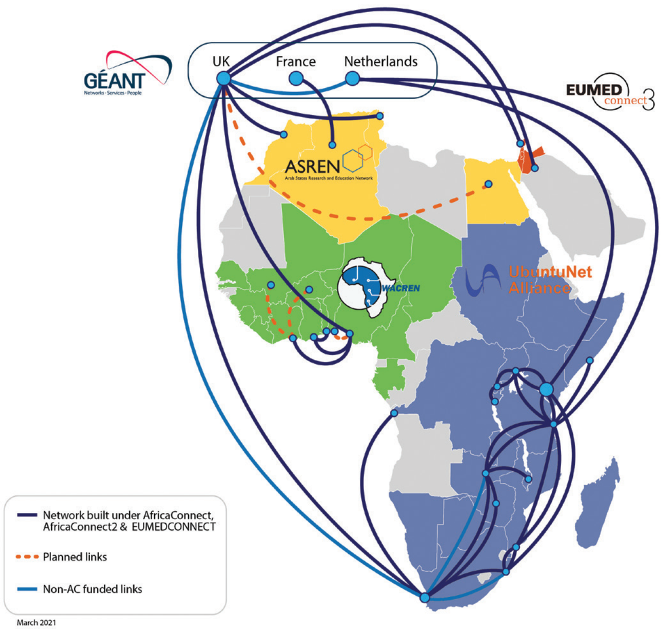

Figure 5: Coverage of African regional RENs
Source: AfricaConnect3

Significant connectivity gaps in Africa are associated with the maturity and effectiveness of the RRENs that, in the context used here, is related to the ability to roll out, operate, and maintain high-capacity regional connectivity based on NREN demands; provide sufficient global connectivity and a range of services, and enable effective regional collaboration among regional communities of practice. From this perspective, the UA is the most advanced RREN in Africa, and it is not surprising that universities in this region (even with the exclusion of South Africa) generally have much higher bandwidths at much lower prices. RRENs or similar models must, therefore, be recognized as critical success factors for the availability of sufficient connectivity, especially in the early stages of NREN development.

Availability and Sufficiency of National Connectivity

Irrespective of the cost estimates to connect 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 to HEI campuses.

National fiber coverage in Africa varies widely, influenced by geography and level of competition and investment by public and private sector operators, among others. While many countries have seen significant deployment of their national backbones, which has enabled connection to major cities, where most of the HEIs are located, last-mile connections to institutions outside major cities are still a big challenge.

The data indicate that small geographic-sized nations, such as Burundi, Cape Verde, Mauritius, Rwanda, and São Tomé and Príncipe, and digitally advanced countries, such as Morocco, South Africa, and Tunisia, have made good progress in building terrestrial backbone networks. 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, such as Egypt, have a very high concentration of the population in urban areas, where fiber networks are well-built. Over half of African countries, however, still need substantial investment into their terrestrial fiber backbone networks.

Thirty-four out of 54 African countries have at least one IXP in the country to help facilitate local traffic exchange and save expensive international transit.[26] In 2010, the Internet Society's (ISOC's) team in Africa set a target endorsed by the African IXP Association to localize 80% of internet traffic at both national and regional levels by 2020. At the country level, this has only been achieved by South Africa, with Nigeria and Kenya at about 70% of their traffic exchanged locally—the latter two make annual savings of approximately USD 40 million and USD 6 million, respectively.[27]

Thirteen out of 54 African countries have at least one carrier-neutral data center, with South Africa having 21, followed by Nigeria and Mauritius with 10 each, and Kenya with 7.

26 Africa IXP Association, http://www.af-ix.net/.
27 Internet Society, Anchoring the African Internet Ecosystem: Lessons from Kenya and Nigeria's Internet Exchange Point Growth (2020).

Existence and Effectiveness of NRENs

The current experience within sub-Saharan Africa has to date shown NRENs to be the most effective approach in accelerating a reduction in HEI connectivity costs through aggregation and economies of scale.

The NREN survey results collected during the gap analysis phase highlight a number of findings summarized in this section.

Figure 6 indicates that all NRENs (100%) serve universities, 85% serve research institutions, while 75% serve TVETs. Other types of institutions served include bodies associated with the educational sector, such as examination bodies and education sector regulators.

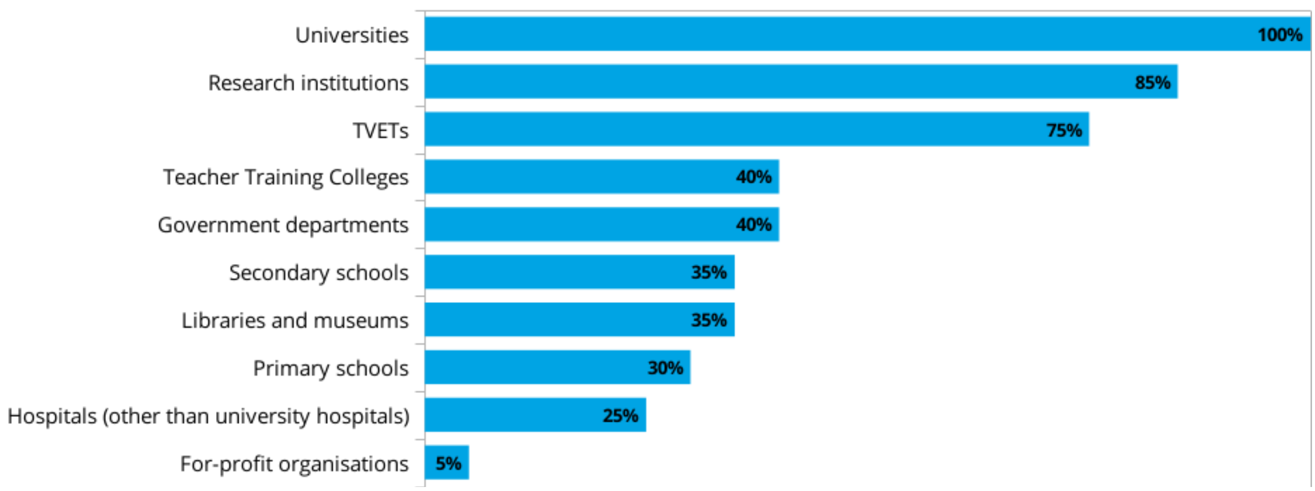

Figure 6: Types of institutions served by African NRENs
Source: NREN survey, 2020

Survey results show that African countries are at different levels of NREN development or maturity based on a number of indicators relevant to higher education connectivity. The most pertinent ones integrated into the cost model include the following (see Table 25):

i. Presence of NREN (1 point);
ii. NREN governance structure (1 point);
iii. Government recognition of NREN/NREN relationships (1 point);
iv. Variety of funding sources for NREN (1 point each for membership fees, government grants, and sale of bandwidth);
v. Whether has a network (virtual 1 point, physical 2 points);
vi. Whether NREN has an Autonomous System Number (ASN) (1 point).[28,29] This facilitates routing within the NREN network, the exchange of routing information with other network operators, and the ability to directly peer with an IXP;
vii. Whether at least one university has its own ASN that can facilitate multi-homing (1 point);
viii. Whether any ASN peers with any other networks (1 point);
ix. NREN regional/global connectivity (transit in Africa 1 point, transit in Europe 2 points);
x. Middle-ware services offered by NREN (1 point each for ICT training, DNS, NOC services);
xi. Advanced services offered by NREN (1 point each for identity and access management, data center services, video conferencing, research management tools).

28 AfriNIC is the regional internet registry that allocates these for the African region, https://afrinic.net/asn.
29 AfriNic ASN Statistics, https://stats.afrinic.net/asn/.

Using a combination of Duncan Greaves' NREN Capability Maturity Model[30] and Mike Foley's levels of NREN development,[31] different African countries can be categorized into four broad groups in terms of NREN maturity, summarized in Table 5.

Table 5: Stages of NREN development

Name	Status	Countries	Contribution to savings via aggregation
No NREN	• No established NREN • Varying levels of awareness about NREN need • Ongoing conversations • HEIs buy bandwidth directly from ISPs	Angola, Cape Verde, Central African Republic, Comoros, Republic of Congo, Eritrea, Equatorial Guinea, Eswatini, Gambia, Guinea-Bissau, Lesotho, Mauritius, São Tomé and Príncipe, Seychelles, South Sudan	0% savings
Emerging NREN	• Formal NREN established as legal entity • Formal commitment from HEIs • Formal NREN organizational structure • Without a network	Botswana, Burkina Faso, Burundi, Cameroon, Chad, Djibouti, Guinea, Liberia, Libya, Mali, Mauritania, Namibia, Niger, Sierra Leone, Sudan, Zimbabwe	30% savings
Connected NREN	• Coherent operations of NREN • With a network of varying coverage • NREN has ASN and peers with other networks • Members may also have own ASNs to support multi-homing • Offers middleware services	Algeria, Benin, Cote d'Ivoire, DRC, Egypt, Ethiopia, Gabon, Ghana, Madagascar, Malawi, Morocco, Mozambique, Nigeria, Rwanda, Senegal, Somalia, Tanzania, Togo Tunisia, Zambia	60% savings
Mature NREN	• Network with high-speed regional or global connectivity to other NRENs • Offers advanced NREN services • International collaboration and access to advanced services	Kenya, South Africa, Uganda	90% savings

Source: NREN survey, 2020

30 Greaves, NREN Model.
31 Foley, National Research and Education Networks in Africa.

Mature NRENs additionally offer a range of traditional services beyond bandwidth services, as detailed in Table 6, that other approaches to aggregation (e.g., using commercial service providers) do not provide.

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.

Table 6: Traditional NREN services

Traditional NREN services	Examples
Network services	Connectivity (ALL), eduroam, IPV6, Network Monitoring, troubleshooting, disaster recover, QoS, managed router services
Security services	CERT/CSIRT, vulnerability scanning, anti-spam solution, intrusion detection services
Identity services	Identity federation, eduroam, eduGAIN
Collaboration services	Journal access, mailing list, e-mail hosting, content management services
Multimedia services	Web conferences, events recording
Storage services	DNS hosting, cloud storage, file sender, virtual machine, web hosting
Professional services	Training and capacity building services

Source: NREN survey, 2020

NRENs charge their members a wide range of prices for bandwidth, from zero in countries such as Côte d'Ivoire, Ethiopia, Gabon, Senegal, and Tunisia (government covers the cost) to as high as $900 per Mbps/month in Chad due to the market structure and regulatory environment. Figure 7 shows that most NRENs charge between $25 and $99 per Mbps/month to account for the high cost of distributing bandwidth to members.

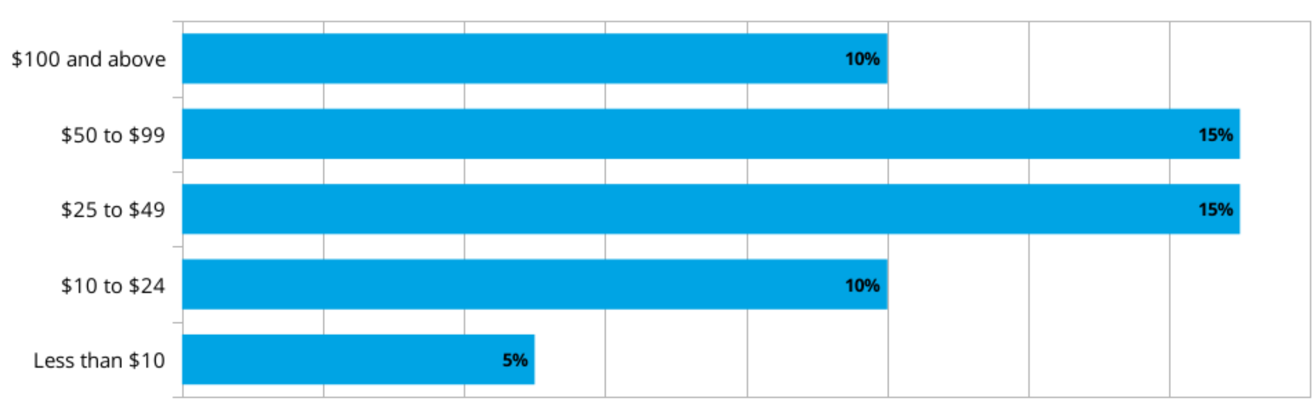

Figure 7: Amount for 1 Mbps/month charged by different NRENs
Source: NREN survey, 2020

Table 7 compares bandwidth pricing among the selected African NRENs that participated in the survey.

Table 7: 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 Survey and Interviews with CEOs, 2020

The level of maturity affects the potential savings through demand aggregation. For example, 40% of NRENs own no physical network that can be used to distribute bandwidth to members. This would potentially increase the cost of bandwidth because NRENs have to rely on other providers to deliver bandwidth to member institutions. This highlights the need to invest in better infrastructure that can be used to distribute high-speed connectivity to universities and TVETs in various countries at cheaper cost.

NRENs face many challenges, including the following:

i. Lack of awareness among both members and other stakeholders including decision makers in the ministries of education, finance, and ICT and heads of HEIs about what an NREN is and how it benefits HEIs;
ii. Constraining policy and regulatory environments that impact NREN operations and also lead to high costs of 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. Competition with commercial service providers, creating a confrontational rather than a collaborative environment;
v. Lack of sufficient funding among member institutions that also have many competing priorities, leading to defaulting on payments or late payments for services;
vi. Poor campus networks at most member institutions so that that more bandwidth does not directly result in visible changes in speed or user experience; and
vii. Low levels of technical expertise among ICT staff, along with retention challenges, within NRENs and at member institutions.

Sustainable NRENs must be recognized as a critical element in delivering sufficient and reasonably priced connectivity to universities at the national level.

NRENs owned and operated by universities are the most successful; such NRENs are responsive to the needs of the users but still need support and funding from government or governmental agencies.[32] In this model, there is mutual recognition of the roles of government on one hand and research and education institutions on the other hand in creating an effective NREN. What has emerged since the publication cited is that

> "this cooperative model, if well handled, produces the best of both worlds: availability of funding from government; and management and control by the universities through a Board and executive arrangement selected by members (with possible government representation). This model permits the NREN to be managed and operated with the structures and efficiency of a private sector organization while maintaining accountability to both government and the members. The best example of this the cooperative approach on the African continent is South Africa: While TENET started and is operated as a grassroots NREN, SANReN – owned by the government of South Africa – later brought on board high-capacity national and international connectivity that has been entrusted to TENET to manage and operate. TENET and SANReN operate under a cooperative umbrella called the South Africa NREN: SANREN. It should be noted that this cooperative arrangement can be transitioned to, regardless of whether the NREN was started by HEIs or by government, though the process can be long. A key element in achieving this is trust, which enables the strengths of each side to create the synergy required for sustainability[33]."

32 Foley, National Research and Education Networks in Africa

33 See GÉANT Policy Paper: "Breaking the Final Connectivity Barriers for Higher Education Institutions in Africa: The Next Steps and A Call to Action" (2021).

Existence and Sufficiency of Campus Networks

The quality of campus networks plays a critical role in the higher education connectivity value chain. Assessments by the Network Startup Resource Center (NSRC) and the International Network for Availability of Scientific Publication (INASP) indicate that most of the campuses in the African HEIs suffer from poor design and fragmented institutional management, with campus ICT services often seen as not critical to the institutions—which leads to lack of funding.

Availability and Sufficiency of Last-inch Connectivity: Individual Access Level

The current modern research and education environment requires that all students, researchers, and faculty have individual and full-time access to online resources and collaboration opportunities. The historical approach for universal access to computers for students at HEIs was computer labs. However, in addition to the challenges of sustainability and the growing numbers of students not resident on campus, the closing of universities during the COVID-19 lockdowns has underscored the reality that computer labs are neither sustainable nor versatile. This has accelerated the shift toward one-to-one computing. This shift brings in the challenge of the affordability of end-user devices for students that come from the poorer sections of society as a gap to be addressed.

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. Previous World Bank studies have confirmed that students from wealthier families dominate higher education enrollment in Africa and are more likely to successfully complete their studies on time.[34] But there are few families that can afford to buy computers (only about 15% of the population in Africa currently lives on more than $5.50 a day)[35] and the model will work for only a small proportion of students in Africa, raising equity challenges. It is imperative that access to end-user devices does not create another rich-poor divide, regardless of whether it is a rural or urban campus, compounding the divide that exists among students throughout their educational life.

34 Darvas, Peter, Shang Gao, Yijun Shen, and Bilal Bawany. 2017. Sharing Higher Education's Promise beyond the Few in Sub-Saharan Africa. Directions in Development.Washington, DC: World Bank. doi:10.1596/978-1-4648-1050-3.

35 https://blogs.worldbank.org/opendata/85-africans-live-less-550-day

The associated challenge, originating from lower levels of education, is the absence of, or very limited, digital literacy, which again affects the poorer sections of the population most.

Summarizing the Dimensions of Connectivity Gaps and Divides

The environment in higher education connectivity is as diverse as the countries involved; therefore, the challenges are often complicated, specific, and contextual. To these must be added the divides within the same country, which include urban versus rural locations; rich versus poor families; and level of digital literacy, which is linked to family wealth.

National ICT indicators collected during the gap analysis phase also have a direct bearing on connectivity for higher education institutors at the country level. The most pertinent integrated into the cost model include the following:

i. Whether the country is landlocked or has access to the ocean, the latter of which allows direct access to submarine cables. Direct access to submarine cables reduces base bandwidth cost.
ii. Number of submarine cable landing stations. Landlocked countries have none, while Egypt has the most with 15. More landings improve competition amongst cable providers, resulting in competitive pricing.

Internet exchange ladder stage. Countries were categorized into four stages (see Table 8) depending on the number of IXPs and carrier-neutral data centers they have as well as the interaction between these two important facilities.[36]

Table 8: Stages of the internet Exchange Ladder

Stage	Status	Countries
Stage 0	No IXP, internet traffic exchanged overseas	Algeria, Cabo Verde, Central African Republic, Chad, Comoros, Equatorial Guinea, Eritrea, Ethiopia, Guinea-Bissau, Lesotho, Libya, Mauritania, Niger, São Tomé and Príncipe, Seychelles, Sierra Leone, Somalia, South Sudan
Stage 1	Domestic internet traffic between ISPs exchanged at IXP	Benin Botswana, Burkina Faso, Cameroon, Congo, Côte d'Ivoire, Egypt, Eswatini, Gabon, Gambia, Guinea, Liberia, Madagascar, Malawi, Mali, Namibia, Rwanda, Senegal, Sudan, Tanzania, Togo, Tunisia, Zambia, Zimbabwe
Stage 2	Diversity of participants at IXP, presence of global Content Distribution Networks (CDNs)	Angola, Burundi, Democratic Republic of Congo, Mauritius, Morocco, Mozambique, Uganda
Stage 3	IXP located alongside carrier-neutral co-location data center	Djibouti, Ghana, Kenya, Nigeria, South Africa

Source: NREN survey and Interviews with CEOs, 2020

iii. Percent of population within 10 km of fiber coverage (reflects fiber network coverage of the country). This has a direct bearing on the cost of connecting especially rural campuses.
iv. Regulatory score, which reflects the maturity of regulatory environment. It is based on individual country scores from ITU Global Regulatory Outlook 2020. A good regulatory environment leads to more competitive offerings.

36 World Bank Group, 2020. National Data Infrastructure The Role of Internet Exchange Points, Content Delivery Networks, and Data Centres (was still in draft form)

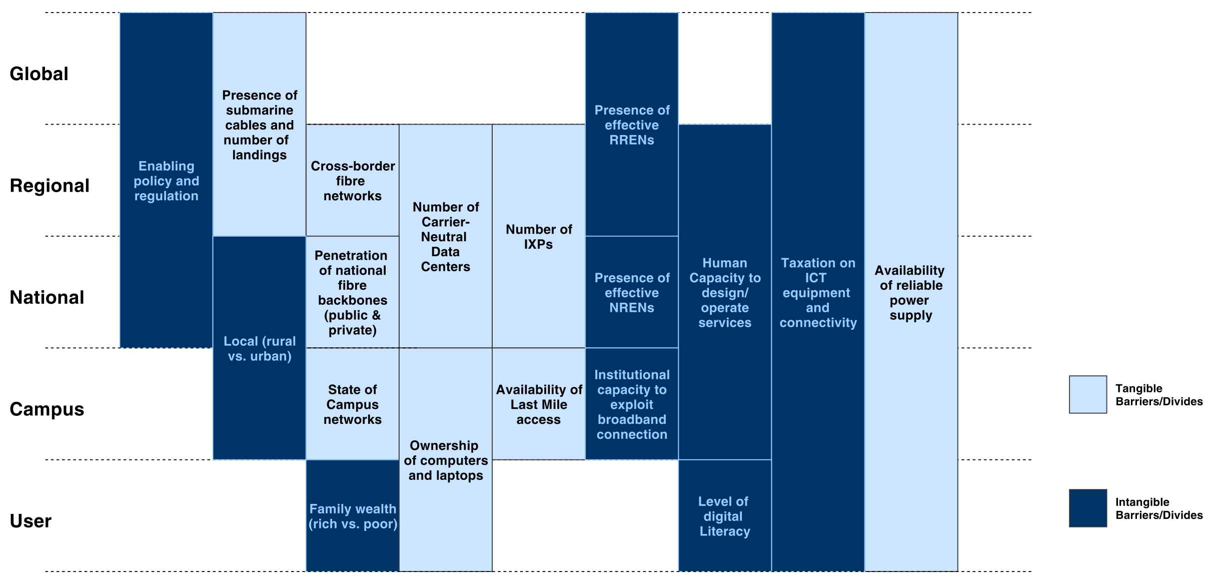

Figure 8: Tangible and intangible barriers for connecting higher education

Source: KCL

A summary of tangible and intangible barriers is given in Figure 8. It is evident from the figure that multiple variables interact and that there can be no one-size-fits-all approach to addressing the gaps. While a general intervention approach can be developed, as is done in this report, it would need to be adapted to the specific gaps and challenges in each country.

A Review of Previous and Existing Programs on the University Connectivity Agenda

Multiple multilateral development organizations, foundations, and multinational companies have been, or continue to be, actively engaged in supporting the advancement of higher education connectivity in Africa, especially over the last 20 years, underscoring the broad interest in advancing higher education in Africa. These have included, among others, the Partnership for Higher Education in Africa (PHEA), which supported the African Bandwidth Consortium; the Leland Initiative, funded through USAID and which provided wireless backbones to campuses in selected countries; and Fostering Research and Education Networking in Africa (FRENIA), funded by the Andrew W. Mellon Foundation, which provided funding for the startup of NRENs in Africa.

The International Development Research Center (IDRC) provided initial funding for NREN development and especially fostered the creation of RRENs, including the UA and the WACREN. The European Commission, through the AfricaConnect[37] Projects, has to date deployed the highest level of resources to support and grow both connectivity and other aspects of NRENs and RRENs in Africa. The World Bank has provided direct funding—Burundi, Mozambique, Tanzania, Somalia, Malawi, and Nigerian NRENs[38] are among the beneficiaries. While not planned directly for university connectivity, the World Bank Regional Communications Infrastructure Project[39] (RCIP) has benefited universities in Rwanda and, much earlier on, Kenya. The Open Society Foundation and Open Society Initiative (OSI) of South Africa have provided support to the UA.

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), which emphasizes 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 HEIs.

37 https://africaconnect3.net
38 The support to Tanzanian universities was directed through a government Ministry.
It subsequently ran into challenges of sustainability.
39 https://www.worldbank.org/en/search?q=Regional+Communications+Infrastructure+Program.

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 HEIs in Africa. These foundations have not only provided funding but also carried out considerable analyses 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 the following:

i. Multinational companies, including CISCO, Google, Intel, Juniper Networks, and Microsoft which provide tools and equipment at concessionary prices along with training opportunities;
ii. Research networks that provide technical assistance and experiential support—GÉANT Association, RedCLARA, and Internet2;
iii. The NSRC at the University of Oregon and ISOC, both of which play a major role in training NREN engineers on network operations and management; and
iv. The African Internet Registry (AfriNIC) in the delivery of IP numbers and other resources.

Table 9 shows the major partners, both previous and current, for university connectivity projects in Africa.

Focus Area	Major Partners	Support	Remarks/Lessons
Capacity building	NSRC, ISOC, GÉANT Association (formerly DANTE and TERENA), RedCLARA, OSI, CISCO, AfDB, European Union	Direct technical training and support, financial support for capacity building, sponsorship for participants, equipment	While NSRC, ISOC, and CISCO provide direct training opportunities, the GÉANT Association and more advanced NRENs open opportunities for bilateral collaboration or twinning, which 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 & Melinda Gates, Ford Foundation, PHEA, and 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 that the Carnegie Corporation of New York was a major player in driving the formation of the PHEA.
Internet resources	AfriNIC	ASN, IP numbers	AfriNIC, through negotiations led by the Research and Education Networking Unit of the Association of African Universities (AAU), 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, AfDB, 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 RRENs through discussions, attachments, and secondments. While a significant part of this has been from outside Africa, the major part has been intra-Africa.

Regional network development	European Commission	Financial resources, long-term leases for fiber	Until the funding of AfricaConnect, the EC had never funded IRUs. Earlier 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 two years before the EC gave consent. IRUs are now a common feature of GÉANT connectivity procurements.

Sources: various

A review of the different initiatives, especially the larger funding to connect higher education, such as the EU-funded AfricaConnect project, 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. Future initiatives should make an effort to bring all stakeholders around an integrated plan of intervention. The PHEA is noteworthy for bringing key American private foundations together around common causes; and the AfricaConnect programs work collaboratively among the GÉANT Association (formerly DANTE and TERENA), NSRC, and ISOC.

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. Networks 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 for such contribution but rather points to the need to get government commitment to counterpart contribution before any intervention. African governments need to step up and take ownership of the national and regional RENs as a critical development necessity. Where governments are not committed, investments will not be sustainable.

Addressing the Gaps

There are challenges and gaps at the five levels of connectivity—global, regional, national, campus, and user. An awareness gap among decision makers was also found as an important bottleneck to the development of connectivity in higher education. All the following need to be considered as part of the business and implementation plans to achieve the goal of connecting all African HEIs to high-speed internet. A gap that cannot be integrated in the business and implementation plans, but is a necessary part of any major implementation is increasing the coordination among the various partners who are either already on board or should be brought on board in order to maximize synergies.

The development of toolkits, policy briefs, and ongoing awareness workshops for decision makers will help address the awareness challenge. Ongoing platforms that bring university and TVET leaders together to discuss device access, campus networking, and NREN issues will be crucial. Development partners could also provide platforms for experience sharing among countries and promote higher ICT strategies for higher education that can serve as avenues for improved understanding of the importance of higher education connectivity.

The promotion of regional and continental collaboration to consolidate markets will attract private sector players to invest in more marine cables, transcontinental cables, and major data centers. The opportunities created by the African Continent Free Trade Agreement (AfCFTA) should be seized to this end. This goes along with regional and continental approaches to enabling policy and regulation.

National governments, once they appreciate the causal linkages between broadband connectivity and individual access in higher education on one hand and development on the other hand need to own and lead efforts at the national level to address the gaps created by policy, regulation, and limited funding for the HEIs sector. This includes support to NRENs, including enabling their start-off where they do not yet exist. The interest of government does not take away the onus on heads of HEIs to work together to set up and exploit the opportunities of NRENs, which in turn are the foundation for the RRENs. National governments must also lead policy and regulation that will attract major private sector player to establish data centers. Moreover, governments need to lead in ensuring a sufficiency of IXPs to keep local traffic local.

The sufficiency and penetration of national backbones, along with a competitive carrier environment, will lead to cost-based pricing and affordability. Eliminating monopolies; reducing the cost of licenses; enforcing the 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 fiber cuts; eliminating or reducing taxes on communication and communication equipment; and deploying universal access funds to enable broadband in remote and sparsely populated areas are all action areas under the direct control of national governments.

Campus networks as well as individual ownership of laptops remain the weakest links in the connectivity value chain. It needs to be noted that campus networks must be approached in the wider context of national-level access to enable non-resident student access and online distance learning and to create resilience of access in periods such as the COVID-19 lockdowns. Campus networks will be the most expensive area of investment. The required quality of campus networks demands the presence of a well-motivated expert ICT technical resource.

Successful interventions point to the following:

i. 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 stakeholders around an integrated plan of intervention.
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.
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 contributions but rather points to the need to get government commitment to counterpart contributions before any intervention. Where governments are not interested, investments will not be sustainable.

The WBG and the partnerships they create are in position to bring influence to bear on, and/or provide funding support for, the following supply side and demand side challenges:

i. Supply Side Challenges (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 a 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 licenses; 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 a loss in revenue that cannot necessarily be recovered without taking governments to court.

Insecurity: This is really just a reality to be recognized. 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 fiber, 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 the 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.[40]

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

40 Refer to Report 3: High-level Strategy to Leverage the Campus Connectivity to Achieve Learning Outcomes in Higher Education.

4 Context and Connectivity Gaps in Higher Education

Based on the numbers of end-users and campuses, this chapter quantifies the gaps at each of the major elements of the connectivity value chain and develops a model to provide cost estimates of the required interventions at national, regional, and continental levels. Starting with the vision and the progressive targets, the model looks at funding needed for

i. Access devices
ii. Campus networks
iii. Upstream connectivity
iv. Regional and global-level connectivity

The Vision and Progressive Targets for Connecting HEIs

These cost estimates are based on a high-level vision of connecting African HEIs to networks and services comparable to the rest of the world and the associated progressive targets.

Vision:

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

To link this to national and regional development benefit requires that these African institutions simultaneously develop the necessary pre-conditions to ensure that the 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.

This vision is not limited to the capabilities or funding from any initiative; it is rather focused entirely on where Africa desires to be. From interviews with various key stakeholders, there is a common aspiration that African HEIs should, at a minimum, be at levels comparable with the rest around the world in terms of connectivity if parity at a global level in both intellectual property output and development benefits is to be achieved.

Setting progressive targets took into account several factors, including the following:

i. The need to factor in the challenges of sustaining major investment that must, in the medium to long term, be taken up by African governments—this pulls down the level of investment.
ii. The current severely suppressed demand due to very high costs. Volume bandwidth procurements using long-term leases where applicable have been demonstrated to drive down prices sharply and therefore increase demand, leading to a virtuous cycle. This pushes up the investment.
iii. The opportunities of next-generation technologies that are coming increasingly into play, leading to much greater bandwidth volumes over existing fiber networks. This maximizes opportunities from the investment.
iv. The bandwidth requirements of commonly used applications, technologies, and resources that can support increased access to and the quality of higher education.[41]
v. The current spend on bandwidth in many HEIs around Africa would be sufficient for the volumes they need to be at par with the rest of the world if the cost of bandwidth was at par. This assures sustainability.

The progressive bandwidth targets in Table 10 with projections for 2025 and 2030 take into account these and also include comparators from around the world.

41 S. Bashir, Connecting Africa's Universities to Affordable High-Speed Broadband Internet: What Will it Take? (Washington, DC: World Bank, 2020).

Table 10: Recommended Progressive Bandwidth Targets for African HEIs

Year	Minimum Bandwidth	Remarks
2021 (target minimum)	0.2 Gbps @ 1,000	Translates to 1 Gbps for a campus of 5,000 and 10 Gbps for a campus of 50,000
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.
2030	20 Gbps @ 1,000	Translates to 100 Gbps for a campus of 5,000 and 1 Tbps for a campus of 50,000. 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: Interviews and discussions with NREN CEOs

In addition to the bandwidth targets, it is also recommended that:

Computing devices: One-to-one for both faculty and students. All faculty should own a laptop within the first year. Ownership by students should be phased in through ensuring that all first-year students can secure personal laptops over a successive number of years. Since most courses have a three-year duration, this means that all students would own a laptop by 2023—this assumes 2021 as the first year of implementation. Section 4.2 discusses the various acquisition models.

Campus networks: Functioning campus networks with external connectivity of at least 2 Gbps per 1,000 students. Moreover, ubiquitous and properly dimensioned broadband Wi-Fi should be achieved by 2025. Immediate focus should be placed on promoting reliable and functioning campus networks over the next two years. Section 4.3 presents the costing for upgrades to campus networks.

NRENs: All countries should have functioning NRENs by 2023. Capacity building along with connecting more HEIs should create opportunities for full NREN maturity by 2025.

RRENs: The three regional RENs that cover Africa have extended connectivity to all African countries and also interconnected their networks at multiple points within the continent by 2025.

Access to Laptops

While smartphones and to a greater extent tablets can support teaching and learning, they still lack the full range of attributes and functionality to serve as full-fledged individual learning platforms—the focus here is therefore transitioning to individual laptops.

Universities and TVETs have adopted many models to ensure that devices are available to students and teachers. The most common models are as follows:

i. Allowing students and faculty to BYOD
ii. Enabling ownership through an institutional scheme

The BYOD Approach

The first seeming challenge of the BYOD approach is that, based on a global population approach, there are few families that can afford to buy computers (only about 15% of the population in Africa currently lives on more than $5.50 a day),[42] and the model will work for only a small proportion of students in Africa, raising equity challenges. The reality, however, is that the nature of the education systems in most African countries is such that it is the richer families that can afford the schools that produce the overwhelming majority of students who get into HEIs through the competitive selection processes.

Where a BYOD approach is adopted, a robust acceptable use policy (AUP) that defines the code of conduct for the ethical and safe use of campus network resources, digital resources, and data in compliance with national and global privacy regulations, intellectual property rights, security, etc. should accompany the scheme. Universities will need to enforce requirements such as minimum specifications of personal devices and security measures.

Box I:

New Brunswick, Canada, Education and Early Childhood Development—Laptop Subsidy Scheme

The New Brunswick Department of Education and Early Childhood Development Bring Your Own Device (BYOD) program is aimed at students in grades 9 to 12. The program is designed to allow for more personalized learning opportunities to help better prepare students for post-secondary education and the workplace.

The Department understands that purchasing a new device may be a financial pressure for families. In response, the Department launched a financial assistance program for low- to middle-income families.

Under the program, parents and guardians have two options to help provide their student with a device:

i. Buy a device that meets the minimum device requirements (see Related Links section) and apply for reimbursement within six months of the purchase. Reimbursements can be provided by e-transfer or check.
ii. Apply for a subsidy online. Once the application is approved, families will receive a subsidy code to apply toward a laptop's online purchase.

Families that receive the full subsidy are entitled to CAN$600 toward the cost of the new laptop.

Source: https://www2.gnb.ca/content/gnb/en/services/services_renderer.201514.Laptop_Subsidy_Program.

42 https://blogs.worldbank.org/opendata/85-africans-live-less-550-day.

Institutional Schemes

Institutional schemes involve bulk educational purchase and delivery of the laptops that are then given to students either at no cost or through a partial subsidy (owner pays a portion) or through loan programs. Bulk purchase, if properly managed and negotiated, exploits economies of scale fully and could be linked to local startups for assembly and service. The management of such a scheme can also be outsourced to suppliers based on negotiated prices to reduce the management and administrative load on the institutions. Box II gives a specific example from Burkina Faso, and Box III gives examples of access and subsidy models for staff and students based on institutional schemes from around the world.

Box II:
Burkina Faso Partial Subsidy of Student's Computing Device Staff Device Subsidy Schemes

The Government of Burkina Faso aims to provide computing devices to students using a subsidy scheme. The "One Student, One Computer" scheme aims to invest US$3.8 million to provide 10,013 undergraduate students with laptops. The government intends to cover 50% of the cost with support from the World Bank. Students must cover the remaining 40% either via direct cash payment or via loan through the Coris money platform. Loans are available from the National Fund for Education and Research (FONER) or the National Centre for Information, Educational and Vocational Guidance and Scholarships (CIOSPB) for scholarship holders. A local company, Horizon Informatique SA, will distribute the computers. Ultimately the government wants to distribute computers to 50,000 students. The supplier is expected to deliver 8000 computers in 2020.

Source: https://www.ecofinagency.com/telecom/0605-41327-burkina-faso-s-govt-officially-launches-its-one-student-one-computer-program.

Box III:
Subsidy Schemes for Access to Laptops for Students and Staff

Staff Device Subsidy Schemes

i. Full subsidy for devices for teaching and learning purpose by the HEI
ii. 50% from the university budget and 50% from research grant and personal funds
iii. Subsidized access to laptops paid by staff through loans

Student Laptop Subsidy Schemes

i. Free laptop scheme—free rotating laptops for students for an academic year and returned at the end of the year or when students complete a semester. University or government pays for the laptops, which are bought on a discount basis.
ii. Laptop checkout program—laptops made available in the university library. Students use a library card to check out a laptop for short- and long-term use, with a nominal fee applied (e.g., North Western University)
iii. Laptop loaner program—many universities in developed countries provide laptops as an integral part of students' loans—a laptop loan is applied to a student loan account

Government partial subsidy (contribution) to the price of the equipment—Seychelles, for example, provides 3,000 Rupees (USD 170) toward the purchase of a computer, with the rest covered by students.[43]

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43 http://www.egov.sc/documents/ICT_LaptopScheme_20140827.pdf

Implementation and sustainability of institutional schemes can be a challenge, pointing to the need for good advance planning including stakeholder consultation. Box IV summarizes the experience and challenges in Kenya, one of the African countries that has demonstrated long-term commitment to the development of digital skills and innovation.

Box IV:

Kenya's Quest towards One-to-One computing for Students

The Kenyan government has been pursuing different models for enabling students' access to computers. The COVID-19 pandemic especially underscored the need for student devices. The Higher Education Loans Board is seeking 2.5 trillion shillings (US$23 million) to distribute laptops to first-year students via loan. The board wants to provide at least 60,000 laptops to government-sponsored students in public universities. The scheme draws on the earlier experience of the government in subsidizing computers for university students: The Wezesha scheme was launched by the Kenya ICT Board and the Ministry of Information and Communication (MoIC) in 2012. It was aimed at providing subsidized laptops for 15,667 university students. The scheme provided 9000 Kenyan shillings (US$120) towards the purchase of a laptop by university students. There were two models of laptops sold by five pre-qualified retailers. The $120 subsidy aimed to reduce the laptop price by 15% and 33%, depending on the laptop model.

Source: https://www.ictworks.org/subsidized-laptops-15667-kenyan-university-students-real-ict4edu-investment/#.YM8hay1h29Y), https://techweez.com/2020/12/08/helb-seeks-billions-to-loan-60000-laptops-to-students/

The Jomo Kenyatta University of Agriculture and Technology has also experimented with a Taifa Laptop program to assemble laptops locally, aimed to be sold to students. While this has faced some challenges, Kenya's quest for different models indicates that countries may need to adopt multiple strategies to realize the one computer per student target.

Source: https://techweez.com/2017/09/04/taifa-laptops-jkuat/, https://kiruik.medium.com/the-taifa-laptop-saga-could-jkuat-have-designed-the-program-better-9ac1d3665dcc

Estimating Laptop Costs

In order to estimate the costs of computing devices, classroom devices, user software, and data storage, a forecast of the number of university students and staff over the next five years (2021 to 2025) based on available data on the number of higher education students for all African countries is used.

Since the time series unit costs for computing devices are not readily available in Africa, average values of the unit costs for these devices (laptops and tablets and other devices such as classroom devices, data storage, software, and graphics) are used. Generally speaking, prices of devices are high in Africa due to high tax rates, often compounded by restrictive trade policies. Table 11 gives the range of costs of laptops and related software across African countries.

Table 11: Average device costs in a 1:1 computing scenario

Type of device	Description	Estimated 1:1 computing per student (USD)
Portable devices	Entry-level laptop for educational purposes	270–450[44]
Software	Word processing, spreadsheet, presentation software	36–108
Total		**306–558**

Source: Calculations draw on European 2nd Survey of IT in Schools, Objective 2: Model for a "highly equipped and connected classroom" https://ec.europa.eu/information_society/newsroom/image/document/2019-10/ictineducation_objective_2_report_final_4688F777-CDED-C240-613EE517B793385C_57736.pdf, see page 84.

44 Estimates are made on a laptop price that ranges between (USD) $270 and $450 used by three students for three years.

Aggregate Laptop Costs for Higher Education

The model gives total costs for the one-to-one ownership of laptops. How this is phased in or out, and over what period of time, will vary from country to country according to national policies and levels of poverty. It will also be influenced by the funding policies of development partners.

Table 12 provides a summary of the aggregate cost of equipping students and staff with access devices. The estimates indicate the cost of equipping first-year students and all staff would be USD 17.3 billion between 2021 and 2025.

Table 12: Cost of equipping students and staff with access devices (2021–2025)

Year	Forecast student enrollment	Forecast staff numbers	Estimated Average cost of devices (USD, million)
2021	18,741,000	848,000	3,478
2022	19,485,000	882,000	3,142
2023	20,190,000	918,000	3,256
2024	20,949,000	949,000	3,888
2025	21,659,000	985,000	3,521
Total	**101,024,000**	**4,582,000**	**17,285**

Source: KCL calculations

Upgrading Campus Networks

All campus networks need to be optimized for the intensive use of wireless services, which also lend themselves more easily to the modern learning and research environments. This does not eliminate the need for wired connections where high performance and improved stability are mission-critical. It should be noted that large numbers of non-resident students, the need for student access during holidays, and addressing the demand for off-campus students (distance education) mean that national-level eduroam needs to be considered as an extension of the campus services.

Staffing and advanced skills are vital requirements for advanced campus networks. This will include ICT engineers and application developers as well as communication and financial specialists. There is no globally agreed yardstick on the number of skilled ICT staff required for the operation of campus networks. Staff number scales based on the number of users, network devices, number of networks, security issues, complexity of routing.[45] In the private sector, one skilled ICT professional typically serves 200 to 300 users.[46] HEIs need at least one skilled ICT professional per 300 to 450 users. Table 13 summarizes the assumptions used for calculating the cost of upgrading campus networks across all African HEIs.

Table 13: Assumptions for calculating campus network upgrade costs in a country

Area	Assumptions
Student enrollment	Average number of students per institution is defined as 3,000 for a small campus, 9,000 students for a medium campus and 24,000 students for a large campus.
Number of buildings	A small campus has 2 medium and 3 large buildings, a medium campus has 4 medium and 6 large buildings while a large campus has 8 medium and 12 large buildings.
Length of back-haul fiber	A small campus needs a 5-km fiber network backbone, while medium and large campuses need a 10-km and a 20-km backbone, respectively. Assumed a unit cost of $20 per meter of laying fiber, including civil works.

45 https://verber.com/it-staffing/.
46 https://www.auvik.com/franklyit/blog/tech-user-ratio/.

Switching centers	Small campuses have a simple network with 1 switching center (with a core router and layer-3 switch), while medium campuses 2 switching centers (each with a core router) and one border router. A large campus has 3 switching centers (each with a core router) and two border routers, giving the network the ability to support 2 independent connections. Given the poor reliability of power in many African countries, each switching center will have a standby generator.
Data center	A campus needs a small data center (tier I) with racks, centralized UPS, and some servers. We budgeted 3 servers for a small campus, 9 servers for a medium campus, and 12 servers for a large campus. The data center, switching center, and network operations center (NOC) should be co-located to save on costs.
Multimedia classroom	A small campus has 1 fully integrated smart classroom with different technologies, including smartboards, projectors, cameras, speakers, audio equipment, lighting, etc. A medium campus has 3 of these, while a large campus has 5 smart classrooms.
Support to institutional library	A local area network and PCs in the main library that are connected to an online public access catalogue (OPAC).
Skilled staff	At least 1 ICT skilled professional for every 450 students that earns at least 1.5K per month to compete with the private sector. The staff should have access to one training opportunity per year in line with the needs of their institution.
Consulting and design support	Institutions should be able to access technical support to help the technical team implement various solutions that address their institution's needs. This can start with campus network design and span to other areas, including installing and maintaining various systems and equipment.
Equipment supplies and maintenance	Institutions should be able to undertake corrective and preventive maintenance to extend the campus network's life and operation.

Source: KCL calculations

Table 14 shows a summary of the estimates of the capital expenditure (CapEx) and operating expenses (OpEx), given at a regional level, for upgrading all university and TVET campus networks across Africa. The OpEx cost covers five years (a default period that can be modified in the model) and includes a maintenance component for the campus networks (15% for hardware and software costs).

It should be noted that the gross estimate of USD 27.3 billion for campus networks is based on the broad categorizations of campuses as small (< 5,000 students), medium (> 5,000 and < 15,000 students), and large (> 15,000). Small campuses account for about 94% of all HEIs and about 83% of the total cost of upgrading campus networks. Where more detailed data on campus sizes are available, the small category can be refined further into micro, mini, small, medium, large, and very large campuses. The modeling of the case study countries at this level (as provided for in the Cost Model) led to reductions in the cost of campus upgrading by 37%, 6.7%, and 32.2%, respectively, for Côte d'Ivoire, Mozambique and Uganda. This potential reduction has not been factored into the gross estimated cost in the summary because the number of countries analyzed is too small to be used as a basis for a reliable generalization across the continent—but it does point to a significant potential reduction in the gross cost.

Table 14: Summary estimates for upgrading campus networks by region (rounded to nearest 10)

Region	CapEx (USD, millions)	OpEx (USD, millions)	Total (USD, millions)
Eastern and Southern Africa	6,470	8,450	14,920
Northern Africa	1,680	2,330	4,010
Western and Central Africa	3,600	4,730	8,330
Total	**11,750**	**15,510**	**27,260**

Source: KCL calculations

Box VII:

Norwegian GigaCampus Project

In 2005, in response to the Norwegian Ministry of Education and Research, the Norwegian Association of HEIs and the higher education sector, the Norwegian NREN UNINETT launched a four-year project entitled GigaCampus 2006–2009. The project was granted financial support amounting to NOK 45.8 million (USD 5 million) to coordinate the evolution of a world-class campus ICT infrastructure around Norway. A key objective was to strengthen the community of network engineers from the various universities and colleges around the country through working groups, seminars, and workshops. They were encouraged to share their experiences on campus network development for the benefit of the whole higher education sector. GigaCampus worked within seven areas of focus that were identified as critical for campus networking, including physical infrastructure, networking and design, mobility, real-time communications, security, network operations, and monitoring. The project held a total of 47 seminars and workshops during the four-year period. The working groups produced a total of 22 best-practice documents. The knowledge exchange encompassed several issues—wireless setups with eduroam; core campus network upgrades with increased capacity, functionality and resilience; IPv6 implementations; security architecture design; network monitoring setup; etc.

GigaCampus was also involved in building campus projects, giving recommendations to the design of the data center and communication rooms. This includes cabling, power, and cooling as well as fire protection systems.

GigaCampus ran several national-level procurement processes for ICT equipment for campus networks. Thirty agreements within 10 principal fields were signed during the four years. The coordination of these purchasing operations resulted in substantial economy of scale advantages for ICT equipment in terms of price and contractual terms. The coordination and standardization of infrastructure, bringing network engineers together and agreeing on joint best practices through technical specifications, generated a long-lasting benefit for the higher education ICT community in Norway.

Source: https://services.GÉANT.net/sites/cbp/Knowledge_Base/Reports/Documents/gigacampus_final_report.pdf

Connecting Campuses Upstream

NREN as a Model of Connectivity for HEI

Following are four models for the connectivity of any HEI depending on the maturity of the NREN, the maturity of the telecommunications markets, the extent of government support, and the financial capacity of the institutions:

i. Model 1: Connecting exclusively via CSPs;
ii. Model 2: Connecting via either CSP or NREN;
iii. Model 3: Connecting exclusively via NRENs;
iv. Model 4: An emerging advanced and hybrid model, connecting to both CSPs and NRENs. In this model, CSPs provide commodity internet[47] and exchange at a far cheaper rate, while NRENs and RRENs handle research and education traffic.

Model 1 is the predominant model in countries without NRENs or with emerging NRENs. This model assumes that the CSP provisions networking infrastructure all the way to the institutional campus. The CSP provides mainly internet connectivity. The model has a major drawback in that HEIs lack easy access to the abundant resources and collaborations available through NRENs. The opportunities for taking advantage of economies of scale are limited, making this model potentially more expensive.

Model 2 is a transitional model as the NREN grows but has not reached all institutions and therefore combines bandwidth aggregation for those not connected, working with CSPs, and provides all connectivity services to those connected to the NREN. NRENs at this stage are normally focused on connectivity services, support for technical capacity building among member institutions, and improvement of campus networks.

As NRENs grow out of model 2 to model 3, they offer an increasing range of services to members, increasing the value proposition.

It should be noted that in models 1, 2, and 3, NRENs and RRENs do not make any distinction between traffic exchanged among users within the closed REN and traffic from such users to customers connected to commercial networks. This enables each institution to connect to an NREN for all types of traffic.

This is important for a developing country context because, based on the surveys as well as specific discussions with CEOs of selected NRENs, a major percentage of the traffic from most HEIs is to non-REN users, largely because research is still limited in most HEIs. Any attempt to limit access to only users and resources within the REN community would eliminate the early development of the value proposition of lower-cost connectivity.

Model 4, emphasizes the importance of CSP and NRENs working together to provide cheaper rates for HEIs. This requires various conditions to have been satisfied in the country, as follows:

i. The telecommunications market is fully mature—providing sufficient and competitive cost-based choices for all services and to all users—including universal broadband service;
ii. Competition in the provision of broadband services is high with open and fair spectrum access to make such access affordable at both the individual and institutional levels;
iii. There is sufficient penetration of IXPs and local hosting of major databases along with low peering costs;
iv. All institutions can afford and sustain the technical environment and human resources; and
v. The income from pure REN traffic and other services is sufficient to sustain the NREN.

No single African country is anywhere close to meeting these pre-conditions yet. While the existence of Model 4 is recognized, it is not included in the cost projections.

Computing Bandwidth Required and Unit Prices

To estimate bandwidth requirements for each country, forecast student enrollment is multiplied by the progressive targets (see Table 10). While the bandwidth requirement can also be estimated based on the number of institutions in a given country, it is difficult to predict the change in the number of institutions while the number of students is expected to increase exponentially over the next decade. As such, although the approach is presented in the supplementary Excel model, this report will focus only on the student enrollment-based estimation.

Based on this, Table 15 shows the projected bandwidth requirements for the African continent on a regional basis using student enrollment, giving a total of 43.3 Tbps by 2025 and 506.8 Tbps by 2030.

47 A general, commercially available connection to the "regular" internet as opposed to a special-purpose restricted network such as Internet2 or the US military's NIPRNet or some other specialized backbone network. Generally, a commodity internet connection offers no content, application protocol, or destination restrictions or quality-of-service controls; see, for example, https://serverfault.com/questions/206557/what-is-commodity-internet.

Table 15: Projected bandwidth by region using student enrollment (2021, 2025, & 2030)

Region	Projected higher education students (thousands)			Projected bandwidth requirements (Gbps)		
	2021	2025	2030	2021	2025	2030
Eastern and Southern Africa	7,470	8,716	10,314	7,470	17,432	206,281
Northern Africa	6,314	6,897	7,607	6,314	13,795	152,147
Western and Central Africa	4,957	6,046	7,416	4,957	12,091	148,326
Total	**18,741**	**21,659**	**25,337**	**18,741**	**43,318**	**506,754**

Source: KCL calculations

Figure 9 shows two ways to determine the unit price (USD/Mbps/month). The unit price of bandwidth varies widely depending on the distance from the fiber network, local access and transit costs, the maturity of the NREN, the national ICT situation, and regulatory score. The local price comprises the cheapest cost of IP transit and the cheapest cost of local access to deliver the bandwidth in a metro area within a country. IP transit is calculated based on 10 GigE volume or more from the cheapest provider in the country. Local metro access costs to deliver bandwidth to HEIs are calculated based on gigabit Ethernet (GigE) circuits where available and smaller circuits in locations without big capacities, assuming that HEIs are located at most 15 km from a provider's PoP in a metro/urban area.

There are a number of countries for which there are no such data. Consequently, average costs were taken at the regional level and applied to all the countries according to location (see Table 16—Local Price).

Instead of using the cheapest provider prices in-country, procurement negotiations that use the cheapest rates from within the region/vicinity can alter the upstream connectivity cost dramatically, and this is the Regional Price (see Table 16—Regional Price).

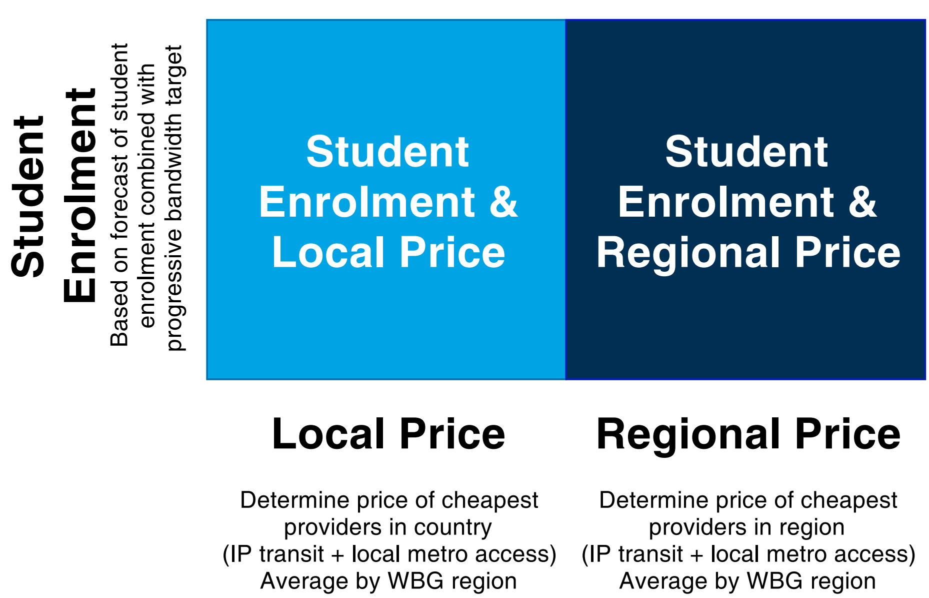

Figure 9: Matrix for determining bandwidth cost

Source: KCL

Table 16: Variation in unit cost price for bandwidth by region

	Local Price (Average rate derived from IP transit and local metro access rates of cheapest provider in country)			Regional Price (Average rate derived from IP transit and local metro access rates of cheapest provider in region)		
	IP transit (USD/Mbps/ month)	Metro access (USD/Mbps/ Month)	Total (USD/ Mbps/ month)	IP transit (USD/Mbps/ month)	Metro access (USD/Mbps/ Month)	Total (USD/Mbps/ month)
Eastern and Southern Africa	48.8	3.8	52.5	10.5	3.8	14.3
Northern Africa	49.5	4.3	53.8	15.9	4.3	20.2
Western and Central Africa	50.3	1.9	52.2	2.4	1.9	4.3

Source: KCL calculations

Impact of Aggregation and Total Cost of Connecting Campuses Upstream

Aggregation refers to pooling demand before procurement in order not only to exploit economies of scale but to bring other factors into play, including market maturity (linked to national ICT indicators) and NREN maturity (linked to the capacity and competence of the NREN to connect and deliver services and the cohesiveness of the in-country NREN community). This approach is informed by the experience of the UA and NRENs in the Alliance's region working with GÉANT, where a combination of procurement based on capitalized long-term leases, smart procurement using a negotiated procedure (suitable for markets that are not yet mature), global and regional benchmarking as a basis for successive rounds of price negotiation, and regional demand aggregation (for the Alliance) as well as national demand aggregation (for the member NRENs) had the following two key outcomes:

i. The quotations in the first round of bidding went down by factors of more than 100 by the end of procurement. Figure 10 shows the drop in the best price for a protected 2xSTM-1 10-year IRU between Nairobi and Kigali, with a drop in Kampala. This very sharp drop was an outcome of the procurement process.[48]

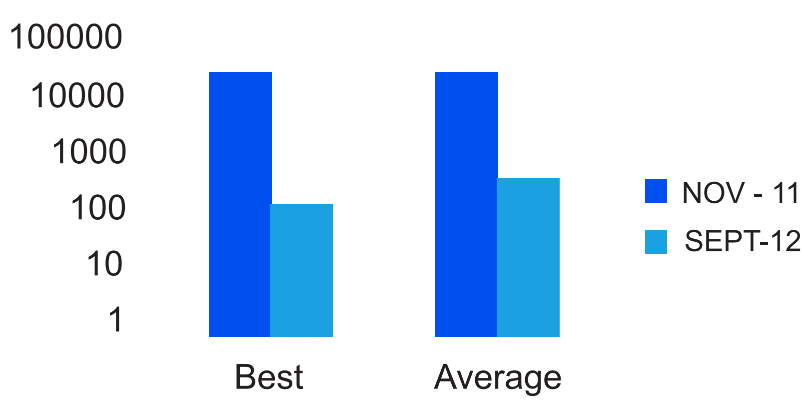

Figure 10: Price drop (USD) for 2xSTM-1 10-year IRU between Nairobi and Kigali with drop in

ii. The procurement, along with increasing sector liberalization in Eastern and Southern Africa, contributed to a major trend of market prices coming down closer to cost-related pricing.

Aggregation as well as the method of procurement are both critical in ensuring the best prices for the HEIs. Table 17 compares the total bandwidth costs for all African countries based on student enrollment using both local and regional prices discussed in section 4.4.2. The projected high impact of aggregation on cost is evident in the savings.

48 Cathrin Stöver, AfricaConnect Update, euroafrica-ict, Nov 2012, Lisbon

Table 17: Total bandwidth cost for all African countries by region using student enrollment (2025)

Region	Total (USD, millions) Using Local Prices		Total (USD, millions) Using Regional Prices		% Savings From Aggregation
	Total No Aggregation	Total With Aggregation	Total No Aggregation	Total With Aggregation	
Eastern and Southern Africa	3,790	1,484	1,381	541	60.8%
Northern Africa	5,386	1,899	1,929	680	64.7%
Western and Central Africa	5,143	1,973	614	235	61.7%
Total	**14,319**	**5,356**	**3,924**	**1,456**	**62.4%**

Source: KCL calculations

Table 18 provides a summary of the total costs for bandwidth indicated in Table 17 for five years starting with the first year of implementation, the initial assumed period being 2021–2025 inclusive. It is also assumed that smart procurement strategies (e.g., benchmarking regional pricing) combined with the procurement of long-term leases will be used to secure the best price advantage.

Table 18: Summary of total cost of connecting all African HEIs to upstream bandwidth for five years

Category	Cost (USD, millions) rounded to nearest 10	
	With Aggregation	No Aggregation
Using Student Enrollment & Local Prices	26,780	71,595
Using Student Enrollment & Regional Prices	7,280	19,620

Source: KCL calculations

Strengthening and Sustaining NRENs

Creating, strengthening, and sustaining NRENs is important to ensure that demand is aggregated and that HEIs have access to shared capacity building initiatives and global research and education resources. The CapEx of NRENs includes the initial network design cost, the cost for the purchase and upgrade of optical switching equipment, and the cost of connecting to university campus network nodes, as summarized in Table 19. Where NRENs are used as the basis for aggregating bandwidth demand for HEIs, investment made in long-term leases for bandwidth will provide NRENs with the necessary resources for CapEx.

Table 19: CapEx and OpEx elements for NREN development

CapEx Elements	OpEx Elements
Initial network design cost	Training and skills
Cost of connectivity lease, IRU or trade, internet connection	Staffing, management, oversight, and governance
Initial optical and switching equipment	Network O&M
Engineering and contracts	Communication and outreach
Physical installation and inter-campus connection	Network services
	Overheads

Source: KCL

NREN OpEx includes staffing, management and oversight expense, training and skills development both for NREN managers and member universities, network operations and management, and communication and outreach.

Discussions with NREN CEOs in Africa indicate that they spend about 60% of their OpEx on connectivity-related expenses (e.g., network services, network O&M) and the remaining 40% on human resources and related costs. While member institutions cover connectivity-related expenses through payments for bandwidth, NRENs often face major challenges in trying to cover core costs as well as costs related to ongoing capacity building for both internal staff and especially member institutions. Supporting NRENs until both their income combined with ongoing government support can sustain them is therefore a critical part of the connectivity initiative.

Support of USD 1 million covering core costs for five years was assumed for each mature NREN, increasing USD 1.5, 2, and 2.5 million, respectively, for each connected NREN, emerging NREN, and no NREN country. The list of countries and levels of support are presented in Table 20.

Table 20: Support for Core Costs of African NRENs

State of NREN development	Countries	Proposed support per year
No NREN	Angola, Cape Verde, Central African Republic, Comoros, Republic of Congo, Eritrea, Equatorial Guinea, Eswatini, Gambia, Guinea-Bissau, Lesotho, Mauritius, São Tomé and Príncipe, Seychelles, South Sudan (15)	USD 2.5 million per country, USD 12.5 million per country over 5 years: USD 187.5 million
Emerging NREN	Botswana, Burkina Faso, Burundi, Cameroon, Chad, Djibouti, Guinea, Liberia, Libya, Mali, Mauritania, Namibia, Niger, Sierra Leone, Sudan, Zimbabwe (16)	USD 2 million per country, USD 10 million per country over 5 years: USD 160 million
Connected NREN	Algeria, Benin, Cote d'Ivoire, DRC, Egypt, Ethiopia, Gabon, Ghana, Madagascar, Malawi, Morocco, Mozambique, Nigeria, Rwanda, Senegal, Somalia, Tanzania, Togo Tunisia, Zambia (20)	USD 1.5 million per country, USD 7.5 million per country over 5 years: USD 150 million
Mature NREN	Kenya, South Africa, Uganda (3)	USD 1 million per country, USD 5 million per country over 5 years: USD 15 million

Source: KCL calculations

In aggregate, countries need about USD 513 million to accelerate NREN growth and promote network capacity building and training within each African country over the next five years.

Strengthening and Sustaining Regional RENs

The three regional RENs, WACREN, UA, and ASREN, aggregate national traffic and connect to international networks. The experience of the UA, summarized in Table 21, shows that 60% of the REN budget is spent on connectivity-related expenses, with about 40% spent on core costs (e.g., human resources and the promotion of coordination among national research and education networks).

Table 21: Cost drivers for UA budget

Regional Research and Education Network	Cost Items (2020)
UA[49] Number of countries connected: 10	CapEx investment in network costs (USD 1.1 million) Connectivity and network operation cost (USD 1.3 million) Human resources costs (USD 0.6 million) Coordination and other costs (USD 1 million) Total = USD 4 million

Source: UA[50]

In Africa, RREN transmission costs are expected to be covered by member NRENs and through international support such as the EU-funded AfricaConnect project; however, the three RRENs do need resources to continue promoting NREN development as well as training and capacity building—for member NRENs and the RRENs themselves.

Assumptions:

i. RRENs spend USD 25,000 per country for NREN development over the next five years. This includes sensitization workshops, short term consulting, and NREN business plan design.
ii. RRENs spend USD 25,000 per country for training and promotion of direct engineering assistance (DEA) over the next five years.
iii. RRENs spend USD 700,000 each, annually, to support the critical mass of human resources, including ICT engineers and application developers as well as communication and financial specialists for the next five years.

Table 22: Support for Core Costs of African RRENs

RREN	UA	WACREN	ASREN
Number of countries with membership region	24	22	10
Number of institutions	4,094	2,329	977
NREN development and promotion costs (USD millions)	3,000,000	2,750,000	1,250,000
Training and capacity building (USD millions)	3,000,000	2,750,000	1,250,000
Human resource costs (USD millions)	3,500,000	3,500,000	3,500,000
Total (USD millions)	**9,500,000**	**9,000,000**	**6,000,000**

Source: KCL calculations

In aggregate, RRENs need about USD 25 million to accelerate NREN growth and promote network capacity building and training over the next five years.

49 UbuntuNet Alliance members, https://ubuntunet.net/about/council-of-members/
50 Interviews with UbuntuNet Alliance management team

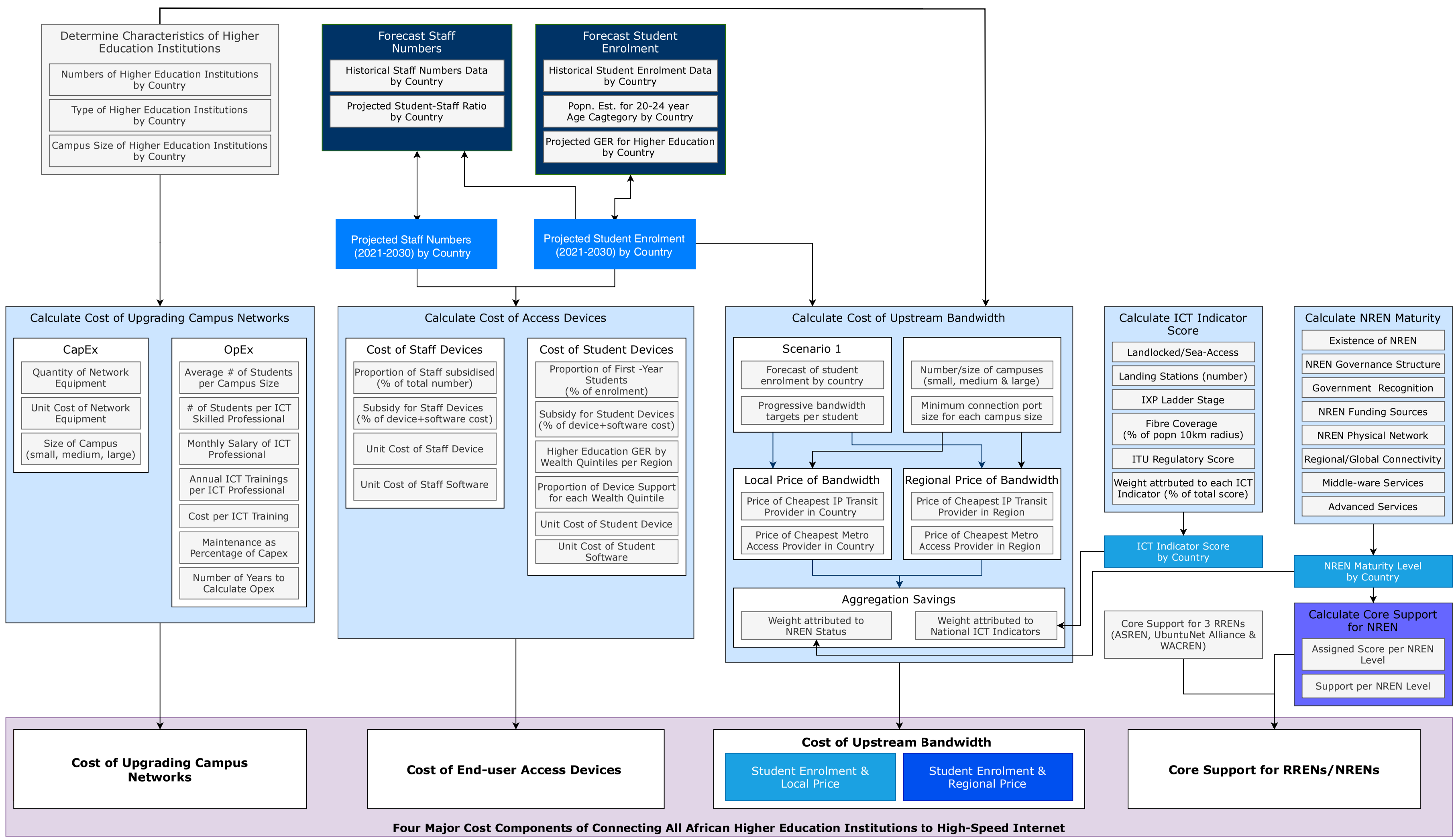

Figure 11 Connecting All African Higher Education Institutions to High–speed Internet

Cost of Connecting African Higher Education

A schematic diagram for arriving at the cost of connecting HEIs is shown in Figure 11.

Figure 12 sums up the cost elements for the different components that make up the total cost of connecting all HEIs in Africa. These include the cost of equipping students and staff with access devices, designing and upgrading campus networks and upstream bandwidth, and providing support to RRENs/NRENs.

The total costs are for five years starting with the first year of implementation, the initial assumed period being 2021 – 2025 inclusive. It is also assumed that the procurement of long-term leases combined with demand aggregation will be used to secure the best price advantages. Potential sources of funding include governments, development partners, students, and HEIs. Actual proportions will vary across countries depending on government funding priorities, development partner funding guidelines, and the means of different stakeholders.

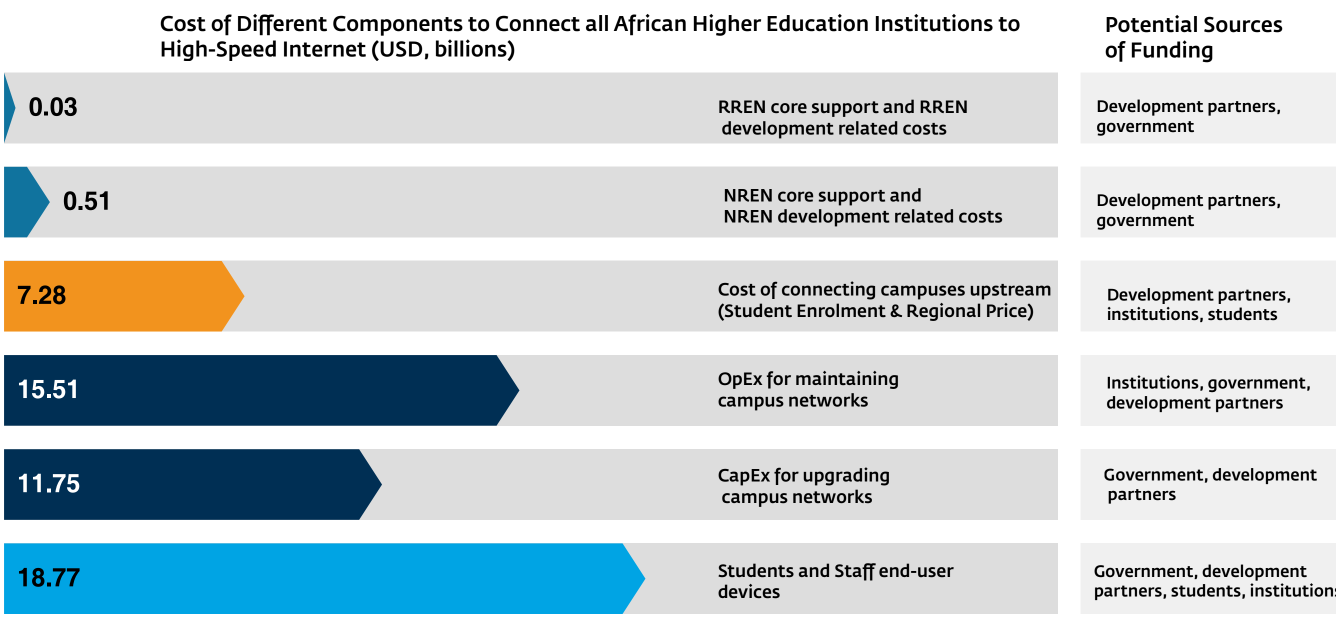

Figure 12: Summary of total cost (USD, billions) of connecting all African higher education institutions to high-speed internet

Source: KCL calculations

It is evident from the above that African countries need about USD 52 billion to connect all HEIs to high-speed internet. This cost can be reduced further if bandwidth prices are reduced to reasonable levels of USD 10 per Mbps/month or less.

5 Leveraging Broadband Connectivity for Improved Learning Outcomes

While getting connected to the internet is crucial, it requires a much broader effort to shift teaching practices to approaches that enhance students' learning ability to meet the new demands of the job market. Learning requires students that are ready to learn, effective teaching that is supported by inputs such as digital technologies, and skilled higher education management that pulls everything together.[51]

While curriculum, pedagogy, and assessment are key elements of the solution, the focus here is therefore on the key ICT-related impediments to the integration of technology into learning and research and recommending a roadmap for addressing them.

The integration of technology in higher education to enable better learning outcomes and academic excellence, foster research and innovation, and achieve greater operational efficiency needs to be accompanied by a digital technology integration vision, policies and strategies, a change in processes, and a shift of the mindsets of people—such as students, administrators, and faculty. A well-staffed corporate ICT department, with highly skilled engineers and a user support team, is as critical as is the presence of technology-savvy teachers and administrators that facilitate students' success in digital technology-enriched learning environments. The heads of the HEIs must lead the way in the integration of digital technologies in the instructional, research, and administrative realms.

There are several well-known impediments to the integration of ICT in support of learning, research, and effective administration in HEIs. These include the following:

i. The absence of, or deficient, ICT policies and strategies, which often arises from lack of awareness of the role of higher education connectivity
ii. Limited ICT awareness and ICT literacy among faculty and administrators
iii. Limited competence of campus ICT personnel
iv. The poor quality of campus networks
v. Poor digital learning spaces
vi. Limitations in resource allocation and coordination
vii. Limited individual access
viii. Limited digital learning resources

All these have to be addressed if the opportunities of broadband connectivity are to be exploited for improved learning and research outcomes.

Deficient ICT Policy and Strategy[52]

A major challenge in many HEIs is the absence of, or deficiencies in the policies that provide for the strategic vision and plan for application of ICT in learning, research, and administrative effectiveness, often because ICT is considered a technology add-on to other policies rather than a priority strategic intervention. A good institutional ICT policy should do the following:

i. Define "the why" and objectives of ICT with respect to the HEI's mission of learning, research, and community outreach, which must also be supported by administrative effectiveness. The policy and strategy should be guided by the strategic priorities of the university or TVET institution.
ii. Define the institutional positioning and organizational arrangements related to ICT in all aspects of the HEI's activities. It is particularly important to note that the direction of ICT in the organization is:
    a) Guided by the aspirations of the business units (learning, research, library, management, and administration), not by ICT personnel.
    b) Requires consensus among stakeholders to minimize the likelihood of system failure even when technical success is achieved.
iii. Define high-level priorities for the key information systems and corporate databases, infrastructure policy, security policy, and AUP. All these would be expanded into planning and operational documents at the implementation level.
iv. Define a transformation enterprise architecture and roadmap for higher education.
v. Address burning issues, such as foundational and capability gaps.

51 World Bank, World Development Report 2018 (WDR 2018)—LEARNING to Realize Education's Promise, https://www.worldbank.org/en/publication/wdr2018.

52 See, e.g., F. F. Tusubira and Nora Mulira, "Integration of ICT in Organisations: Challenges and Best Practice Recommendations Based on the Experience of Makerere University and Other Organisations," http://ahero.uwc.ac.za/index.php?module=cshe&action=viewtitle&id=cshe_426.

vi. Define the ICT management, control, and maintenance unit, ensuring that it reports to the top level of the HEI as its role is cross-cutting.
vii. Provide an implementation Master Plan and Budget that guides prioritization and integration in the HEI expenditure plans.
viii. Provides for annual review and adaptability in recognition of the rapid evolution of the opportunities created by technology.

Limited ICT Awareness and ICT Literacy among Faculty

In HEIs, faculty are always part of any key decision. While the younger faculty are largely ICT literate, the decision levels are still dominated by the older generation, who went through their schooling to postgraduate level without experiencing ICT-enabled learning and research environments. This drives appreciation down, fuels resistance, and impedes key decisions around ICT that would lead to major changes in all aspects of achieving the HEI mission. Across higher education, the improvement of faculty skills in the latest tools and technologies and ability in leveraging digital tools to conduct teaching, assessment, and research should therefore be given high priority.

The shortage of skills is often acute in the computer sciences and other ICT-intensive fields. Digital skills are inherently practical, and staff who can teach by example and understand business applications for these skills can ensure their relevance to market needs.

It is particularly important to develop and follow comprehensive change management strategies to bring faculty on board in both formulating enterprise architecture and ICT policy and strategy and leading their own individual transformation.

Limited Competence of Campus ICT Personnel

The development of campus ICT environments depends greatly on the availability of skills and resources. One of the biggest challenges to HEIs with respect to hiring, developing, and retaining competent ICT human resources in African HEIs is direct competition with the rapidly growing ICT private sector. With the exception of very large and well-endowed institutions, HEIs cannot hope to compete sustainably with the private sector for expert ICT human resources and will need to adopt different approaches, which include the following:

i. Leveraging the continuous flow of engineering and other ICT students on campuses; these are always looking for practical training opportunities as part of their courses, are innovative, and offer free services in exchange for training. They are also able to work as interns at modest costs.
ii. Sharing a pool of professionals so that cost is distributed among different institutions and/or outsourcing services, where it is more cost-effective to do that than having full-time staff in particular disciplines.

Just as faculty need to understand and appreciate the importance of, and how to use, ICT in learning, research, administration, and management, it is critical for ICT personnel to understand and appreciate the importance of letting business owners lead in defining functionality. ICT personnel particularly need to understand enough about learning, research, library services, administration, and other campus business processes to provide support that is empathetic and relevant.

Poor Quality of Campus Networks

The GÉANT Association has, through the AfricaConnect project and working with ISOC and NSRC (Box III), funded a great deal of the DEA in the design of campus networks across Africa, bringing out the importance of ongoing technical support and training in the latest campus network design techniques. Further, drawing on the European experience, there is a need for national initiatives that facilitate the sharing of experience on-campus networking design and technology environments. Such initiatives should allow HEIs to organize workshops to share campus network experiences; set up working groups around design, infrastructure, mobility, security, identity management, etc. issues; coordinate the purchase of network equipment to benefit from economies of scale; and develop a shared national campus best practices repository.[53]

Infrastructure is another important aspect that determines the quality of campus network. Putting campus connectivity infrastructure, such as cable, copper, and fiber optics, in place presents a significant challenge because most of the buildings in higher education on the continent were designed for the traditional teaching and learning environment. The alteration of these buildings is often complicated—in some cases, the presence of asbestos makes this hazardous for IT experts in wiring the building.

53. GÉANT, Campus Best Practices, https://services.geant.net/sites/cbp/Knowledge_Base/Reports/Documents/geant-campus-best-practices.pdf.

Resource Allocation and Coordination

Resource constraints, including the funding of HEIs, are considered challenges to the under-resourced campus networks. This is compounded where senior management and faculty are not familiar with the critical importance of well-resourced, well-designed, and functioning campus networks to achieve organizational objectives.

Most HEIs have small and fragmented ICT support departments. Consequently, there is limited coordination in providing resources and centralizing the design and implementation of the different information systems, often with some departments acquiring donated equipment that may not be compatible with the network, raising disputes between departments and central IT management.

Resource allocation and coordination challenges will need to be addressed through enterprise architecture that serves as a blueprint for higher education business processes, the information needed and supporting technologies, and ICT policy and strategy and change management.

Digitally-Enriched Learning Spaces

Digital and physical learning space is increasingly becoming an important aspect of student-centered learning. Higher education spaces are typically designed for traditional teaching methods and therefore need to be upgraded to meet the growing blended learning requirement. African higher education needs to develop and adapt its physical learning spaces to facilitate the integration of technology into the classroom (e.g., through the use of smart classrooms), campus, and residences and also to ensure that virtual learning spaces are safe.

The ministries of higher education and those responsible for infrastructure need to develop new building codes that help create modern institutions with blended learning. The physical and architectural design of new educational institutions should take the need for interactive classrooms and digital-enabled learning into consideration.

To ensure the safety of the virtual environment, universities and TVETs need to develop risk-based security strategies that keep pace with security threats and challenges and ensure adherence to acceptable technology use policies by students and faculty. This will increase safe learning and caring in increasingly digital environments.

Limited ICT Literacy and Individual Ownership of Laptops

Limited ICT literacy among students and the limited individual ownership of laptops create a vicious cycle—unfortunately, a combination of poverty and school systems where ICT literacy is not addressed as a key area of learning mean that a major section of the student population needs remedial intervention as a first-year requirement. Some HEIs have instituted remedial learning, such as based on the International Computer Driving License (ICDL)[54] structure or other, but the success of this is constrained by the limited ownership of laptops.

It is evident that programs to ensure access to owned computers[55] and address ICT literacy for first-year students must be part of the interventions aimed at addressing the remaining ICT-related challenges.

Limited Digital Learning Resources

Related to limited skills among faculty is the shortage of digital learning resources. While there is a growing trend toward massive open online courses (MOOCs) and small private open courses (SPOCs), efforts to develop African MOOCs and 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 is expected to be low, particularly if studying for certificates, because individual students must meet their own costs. While efforts have started,[58],[59] these are still limited to South Africa[60] and Northern African countries such as Egypt, Morocco and Tunisia.

The development of Study Webs of Active Learning for Young Aspiring Minds (SWAYAM)[61] in India provides a great example of how such a MOOC can be launched and maintained with access, equity, and quality in mind.

54 https://icdlafrica.org.
55 Refer to Report 2: Cost Estimates for Connecting All African HEIs.
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://trueafrica.co/lists/e-learning-platforms-africa-tutor-ng-mest-school-education-startups/
59 https://www.atingi.org/en/tool
60 https://www.news.uct.ac.za/article/-2020-04-29-massive-uptake-in-mooc-participation
61 Majumder, C., 2019. SWAYAM: The Dream Initiative of India and its uses in Education.

Strategy and Roadmap for Change

Change at the infrastructure/technology level is easy, but the changes required will not be sustainable unless accompanied by changes in people and processes. Intervention should also be carried out at the regional, national, and institutional levels. The following four recommended strategic interventions provide the framework under which detailed activities would be undertaken:

i. Establishing and sustaining regional partnerships with other agencies and organizations that are interested and active in digital technologies for improving learning outcomes and employability in Africa;
ii. Identifying leadership and catalyzing the formation of national-level coalitions that will be responsible for spearheading change in the integration of technology in higher education;
iii. Guiding national- and institutional-level approaches through toolkits; and
iv. Supporting specific quick-win demonstration projects.

These are expanded on in the following sections.

Establishing and Sustaining Partnerships

The success of the recommended interventions will require significant funding as well as expertise in the relevant areas of improvement or transformation. Partnerships will bring together key agencies and organizations that bring on board the following:

i. Funding (for example, European Commission, AfDB, bilateral and multilateral development agencies, private charities, the private sector, NGOs, and ICT industry both within and outside Africa);
ii. Policy leadership (for example, the African Union, the AAU, regional groupings of universities in the different regional communities, RRENs, and NRENs); and
iii. Expertise (for example, communities of practice, learning associations, RRENs and NRENs, NSRC, and ISOC).

The partnerships create resources that can work together to create synergy and generate push for the integration of ICT in higher education in the region. The PHEA[62], which brought together seven private foundations for 10 years (2000–2010), could be examined for experiential lessons about working toward a common goal through joint funding. While it might be harder for public funders to do the same, an integrated intervention plan would create the required synergy.

62 See Report on a Decade of Collaborative Foundation Investment, https://www.fordfoundation.org/media/1760/2010-accomplishments-of-the-partnership-for-higher-education-in-africa.pdf.

Formation of National-level Leadership and Coalitions

Policy is vested in the ministries responsible for higher education, and that is a necessary starting point for establishing national leadership. The ministry will, in most cases, have direct control of policy for TVETs with respect to pedagogy but will not have direct control of such policy in universities. The coalition should include the ministries responsible for ICT, science, and industry; associations of vice-chancellors, presidents, and rectors; the national bodies responsible for HEI quality, standards, and accreditation; HEI academic and business leaders and the ICT directors of HEIs; the NREN; and the ICT service providers.

The formation of such coalitions should be followed by a dialogue among these players at the national level on the integration of technology in education. A nationwide higher education ICT integration master plan that is sponsored by the relevant ministry can be a starting point for such discussion. The plan could, among others, outline strategies and steps to upgrade campus networks, improve access to devices by students and faculty, enhance the development and exchange of learning content, promote the digital skills of faculty across the country, and provide approaches to funding and sustainability.

Guiding National and Institutional-level Approaches for ICT Integration in Education

Many of the key changes required to deal with the ICT-related gaps are not context specific and can therefore be guided by toolkits that provide menus of choices and also point to resources. Toolkits and/or guidelines can be developed for the following specific areas:

i. Institutional enterprise architecture and ICT policy and strategy development and implementation
ii. The roles, membership, and structure of the National Level Leadership Team
iii. Laptop ownership strategies that ensure sustainable interventions
iv. Sustainability strategies for major initiatives
v. Campus network design principles and blueprints
vi. Effective methods for building faculty digital skills[63]
vii. The development of MOOCs and SPOCs
viii. The development of digital technology integration self-assessment tools.

63 See, for example, the all aboard initiative in Ireland, https://www.allaboardhe.ie/.

Support for Specific High-impact Interventions and Quick-win Demonstrators

In addition to any major systemic interventions, there are various opportunities for specific interventions that would accelerate the pace of change or support countries and institutions that come up with quick-win proposals. The following attributes should be satisfied by each:

i. Should be in one of the key areas where change is required;
ii. Should be bedded in a supportive policy and strategy environment;
iii. Should bring on board a good number of the key stakeholders around the initiative;
iv. Should be based on a strong theory of change with measurable outcome indicators; and
v. Should have significant internal funding to show ownership along with a realistic sustainability plan.

Possible high-impact interventions and demonstrators include the following:

i. Working with regional RENs, the identification of universities in Africa and other developing regions, as well as those than can provide good examples in more advanced countries, as an aide to peer-learning and twinning in creating digitalized campuses. Several African NRENs were able to develop through peer-learning and twinning arrangements, and this is an approach that can produce visible high impact in a short period of time.
ii. Working with regional university associations, MOOCs and SPOCs providers rolling out comprehensive ICT-enabled learning in selected pilot courses across selected locations as demonstrators and program learning opportunities.
iii. Working with NRENs in developing national blueprints for digital campuses, and leading their rollout and implementation, along with capacity building for campus ICT staff; developing/updating and rolling out training programs to develop awareness among HEI governance, management, and faculty levels and skills for faculty, administrative staff, and students; and supporting the development and rollout of shared skills and resources, including human expertise.
iv. While regional- and national-level initiatives are essential, real progress can only be made at institutional levels. This leads to the support of selected HEIs to measure progress and facilitate knowledge exchange on how best to create digitalized higher education environments with a focus on the following:

    a) The development/updating of institutional ICT policies to ensure digital technologies are fully integrated into teaching, learning, and administration;

    b) Designing and implementing a robust campus digital infrastructure;

    c) The design of digital services with consideration for accessibility to all devices (mobile phones, tablets, computers, and future devices);

    d) Evaluating physical spaces in relation to changing pedagogical models, accessibility needs, and emerging instructional technologies and fostering innovation in learning spaces;

    e) Staffing IT operation departments and motivating and retaining engineers and a support team;

    f) Developing, implementing, adapting, and sharing lessons on AUPs; and

    g) Sharing ICT expertise with other institutions.

Implementation

Leveraging connectivity, as outlined in this section, involves major initiatives, with multiple elements and inter-relationships. The recommendations, therefore, need to be examined in considerable depth as part of implementation planning. Everything proposed above is doable and achievable within clear time-frames, depending on policy-level commitment and the availability of sufficient funding.

The impediments discussed above provide the starting-state of digitalization in higher education. The end-state would be fully digitalized campuses where all categories of users, both on and off campus, can exploit the opportunities of digital technologies for their work—with competent ICT support staff enabled by sustainable funding to maintain the resources in optimum working condition. The rapid evolution of technology, however, means that change and improvement are open-ended processes. While funding from external sources remains critical for the achievement of progress for up to five years or more and then phasing out over another five years, consistent funding from HEIs and national governments should be available to ensure that national economies continue benefiting from the returns from digitalized HEI campuses.

6 Looking Ahead

The following key considerations are important when looking ahead at implementation:

i. First, there is a need for increasing awareness among decision makers about the different connectivity issues and challenges. This is especially important for those in the ministries of education, ministries responsible for digital technologies, ministries responsible for finance and investment, and HEI leaders. An awareness of the magnitude of the challenges (e.g., the need for access to computing devices, the importance of the upgrading of campus networks, NREN development) is critical to ensure that adequate resources are available for higher education connectivity.
ii. Second, there is a need for accelerating connectivity to facilitate teaching, research, learning, and administration in higher education in order to improve learning outcomes.
iii. Third, connectivity should be accompanied by the digitalization of campuses, building ICT literacy among staff and students and enabling the individual ownership of laptops to support reforms in learning and new ways of teaching digital and soft skills to meet the demands of 21st-century jobs.
iv. Fourth, coordination is an essential prerequisite for achieving higher education connectivity and attaining reforms in learning and digital skills.

Government and development partners need to work together to push the connectivity, learning, and digital-skills agenda forward, which demands

i. Engaging stakeholders;
ii. Cost sharing at all levels; and
iii. Adhering to and implementing a timeline for connecting HEIs in Africa.

Key required policy interventions to address the availability and sufficiency of regional connectivity include

i. Harmonizing ICT policy and regulation across neighboring countries or within regional blocks. Some of these can be addressed through the now-operational African Continent Free Trade Agreement (AfCFTA).
ii. Creating incentives to attract investment in inland data centers, which will attract major carriers to roll out more inland capacity and facilitate more exchange of local traffic.
iii. Minimizing barriers for cross-border infrastructure, such as by eliminating the need for national licenses to exchange traffic at IXPs to enable regional traffic exchange or minimizing the licenses required for multi-country fiber projects.

There are a number of policies that can help to improve the availability and sufficiency of national backbone networks by increasing competition and reducing prices through increased investment. These include the following:

i. Eliminating monopoly provisions from the market structure;
ii. Reducing the cost of operator and spectrum licenses, hence the barriers to entry and costs to the end-user;
iii. Enforcing the 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 fiber cuts;
v. Eliminating or reducing taxes on communication and communication equipment, which will reduce end-user costs and drive-up demand; and
vi. Deploying universal access funds that have provided funds for infrastructure in remote and sparsely populated areas of the country.

The development of the campus ICT environment depends mainly on the availability of skills and resources. In addition to increasing higher education leaders' awareness of the importance of the digital environment for improved teaching, learning, and research, there is a need for:

i. Designing campus networks for changing learning and teaching requirements, including advanced research, innovation, and digital entrepreneurship;
ii. Improving the skills of the technical teams in HEIs through DEA;
iii. Investing in engineers and IT staff to maintain and grow the campus network facilities and services;
iv. Investing in campus-wide digital infrastructure, in particular local area networks, network monitoring and management systems, identity management systems, wireless services, data storage, and high-performance computing; and
v. Developing AUPs, which should be communicated to end-users to make them aware of the services available to them and should state the end-users' rights and obligations regarding how they use those services.

Engaging Stakeholders

While the specific approach to each stakeholder is different, there must be common key messages. The following are recommended as key messages:

i. Ensuring that all African HEIs are connected to broadband will lead to global economic benefit;
ii. Getting connectivity and individual laptop access to all students and staff in African HEIs will require USD 52 billion over the next five years;
iii. There is a need for coordination among development agencies to create synergy; and
iv. African countries must take ownership and make contributions to the initiative.

Table 23 lists the key stakeholders that need to be brought on board, and their potential roles. The stakeholders may be beneficiaries—the primary target of the interventions or implementers—possess the technical know-how to implement ICT in HEIs at the campus, national, and regional levels. The roles entail a range of different activities, which include the following:

i. Planning, policy, and regulation—positioned to ensure both policy and regulation as well as the integration of access to broadband as key elements of national and regional development initiatives.
ii. Funding—positioned to directly fund and, because of the nature of the organization, to be able to mobilize additional funding from other partners.
iii. Knowledge—possessing documented experience, research findings, best practices, and toolkits that can guide all the different roles on different aspects of ICT integration in higher education.
iv. Capacity building—provide direct training opportunities, opportunities for bilateral collaboration or twinning, and attachments and secondments for staff.
v. Content—positioned to provide or guide the development and distribution of learning content for HEIs.
vi. Publicity—positioned to disseminate the key messages effectively as both a mobilization and partnership sustainability tool.

Table 23: List of key stakeholders

	Organization/ Country/Region	Implementer	Beneficiary	Planning, Policy, and Regulation	Funding	Knowledge	Capacity Building	Content	Publicity
1	AU, AUC, regional economic communities (RECs), UNECA, African countries		X	X	X	X			X
2	Ministers responsible for higher education, ICT, Finance and Economic Development and national planning Agencies	X		X	X				X
3	AAU and Regional University Associations (IUCEA, SARUA, AWAU)		X	X		X			X
4	Staff and Student Associations		X		X				X
5	African RRENs and NRENs	X	X			X	X	X	X
6	African national regulatory agencies and regional regulatory organizations (CRASA, EACO, WATRA)			X	X				X
7	The World Bank				X	X	X		X
8	European Union				X	X			
9	AfDB	X		X	X	X			
10	Other multilateral agencies (e.g., UNESCO, ITU, UNDP, UNCTAD)			X	X	X	X		X
11	Major private foundations (e.g., PHEA, Bill & Melinda Gates, MasterCard Foundation)				X	X			X
12	Bilateral donors (e.g., USAID, Sida, SDC, GIZ, IDRC/CIDA, DANIDA, FDCO/UK, JICA, KOICA)				X	X	X		
13	Advanced RRENs—APAN, GÉANT Association, RedCLARA, Internet2, TEIN	X				X	X		X
14	Agencies from new economic power centers				X				
15	Major connectivity and equipment providers (e.g., WIOCC, Seacom, Hurricane, Liquid Telecom, WACS, Huawei, Cisco, Juniper)	X							X
16	Multi-national providers operating on the African continent—Bharti Airtel, MTN Group, Orange	X							X
17	Major content providers and content delivery networks (e.g., Akamai, Amazon, Cloudflare, Google, Facebook, Microsoft)	X			X			X	X
18	Major training and knowledge providers (NSRC, INASP)	X				X	X		X
19	Major policymaking and civil society organizations working on connectivity-related issues—World Economic Forum (WEF), New Partnership for Africa's Development (NEPAD), United Nations ICT Task Force, Association for Progressive Communications (APC), Alliance for Affordable Internet (A4AI)			X					X
20	Major public and private online learning content providers							X	
21	Media houses and journalists								X

Cost-sharing

Development experience has shown that sustainability requires ownership of the initiative by beneficiaries, which means having a say in the formulation and planning as well as implementation and that they need to make a contribution. An approach akin to what EUC has used for AfricaConnect is therefore recommended—beneficiaries (in this case RREN) that are still emerging contribute 20%, increasing to higher percentages as maturity increases. The actual starting percentage and how it grows will call for negotiations between funders and beneficiaries, and this would increase in steps at predefined levels of maturity.

An associated and important consideration is that beneficiaries should be prepared to meet recurring costs that, as a minimum, would be about 15% of capital investment. It is recommended that the cost of long-term leases as well as the annual O&M associated with IRUs are paid upfront for the duration of the leases and therefore capitalized upon, as has been done under the AfricaConnect project.

Implementation Timeline

Table 24 summarizes the timeline for reaching different levels of individual access, broadband, and NREN maturity. Projections beyond 2025 are not given as the rapid evolution of technology, combined with the current suppressed demand for higher education in African countries, makes projections of required connectivity and costs beyond five years unrealistic.

Parallel to these activities and also starting from the first year is developing the necessary pre-conditions in HEIs to ensure that improved connectivity translates to improved learning outcomes, a national-level activity around educational policy and regulation. Other than the right campus network environment, which is included in the cost projections, the broad range of soft activities required to achieve this are not part of the cost projections.

Table 24: Prioritizing connectivity to African higher education

<table>
<tr><th>Timeline/ priorities/</th><th>Year 1</th><th>Year 2</th><th>Year 3</th><th>Year 4</th><th>Year 5</th></tr>
<tr><td>Devices</td><td>Individual ownership for all first-year students</td><td>Individual ownership for all first-year students</td><td>Individual ownership for all first-year students</td><td>Individual ownership for all first-year students</td><td>Individual ownership for all students and staff</td></tr>
<tr><td>Campus network</td><td colspan="3">Build functioning campus networks across HEIs</td><td colspan="2">Nationwide support for evolution of a world-class campus network</td></tr>
<tr><td>Connectivity</td><td colspan="3">"All institutions progress to a goal of 2 Gbps per 1,000 students"</td><td colspan="2">"Start work toward a goal of 20 Gbps per 1,000 students"</td></tr>
<tr><td>NREN development</td><td colspan="2">Aggressive NREN development support to all countries; special focus on countries without sustainable NRENs</td><td colspan="3">Intensive support to upgrade countries to the NREN Exclusive model</td></tr>
<tr><td>RREN interconnections</td><td colspan="5">Each African country is connected though at least one regional REN, and the RRENs are interconnected at multiple points throughout the continent</td></tr>
<tr><td>Developing pre-conditions for leveraging connectivity for improved learning outcomes</td><td colspan="5">Enabling policy environments related to the use of ICT in teaching, learning, and research; curriculum; pedagogy; assessment; quality management; and industry linkages developed and implemented in HEIs along with the necessary institutional arrangements</td></tr>
</table>

Source: KCL

Ultimately, connectivity for higher education rests on the national governments. Each country needs a concerted national effort to expand connectivity, accelerate online learning, improve campus networks, and promote NREN development.

Each country needs to assemble a high-level team drawn from the ministries responsible for higher education, the ICT sector, and finance; HEIs; NREN, where present; the ICT private sector; key development partners; and other stakeholders in order to develop a national plan for connecting its HEIs and accelerate learning and digital skills for the jobs of the future.

The key strategic interventions to move this plan ahead include:

For African Governments:

- Support the development of comprehensive higher education ICT policies that address device, connectivity, campus networking, and capacity issues
- Support the development of NRENs
- Promote access to devices through national negotiation with suppliers and industry players
- Allocate resources for higher education connectivity through universal access funds and donor funding.

For Development Partners:

- Promote information exchange among countries on the different issues of connectivity
- Support projects that enhance the connectivity of higher education and those that leverage advanced networks to solve social and economic challenges.

For Leaders of HEIs:

- Support the development of NRENs
- Allocate resources to ensure sufficient bandwidth is available for higher education
- Sponsor projects that leverage connectivity to enhance teaching, learning, and research collaboration
- Serve as advocates for higher education connectivity.

For Private sector:

- Recognize the specific connectivity requirements of HEIs and engage in dialogue with NRENs to optimize service offerings, including through service level agreements
- Consider offering preferential rates or tailored service offerings for HEIs, in cooperation with REN.

Appendix A

Table 25: Maturity of NRENs in different countries

Regional REN	Country	NREN name	Has governance structure	Has government recognition/ relationships	Has variety of funding sources	Has physical network	Regional/global connectivity	Maturity stage
UA **Eastern and Southern Africa**	**Botswana**	**BotsREN**	**No**	**No**	**No**	**No**	**No**	**Emerging NREN**
	Burundi	BERNET	No	Yes	No	No	Yes	Emerging NREN
	Congo, Democratic Republic of	Eb@le	Yes	Yes	Yes	No	Yes	Emerging NREN
	Ethiopia	EtherNet	Yes	Yes	Yes	Yes	Yes	Connected NREN
	Kenya	KENET	Yes	Yes	3	Yes	Yes	Mature NREN
	Madagascar	iRENALA	Yes	Yes	Yes	No	No	Connected NREN
	Malawi	MAREN	Yes	Yes	Yes	Yes	Yes	Connected NREN
	Mozambique	MoRENet	Yes	Yes	2	Yes	Yes	Connected NREN
	Namibia	Xnet				No		Emerging NREN
	Rwanda	RwEdNet	Yes	Yes	Yes	Yes	Yes	Connected NREN
	Somalia	SomaliREN	Yes	Yes	3	No	Yes	Connected NREN
	South Africa	TENET	Yes	Yes	3	Yes	Yes	Mature NREN
	Sudan	SudREN				No	No	Emerging NREN
	Tanzania	TERNET	Yes	No	2	Yes	Yes	Connected NREN
	Uganda	RENU	Yes	Yes	2	Yes	Yes	Mature NREN
	Zambia	ZAMREN	Yes	Yes	3	Yes	Yes	Connected NREN
	Zimbabwe	ZARNet				No	Yes	Emerging NREN
WACREN **West and Central Africa**	Benin	RerBenin	Yes	Yes	Yes	Yes	Yes	Connected NREN
	Burkina Faso	FasoREN				No		Emerging NREN
	Cameroon	RIC				No	No	Emerging NREN
	Chad	TchadREN	Yes	Yes	2	No	No	Emerging NREN
	Côte d'Ivoire	RITER	Yes	Yes	2	Yes	Yes	Connected NREN
	Gabon	GabonREN	Yes	Yes	2	No	No	Connected NREN
	Ghana	GARNET	Yes	Yes	2	No		Emerging NREN
	Guinea	Gn-REN	Yes	Yes	2	No	Yes	Emerging NREN
	Liberia	LRREN				No		Emerging NREN
	Mali	MaliREN	Yes	Yes	Yes	No	Yes	Emerging NREN
	Niger	NigerREN				No		Emerging NREN
	Nigeria	NgREN	Yes	Yes	Yes	Yes	Yes	Connected NREN
	Senegal	SenRER	Yes	No	Yes	Yes	No	Connected NREN
	Sierra Leone	SLREN	Yes	Yes	Yes	No	No	Emerging NREN
	Togo	TogoRER	Yes	Yes	Yes	Yes	Yes	Connected NREN
ASREN **Northern Africa**	Algeria	ARN	Yes	Yes	Yes	Yes	Yes	Connected NREN
	Djibouti					No		Emerging NREN
	Egypt, Arab Republic of	EUN & ENSTINET	Yes	Yes	Yes	Yes	Yes	Connected NREN
	Libya	LibREN				No		Emerging NREN
	Mauritania					No		Emerging NREN
	Morocco	MARWAN	Yes	Yes	Yes	Yes	Yes	Connected NREN
	Tunisia	RNU & RNRT	Yes	Yes	Yes	Yes	Yes	Connected NREN

Appendix B

Summary of Country Case Studies—Burkina Faso, Cote d'Ivoire, Mozambique and Uganda

The four case study countries, Burkina Faso, Côte d'Ivoire, Mozambique, and Uganda, represent divergent higher education and connectivity environments. While Burkina Faso and Côte d'Ivoire are French-speaking with an education system influenced by the French model, Mozambique's and Uganda's education systems are modelled after the Portuguese and British models respectively. All four countries have made progress with enrollment in lower levels of education, but are still struggling with students' transition from lower education to higher education. Gross Enrolment Ratio (GER) for higher education in Burkina Faso was reported at 7.1% (2019), Côte d'Ivoire at 9.3% (2017), Mozambique at 7.3% (2018) and Uganda at 6.8% (2018). All are below the estimated average for sub-Saharan Africa of 9.4% (2018), and far below the world average of 38.8% (2019).

Burkina Faso provided very useful insights into and an extreme experience of the situation in a landlocked country in West Africa. Connectivity in Burkina Faso HEIs is only available for staff, not for students. In Côte d'Ivoire, the private higher education sector caters to 50% of the enrollment and relies on government subsidies, just like the national research and education network RITER, which is heavily dependent on its government subsidy to provide connectivity. The Government of Mozambique is the main provider of Mozambique's education and connectivity, thus investment by the government is critical for its enhanced connectivity. The Mozambique Research and Education Network (MoRENet) is still a project under the Ministry of Science and Technology, Higher Education and Vocational Training and provides subsidised connectivity to HEIs. Uganda, on the other hand, has a relatively matured NREN, the Research and Education Network of Uganda (RENU), owned by the HEIs, and a competitive ICT environment that has paved the way for the improved connectivity of the higher education in the country although this connectivity is yet to reach all institutions.

The Education Sector

Burkina Faso

The higher education sector in Burkina Faso comprises 18 accredited universities (10 public and 8 private) and 75 Grandes Écoles ("Great Schools" or elite HEIs with highly competitive admission requirements) (23 public and 52 private). Student enrollment in higher education in 2020 was estimated at 145,000 students with the University of Ouagadougou, the largest HEI, accounting for over 50% of total enrollment. Private sector participation in providing higher education has been increasing, currently accounting for about 21% of the total enrollment. Student enrollment is projected to grow to 297,000 students by 2030.

Based on the forecast of student enrollment and population in the age category 20–24, Burkina's GER for higher education is estimated to reach 9.8% in 2025 and 11.2% in 2030. While this will eclipse the estimated sub-Saharan Africa average of 9.1% in 2018, it is still far below the world average of 38.7 % at the time.

Connectivity at all levels of education is still a major challenge. Based on a recent survey University Ouagadougou I Professeur Joseph Ki-Zerbo, with about 70,000 students, offers only 34 Mbps to its users. Only the academic and administrative staff at the University use the connectivity provided by the university. Students have to buy their connectivity from commercial providers with coverage around the campus.

Côte d'Ivoire

There are currently 403 entities providing higher Education in Côte d'Ivoire. These include 7 public and 33 private universities, as well as 35 public and 328 private specialized schools (Grandes Écoles). Due to limited capacity, the Government has been directing new tertiary students to subsidized private institutions, which accounted for over 50% of all enrollment in 2018.

Côte d'Ivoire's literacy rate for 2018 was 58.4%. The primary and secondary schools' enrollment rates are increasing with GERs reported at 100.3% and 54.6% for primary and secondary education respectively in 2019. Like other African countries, Côte d'Ivoire is struggling with the transition of students from lower levels of education into higher education. The gross enrollment ratio (GER) for higher education was 9.3% compared to a sub-Saharan average of 9.4% and a world average of 38.8% in 2018. The population in the HEIs was 253,955 in 2019 and is projected to reach 396,000 students in 2025.

Mozambique

There are currently 53 HEIs—19 accredited universities, 27 institutes, four schools, and three academies. Student enrollment in higher education in 2020 stood at 240,000 students and is projected to grow to 380,000 by 2030. While the private sector accounts for 58.5% of all HEIs, the public sector still accounts for most student enrollment (61.5%).

Despite the growth in student enrollment, the GER for higher education in Mozambique was only 7.3% in 2018, below the estimated sub-Saharan Africa average of 9.4% and far below the world average of 38.8% for the same year.

Uganda

At the higher education level, there are currently 52 accredited universities and 184 TVETs (classified into "other degree awarding institutions" and "other tertiary institutions"). With about 259,000 students, universities have higher enrollment (72%) compared to TVETs (24%). Lower enrollment in TVETs is attributed to the negative image associated with TVETs, the general perception being that those pursuing TVET courses are failures that did not make it to university.

Based on the latest data from the National Council for Higher Education (NCHE), Uganda's GER for higher education was only 6.9% in 2018.[1] This is below the sub-Saharan Africa average of 9.4% and far below the world average of 38.8% in 2018.[2]

Education Sector Challenges

The four countries exhibit similar challenges in relation to leveraging ICT for learning. The higher education sector challenges across the four countries include:

i. Lack of an ICT policy for the sector to promote digital literacy and e-learning as an avenue to improve learning outcomes, particularly in higher education;
ii. Generally low digital literacy among both lecturers/tutors and students on how to leverage ICT for teaching and learning;
iii. Lack of knowledge and capacity on how to leverage ICT to improve teaching and learning;
iv. Very limited investment in campus ICT resources and infrastructure compounded by inadequate public funding for higher education that has not kept pace with growth in enrollment;
v. Lack of mechanisms to evaluate and identify relevant and/or appropriate digital content and applications for different levels and programs of education;
vi. Lack of an adequate pool of high-level ICT champions within higher education that can promote the adoption and use of ICTs within their institutions.

1 NCHE, The State of Higher Education Report 2017/18 (2019).
2 World Bank data, https://data.worldbank.org/indicator/SE.TER.ENRR?end=2020&locations=ZG-1W-UG&start=2010.

Communication Sector Environment

Burkina Faso

The ICT environment has been improving in Burkina Faso over the last 10 years, yet there is a still a significant market concentration that makes affordable network pricing a challenge—the duopoly between Onatel, the incumbent operator, and Orange controls the market. Broadband prices remain very high, and broadband access is still restricted to the major urban centers of Bobo-Dioulasso and Ouagadougou.

The cost of connectivity in Burkina Faso is prohibitive. On Onatel's website, the cost of 2 Mbps per month is 2 million XOF (about USD 1,800), while the price of 20 Mbps per month is USD 10,000. Moreover,

i. Broadband prices remain very high, and broadband access is still restricted to the major urban centers of Bobo-Dioulasso and Ouagadougou;
ii. Students are not allowed to access the limited connectivity available at HEIs. Even in the capital city, none of the universities interviewed offers internet access to their students in Burkina Faso. Universities provide the limited connectivity to administrative staff and sometimes to academic staff and researchers;
iii. There is a lack of ICT infrastructure in HEIs (electricity, computers, multimedia rooms, networks), particularly in rural areas, compounded by a lack of ICT procurement strategy and specialists; and
iv. The nascent national research and education network, FasoREN, cannot as of yet provide any services. Each university/institution still buys its internet capacity directly from the ISPs, mainly Onatel, the incumbent operator.

Burkina Faso invested in creating Burkina Faso Internet Exchange Point (IXP) in Bobo-Dioulasso to provide a mechanism for local providers to aggregate and exchange traffic. It has also created two Virtual Landing Points (VLPs), one in Ouagadougou and a more recent one in Bobo-Dioulasso. But it still lacks a carrier-neutral data center to facilitate its digital ecosystem.

Côte d'Ivoire

The ICT sector in Côte d'Ivoire has seen sustained growth led by an expansion of the mobile sector and the increasing adoption of digital technologies by the government and the private sector. The country adopted a unified technology-neutral licensing framework in 2016; still, the market remains dominated by three providers—Orange, Moov Telecom, and MTN. Cote d'Ivoire has seen an expansion of advanced services. Data from the regulator, ARTCI, indicates a 3G coverage of 94% and 58.5% 4G coverage in 2020. There were 37 million mobile subscribers, representing 150% SIM card penetration due to the use of multiple SIM cards. Eighteen million Ivorians (79%) use mobile broadband to connect to the internet.

Côte d'Ivoire is connected to four different submarine cables—SAT-3/WASC, ACE, WACS, and MainOne—and has one of the most extensive national fiber backbones in West Africa, with 15,750 km of operational fiber as of the end of 2019. The cost of interconnection between any of the four landing stations is, however, prohibitive, making a mix-and-match approach to get the best of available pricing very difficult. The high cost of access and devices and lack of confidence or skill to use the internet were cited as the main reasons hindering internet access at the household and individual levels in the country.

The Côte d'Ivoire Internet Exchange Point (CIVIX) connects 11 members, including all licensed telecommunication providers, ISPs, and some international internet actors. CIVIX hosts nine Autonomous System Numbers (ASNs), terminates 60 optic fibers, and provides 96 Ethernet ports. The IXP has 2 PoPs—one hosted by Orange Côte d'Ivoire and the other by MTN Côte d'Ivoire. In terms of data centers, MainOne has begun collaborating with Orange to build a data center that is co-located with MainOne's submarine cable landing station in Abidjan.

The country is working to address its poor cybersecurity image, having been reported to host 45% of the crime and cybercrime servers in Africa, ahead of South Africa (19%) and Morocco (17%). It has been working to address cybersecurity issues and crack down on cybercrime by developing a cybersecurity strategy framework and setting up specialized agencies and departments to tackle the vice.

Mozambique

Mozambique's ICT sector is competitive, with different players in the market, but the cost of broadband remains high. Mozambique adopted a technology-neutral licensing framework in 2016 and currently has 42 licensed operators. Despite this, the market is dominated by three major providers—Movitel, Tmcel, and Vodacom. Mozambique is connected to two different submarine cables—SEACOM and EASSy—located in the capital, Maputo. GoM operates a data center at the Maluana Science and Technology Park, in Manica, which supports e-government services provided by different MDAs. The data center hosts the Mozambique Internet Exchange Point (MOZIX), which facilitates the exchange of local traffic among 18 local networks, including MoRENet.

Uganda

Uganda's ICT sector is highly competitive. There are 33 telecommunication service providers, but the market remains highly concentrated, rendering competition suboptimal. Mobile voice is the predominant service, while the use of data services is still limited, with access largely via mobile phones due to the wide coverage of the mobile networks. Recent data from UCC indicates that 85% of the population lives within coverage of a 3G mobile network and 61% within coverage of 4G. However, the proportion of individuals using the internet is still low, at only 24%, compared to an African average of 28% and a world average of 54%.

Although ICT policy and regulation encourage infrastructure sharing, this has yet to be fully embraced. Uganda now has about 21,472 km of fiber-optic cable laid by both public and private licensed providers. This covers 49% of all districts and 24% of sub-counties, but the duplication among licensed operators on certain routes means that effective coverage is limited and mainly covers major urban centers. Total international bandwidth grew to 175 Gbps in 2020.

The Uganda Internet Exchange Point (UIXP) has 29 networks that peer at the exchange and provide access to content caches from Google, Facebook, and Akamai. Besides the National Data Center built and operated by NITA-U, and largely used by government MDAs, First Brick Holdings is building Uganda's first tier-III carrier-neutral data center—Raxio Data Center. Namanve Industrial Park, along Jinja road, the main fiber route between Kenya and Uganda, hosts the new data center. The country also has two major national computer emergence response teams (CERTs)—CERT-UG, under NITA-U, and a telecoms sector CERT under UCC. These are complemented by the cybercrimes unit under the Directorate of Forensic Services of the Uganda Police Force. However, cybersecurity awareness and investigative capacity for computer-related crimes are still low.

ICT Sector Challenges

From an ICT sector perspective, the four countries share similar challenges that inhibit the use of ICTs in higher education and better connectivity, including the following:

I. Inadequate development and deployment of ICT infrastructure to cover the whole country, particularly rural under/unserved areas;
Ii. Poor-quality and limited geographical reach of the national electricity grid, particularly in rural and peri-urban areas;
Iii. High cost of broadband services, which cannot be afforded by the majority of the population due to poverty;
Iv. Lack of awareness among leadership of government agencies about the importance and potential benefits of ICT in developing their institutions as well as the socio-economic development of the country;
V. Insufficient coordination and alignment among public institutions in relation to ICT projects and initiatives, resulting in duplication as well inefficiencies in public service delivery;
VI. Lack of sufficient numbers of qualified human resources to serve the ICT sector both in private and public institutions to ensure successful implementation of different ICT projects and initiatives;
VIi. Poor integration of the ICT component within the objectives and strategic documents designed to guide the development of the country; and
VIii. Lack of a vibrant and competitive local ICT sector that nurtures innovation and entrepreneurship in various technology areas.

National Research and Education Networks

FasoREN, Burkina Faso

FasoREN, the Burkina Faso research and education network, is still under development. Using resources from the Education Access and Quality Improvement (EAQIP)[3] project financed by the World Bank, FasoREN has been working on a business plan to develop a fully functioning NREN that can deliver applications, services and high-speed connectivity to HEIs across the country.

Riter, Côte d'Ivoire

The Réseau Ivoirien de Télécommunication pou Enseignement et la Recherche (RITER), the Ivorian Research and Education Network, was created in September 2012 by the seven public universities of Côte d'Ivoire to federate telecommunications infrastructure. It is an entity under the supervision of the Ministry of Higher Education and Scientific Research. It has 2Gbps internet that costs USD 55,000 monthly and is supported by the ministry.

RITER offers 10, 20, or 30 Mbps access to internet to its members depending on their size. A plan is underway to connect RITER to the international research and education network through the WACREN network. This new link is expected to add another 1 Gbps internet bandwidth to the RITER community. RITER is also unique in the sense that the network also connects both public and private universities.

MoreNET, Mozambique

MoRENet is a project under MCTESTP that is meant to address the research and education networking needs of the higher education sector in Mozambique. The network currently provides broadband connectivity to 18 universities and 29 TVETs although the amount of bandwidth is still far below the recommended minimum. The bandwidth requirement for the current enrollment of 240,000 higher education students is about 240 Gbps (based on a minimum of 1 Gbps per 1,000 students), but MoRENet has only 5.9 Gbps.

Following the COVID-19 lockdowns of educational institutions, MCTESTP negotiated with the three major licensed operators to provide special rates that allow unlimited internet access for the registered students and staff of HEIs to designated academic systems and content via their regular mobile phones.

RENU, Uganda

The RENU network is the most advanced among the case study countries. It consists of dark fiber and a managed bandwidth backbone at speeds of up to 20 Gbps in metro areas and 1 Gbps access links that connects 204 campuses across the country, including 30 universities (out of 52) and 16 TVETs (out 184). Other connected institutions include 57 research institutions, seven teaching hospitals, 52 secondary schools, and 28 institutions affiliated with the education sector.

RENU charges member institutions the same unit rate for bandwidth irrespective of location, but there is a requirement to procure a minimum of 10 Mbps to justify the distribution costs. For connected institutions, current bandwidth amounts are inadequate for teaching and research purposes, but they lack resources to buy more bandwidth. It is a kind of "chicken-and-egg" problem—institutions need to consume more bandwidth in order to lower the unit cost, but RENU and its members currently lack sufficient resources to commit to larger volumes of bandwidth through long-term leases, which could help lower the unit cost of bandwidth, allowing them to get more bandwidth even within their current budgets.

Challenges at the NREN-level

Despite the different levels of NREN maturity across the four countries—FasoREN is categorized as an emerging-NREN, RITER and MoRENet as connected-NRENs, and RENU as a mature-NREN—they face a number of similar challenges that hinder better performance. These include the following:

i. HEIs have inadequate budgets for bandwidth. Institutions currently only provide bandwidth for staff.
ii. Campus networks at HEIs are still in a poor state.
iii. Institutions have low levels of technical expertise among their ICT teams to manage their networks and provide the requisite services.
iv. Awareness about the potential benefits of an NREN among HEIs and other stakeholders is still very low.
v. The cost of last-mile connectivity to facilitate the distribution of bandwidth is high, especially to the HEIs in rural areas.

3 https://projects.worldbank.org/en/projects-operations/project-detail/P148062.

Cost of Connecting Higher Education in Burkina Faso, Côte d'Ivoire, Mozambique and Uganda

Calculations were made to connect all HEIs in the four countries based on the cost estimates discussed in Chapter 4.

Burkina Faso

The overall total cost of connecting HEIs in Burkina Faso to high-speed broadband is USD 455 million over a period of five years (2021–2025). This includes the expense of providing laptops to students and staff (USD 67 million) and the cost of upgrading and maintaining campus networks (USD 343 million)—the major costs being core support to FasoREN (USD 10 million) and the bandwidth cost for upstream connectivity (USD 35 million). The potential savings on bandwidth cost in Burkina Faso from demand aggregation, smart procurement strategies (e.g., benchmarking regional pricing), and procuring long-term leases are estimated at 39%.

Côte d'Ivoire

The overall total cost of connecting HEIs in Côte d'Ivoire to high-speed broadband is USD 876 million over a period of five years (2021–2025). This includes the expense of providing laptops to students and staff (USD 125 million) and the cost of upgrading and maintaining campus networks (USD 711 million)—the major costs being core support to RITER (USD 10 million) and bandwidth cost for upstream connectivity (USD 30 million). The potential savings on bandwidth cost in Côte d'Ivoire from demand aggregation, smart procurement strategies (e.g., benchmarking regional pricing), and procuring long-term leases are estimated at 64%.

Mozambique

The overall total estimated cost of connecting HEIs in Mozambique to high-speed broadband for a period of five years (2021–2025) is USD 452 million. This includes the expense of providing devices to students and staff (USD 109 million), the cost of upgrading and maintaining campus networks (USD 238 million), support to MoRENet (USD 10 million), and bandwidth cost for upstream connectivity (USD 95 million). The potential savings on bandwidth cost in Mozambique from demand aggregation, smart procurement strategies (e.g., benchmarking regional pricing), and procuring long-term leases are estimated at 61%.

Uganda

The estimated overall total cost of connecting HEIs in Uganda to high-speed broadband is USD 730 million over a period of five years (2021–2025). This includes providing devices to students and staff (USD 110 million) and upgrading campus networks (USD 574 million)—the major cost being core support to RENU (USD 6 million) and bandwidth cost for upstream connectivity (USD 41 million). The potential savings on bandwidth cost in Uganda from demand aggregation, smart procurement strategies (e.g., benchmarking regional pricing), and procuring long-term leases are estimated at 73%.

Comparison of Country Costs

Table 26: Comparison of factors and costs across case study countries (2021–2025)

	Burkina Faso	Cote d'Ivoire	Mozambique	Uganda
Projected population (2025)	23,352,000	29,160,000	35,000,000	50,976,000
Forecast HEI Student and Staff population (2025)	230,000	339,000	313,000	352,000
GER for higher education	11.2%	9.3%	7.3%	6.9%
Cost of connecting campus upstream using Regional Price with Aggregation saving (USD, millions)	35	30	95	41
Cost of laptops for first-year students and staff (2021–2025) (USD, millions)	67	125	109	110
Number of HEIs	93	330	53	236
CapEx + OpEx (USD, millions)	343	711	238	574
NREN core support and development-related costs	10	10	10	6
Total Cost Estimate (USD, millions)	**455**	**876**	**452**	**731**

Source: KCL calculations

It is evident from the table above that Burkina Faso currently has a higher enrollment rate for higher education and more connectivity challenges than the rest of the countries, which increases its cost of upstream connectivity. Burkina Faso needs extensive support in the development of its nascent FasoREN. Uganda's low GER for higher education weighs on its upstream and devices cost. Cote d'Ivoire and Mozambique have large student populations in public and private sectors subsidized by the government, increasing their overall cost of connecting students and staff by 2025. These subtle differences among the countries indicate the importance of national contexts that influence the cost of connectivity. The cost estimates have been developed to accommodate these differences between the countries.