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

Report 2:

Cost Model and Cost Estimates to Connect All African Higher Education Institutions to High-Speed Internet

DIGITAL DEVELOPMENT PARTNERSHIP

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Abbreviations

Term	Description
ASN	Autonomous System Number
AUP	Acceptable Use Policy
CAP	Country Action Plan
CapEx	Capital Expenditures
DE4A	Digital Economy for Africa initiative
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
GIS	Geographical Information System
HEI	Higher Education Institution
ICT	Information and Communications Technology
IRU	Indefeasible Right of Use
ISP	Internet Service Provider
ITU	International Telecommunications Union
IXP	Internet eXchange Point
KCL	Knowledge Consulting Ltd
Mbps	Megabits per Second
MDAs	Ministries, Departments and Agencies of Government
NREN	National Research and Education Network
NSRC	Network Startup Resource Center
OpEx	Operating Costs
PoP	Point of Presence
RREN	Regional Research and Education Network
SDG	Sustainable Development Goal
Tbps	Terabits per second
TVET	Technical and Vocational Education and Training
UIS	UNESCO Institute of Statistics

Term	Description
UNESCO	United Nations Education Scientific and Cultural Organization
WBG	World Bank Group
Wi-Fi	Wireless – Fidelity – Local area wireless computer networking technology

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

10	Kenya (KENET)	Meoli Kashorda
12	Madagascar (iRENALA)	Harinaina Ravelomanantsoa
13	Malawi (MAREN)	Solomon Dindi
14	Mali (MaliREN)	Pierre C. B. Traoré
15	Morocco (MARWAN)	Redouane Merrouch
16	Mozambique (MoRENet)	Lourino Chemane
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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
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Executive Summary

As part of the Digital Economy for Africa (DE4A[1]) initiative, the World Bank commissioned a feasibility study to develop an operational roadmap to connect all African higher education institutions (HEIs) to high-speed Internet. The initiative, in support of the African Union Digital Transformation Strategy for Africa (2020-2030)[2], 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. This study has received funding from the Digital Development Partnership (DDP)[3].

The feasibility study aims to establish a roadmap for connecting all African TVETs and universities, and other closely related institutions, to high-speed Internet; and estimate the costs based on different options. A gap-analysis[4] was carried out to examine the connectivity ecosystem challenges (policy, regulation, institutions, human capacity, funding, etc.) and to set progressive targets for connecting all African HEIs and TVETs to high speed internet. Building onto that, this report presents the cost models and provides cost estimates for connecting all higher education institutions (HEIs) in Africa to high-speed Internet.

Connectivity, recognised as a foundation for learning and innovation, has 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.

Overall Costs of the Proposed Intervention

The overall total cost of connecting African higher education institutions includes the expense of providing devices to students and staff (USD 17.3 billion), the expense to upgrade campus networks (USD 27.3 billion), bandwidth cost for upstream connectivity (USD 7.2 billion) and NREN and RREN development/support (USD 538 million). All total costs cover a period of five years (2021 to 2025).[5]

It should be noted that the gross estimate of USD 27.3 billion for campus networks is based on the broad categorisations of campuses as Small (less than 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,

1 *See https://www.worldbank.org/en/programs/all-africa-digital-transformation.*
2 *https://au.int/en/documents/20200518/digital-transformation-strategy-africa-2020-2030.*
3 *https://www.worldbank.org/en/programs/digital-development-partnership.*
4 *See parallel Report produced under the same study: "A Connectivity Gap Analysis and A Review of Existing Programs"*
5 *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*

small, medium, large and very large campuses. Modelling of the case study countries at this level (as provided for in the Cost Model) led to reductions of the cost of campus upgrading by 6.7%, 32.2%, and 37% respectively for Mozambique, Uganda. This potential reduction has not been factored into the gross estimated cost in the summary because the number of countries analysed is too small to be used as a basis for a reliable generalisation across the continent – but it does point to a significant potential reduction in the gross cost.

From the Table below that provides a summary of all the cost projections, the overall cost of the proposed intervention is USD 52 billion. All total costs assume an aggressive and aggregated procurement of capacity in the form of Indefeasible Rights of Use (IRUs) to secure the best price advantages. Potential sources of funding include governments, development partners, students, and higher education institutions. Actual proportions contributed by each group will vary across countries depending on government funding priorities, development partner funding guidelines and the means of different stakeholders.

Category	Cost (USD, millions)	Potential Sources of Funding
End-user devices		
Students and Staff	17,284	Government, development partners, students, institutions
Sub Total	**17,284**	
Upgrading campus networks		
CapEx	11,750	Government, development partners
OpEx	15,510	Institutions, government, development partners
Sub Total	**27,260**	
Cost of connecting campuses upstream		
	With Aggregation Savings	
Using Student Enrolment & Regional Price	**7,280**	Development partners, institutions, students
RRENs/NRENs development and support costs		
NREN core support and NREN development related costs	**513**	Development partners, government
RREN core support and NREN development related costs	**25**	Development partners, government
Total Cost Estimate (USD, billions)	**52**	**Using cost of connecting campuses upstream based on student enrolment and regional price**

Source: KCL calculations

End-User Devices

While devices like smartphones and tablets have been loaded with increasingly sophisticated applications, laptops are recommended as they possess both the functionality and attributes to be used as teaching, learning and research platforms. The benefits of connectivity can only be maximized when students and staff have 1:1 access to computing devices: shared access is difficult to manage and sustain, and does not respond to circumstances like the COVID-19 lock-downs.

HEIs have adopted many different models to ensure that devices are available to students and teachers. The two most common models are allowing students and staff to bring their own devices (BYOD); and enabling ownership through subsidy and/or loans. Since affordability is still a challenge to many HEI entrants, the recommended entry model is a combination of BYOD (provided suitable acceptable use policies [AUPs] are developed and enforced), and subsidies/loan schemes. In the latter model, owner contribution must be emphasized.

Regardless of which scheme is used, the recommended approach to total coverage is a phasing in by providing laptops for only first year students each successive year, and scaling down external support over agreed periods as institutions and countries take up the financing. Since most courses in HEIs are 2 (TVETs) to 3 (universities) years, this would ensure that almost all students have laptops within three years. All staff would be equipped with fully subsidized devices over the same period. Estimates based on available data on the number of higher education students and staff indicate that African countries need USD 17.3 billion to roll out 1:1 computing devices between 2021 and 2025. It should be noted that this figure includes the full cost of first-year students and staff devices from 2021 to 2025: this cost would be allocated between the funders and the users guided by the adopted laptop access scheme on a country by country basis.

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 or other academic and research resources. Campus networks have been found to be the main bottleneck in the connectivity value chain due to poor design. The design of campus networks is subject to multiple factors that include physical characteristics like the number of buildings, the distance between buildings, the skills of 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.

Campus networks require equipment such as serves, switches and routers, wired and wireless network, network management and monitoring tools and staff with diverse internetworking skills set. The capital and operating costs of campus digital infrastructure depend on the size of campuses, the number of users, the quality of the pre-existing network and the skills sets to design and upgrade the network.

There is a lot of variability in campus network costs estimates. Our estimates that rely on benchmarks and take into account the different size of higher education institutions show that African countries need CapEx of USD 11.8 billion to upgrade campus networks over the next five years and OpEx of USD 15.5 billion to maintain the networks over five years. Campus network design capability is an essential factor in cost and sustainability, calling for concerted national efforts to effect improvements.

Connecting Campuses Upstream

The developments of Research and Education Networks (RENs) has already shown that such networks serve as anchors for high-capacity bandwidth delivery and as catalysts for communities' digital literacy, broadband deployment, and adoption. They provide the basis for blended and online learning, digital skills and innovation, and are therefore a key part of the value chain. A fully functional National Research and Education Network (NREN) can help aggregate traffic at the national level and in turn connect to regional RENs like UbuntuNet Alliance, WACREN, ASREN and further to GÉANT, RedCLARA, APAN or Internet2 so that there is full integration in the global research and education fabric. COVID-19 has also brought into focus the critical need for national level access to eduroam and eduGAIN services, both of which are best provisioned by NRENs working with the private sector.

Connectivity to campuses can be achieved through four progressive models.

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

Model 1, exclusive connectivity via service providers, will remain the common entry option for African countries without NRENs or those with emerging NRENs. When countries establish NRENs, institutions will start connecting via the NREN, and those HEIs not yet connected to the NREN will still connect through CSPs (Model 2). The third model works in countries where NRENs are mature and able to provide Internet 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 and data centre environments; and where higher education institutions are research intensive, and are well resourced.

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

The projections for connectivity costs to HEI during 2021 are based on a minimum connection of 1 Gbps for a small campus (≤ 5,000 students), 10 Gbps for a medium campus (5,001-15,000 students) and 100 Gbps for a large campus (> 15,000 students); and expected to rise by 2030. The cost projections from 2025 up to 2030 are not given because it is not realistic to base this on current figures, especially considering technology evolution.

The actual connectivity of higher education in Africa will depend on many factors including NREN maturity; market structure and the level of broadband competition; and economic and geographic aspects. Data for the indicators used was collected from various databases as part of the Gap Analysis phase. Duncan Greaves' NREN Capability Maturity Model[6] and Mike Foley's levels of NREN development[7] have been used as a basis for deriving a mechanism 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 network), Connected NREN (has network and offering middle-ware services), and Mature NREN (has network with high-speed regional/global connectivity to other NRENs and offering advanced services). ICT Indicators at a country level with a direct bearing on connectivity include landlocked, number of landing stations, Internet eXchange Ladder Stage (reflects number of IXPs and carrier neutral data centres and their interaction), percentage population within 10-km of fibre coverage (reflects fibre network coverage of the country) and a regulatory score, which reflects the maturity of regulatory environment (based on country scores from ITU Global Regulatory Outlook 2020). Estimates based on these factors indicate an aggregate cost of USD 7.2 billion for upstream connection. Policy and regulatory reform at both regional and national levels is key to making broadband available to the population in general and the higher education institutions in particular: this will be an important area of intervention in improving the broadband connectivity ecosystem in Africa.

Nationally, NREN member institutions cover connectivity-related expenses through payments for bandwidth. However, NRENs often struggle to cover core costs as well as costs related to ongoing capacity building for both internal staff, and especially for the ICT support staff of member institutions where the value of connectivity is realised. 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 ten years. Continuing funding for the growth and operations of NRENs is essential in order to reap the resulting value of the NREN, starting with the delivery of tailored high-speed connectivity to the provision of the many REN services that are core to effective education and research. African countries will need USD 513 million to support NREN activities – especially capacity building for the ICT support staff of HEIs, over a five-year period.

Regionally, there is a need for strengthen the West and Central African Research and Education Network, the UbuntuNet Alliance, and the Arab States Research and Education Network that provide regional connectivity as well as upward connectivity to other regional

6 *Greaves, D. (2009). An NREN Capability Maturity Model.*
7 *Foley, M. (2016). The Role and Status of National Research and Education Networks in Africa. World Bank.*

networks such as GÉANT, RedCLARA, APAN and Internet 2. Regional Research and education networks 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.

1. Introduction

1.1 Background

The African higher education sector comprising public and private universities, colleges, technical training institutes, and vocational schools[8] plays a critical role in training a skilled workforce, conducting research and building the knowledge base and the human capital necessary for countries' transition to digital economies. Digital technologies provide opportunities for addressing the challenges facing higher education – growing demand for higher education, falling quality, the mismatch between education and employability and disconnection between research and development challenges. However, higher education institutions on the continent do not have access to affordable and functional quality broadband connectivity. In addition, the available bandwidths are expensive and limited in capacity, thus unable to meet modern institutions' research and education requirements. Ultimately, this negatively affects national education goals and targets as enshrined in the Sustainable Development Goals (SDGs) and various country specific Development Plans.

As part of the Digital Economy for Africa (DE4A[9]) initiative, the World Bank commissioned a feasibility study to develop an operational roadmap to connect all African HEIs to high-speed Internet. The initiative, in support of the African Union Digital Transformation Strategy for Africa (2020-2030)[10], 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. This study has received funding from the Digital Development Partnership (DDP)[11].

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

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

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

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

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

1.2 Objective

The WBG's Digital Economy for Africa' feasibility study aims to establish a roadmap for connecting all African TVETs and universities, and other closely related institutions, to high-speed Internet; and estimate the costs based on different options. This is achieved through three sub-objectives:

i. Production of a gap-analysis report addressing the connectivity, ecosystem challenges (policy, regulation, institutions, human capacity, etc.), and funding.
ii. Development of an implementation cost estimate, and
iii. A final report that presents the summary of the feasibility study and establishes a roadmap for connecting all African TVETs, universities, and other closely related institutions, to high-speed Internet.

This report addresses the second task, the development of implementation cost estimates. The Report provides cost models and gives cost estimates for the establishment and operations of the required data networks. The models address: equipping students and staff with laptops; upgrading campus networks; establishing upward connectivity to the global research and education fabric based on an aggregation approach; and support to strengthen and support the activities of NRENS and Regional RENs.

The report is accompanied by a number of stand-alone annexes that include:

i. Annex 1: Burkina Faso country case study report
ii. Annex 2: Côte d'Ivoire country case study report
iii. Annex 3: Mozambique country case study report, and
iv. Annex 4: Uganda country case study report.

1.3 Organisation of the Report

The report is organised as follows: Following the Introduction in Chapter 1, Chapter 2 discusses the overall approach and assumptions for connecting higher education institutions in Africa. Chapter 3 discusses access to computing devices for students and staff in higher education institutions. Chapter 4 reviews the necessary upgrades to campus computing infrastructure in order for higher education institutions to be able to leverage the campus networks. Chapter 5 discusses upstream connectivity options for campuses based on aggregation model while Chapter 6 brings all of these components together to determine the actual cost of connecting African Higher Education Institutions to improved connectivity. Chapter 7 concludes this report.

2. An Approach towards Connecting Higher Education Institutions

Higher education across the world is under great pressure to deliver high-quality learning at a distance. The COVID-19 pandemic has underscored the critical importance of online education and digital technologies. The African continent is generally ill prepared for online learning due to limited connectivity and capacity issues, especially the readiness of staff in embracing digital technologies for teaching, learning and research.

Reliable connectivity is foundational to creating an effective learning environment. Yet, connecting higher education depends on multiple factors including the availability of devices, the presence of good campus networks and leadership and institutional policy that determine resource allocation. National concerted efforts of governments and policymakers in promoting economic growth and expanding connectivity are needed.

Reform in the communication sector remains the main driving force for private sector participation in the expansion of connectivity. Once a country introduces structural changes in its public policies, and supportive regulatory frameworks, progress can be made in the diffusion and adoption of digital technologies across the board, especially in the higher education sector. Reform is also crucial for reducing the cost of connectivity and the barriers of access to wireless networks.

2.1 General Considerations for Connecting Higher Education

The goal of any future higher education connectivity will be to ensure that high education institutions in Africa secure broadband access comparable to their peers in developed countries in ten years, with an initial goal of attaining at least 2 Gbps per 1000 students by 2025. There are however additional requirements because higher education connectivity is an integration of:

i. What happens at campus level—equipping students, staff and teachers with access devices, designing and maintaining robust campus networks as well as the access network to interconnect campuses,
ii. What occurs at national level—aggregating traffic from universities nationally using backbone networks and connecting cross–border/regionally, and
iii. What occurs at regional level—aggregating traffic from countries regionally and connecting internationally.

Connecting higher education institutions therefore depends on addressing gaps at individual, campus, national and regional level. It is necessary to ensure:

i. Access to computing devices;
ii. Well–structured campus networks;
iii. High–speed connection in and out of higher education through national networks; and
iv. High-speed connection from national to regional and global networks.

Figure 1 presents a schematic diagram for estimating the cost of connecting all higher education institutions to high-speed broadband.

Higher education institutions are required to design and maintain robust campus digital infrastructure. Universities that have campuses scattered around metro areas require robust metro networks to interconnect them. Countries must be able to aggregate traffic from higher education institutions through national backbones, exchanging traffic that needs to stay local and connecting regionally and globally for traffic that is destined for other parts of the globe.

A fully functional National Research and Education Network (NREN) can help aggregate traffic at the national level and in turn connect to regional RENs like UbuntuNet Alliance, WACREN, ASREN, GÉANT, RedCLARA, APAN or Internet2 so that there is full integration in the global research and education fabric. Regional RENs play critical roles in supporting regional aggregation and upward connectivity to the global networks.

Governments, working with the private sector, will play a key role in achieving the necessary pre-conditions including: expanding national broadband infrastructure in terms of both reach and capability; lowering connectivity costs by reviewing the entire ecosystem to address those factors, including taxation and licence costs, that lead to high end-user prices; and making special provisions for access by educational institutions.

The rapidly evolving user-expectations and technology environments demand that future–proofing is always a priority consideration in design and procurement. The COVID-19 pandemic has exposed a big gap in the assumption that concentration of need is at the campus level: future proofing therefore also calls for the recognition of the “nomadic” lifestyle of the future student. Campuses must have ubiquitous and sufficiently-dimensioned Wi-Fi coverage; and national as well as global roaming must be a given, making identity management and federation, eduroam[12] and eduGAIN[13] key considerations.

12 *eduroam provides simple, easy, secure connectivity from thousands of hotspots across more than 100 countries (https://www.eduroam.org/)*

13 *The eduGAIN interfederation service connects identity federations around the world, simplifying access to content, services and resources for the global research and education community. eduGAIN comprises over 60 participant federations connecting more than 5,000 Identity and Service Providers (https://edugain.org/).*

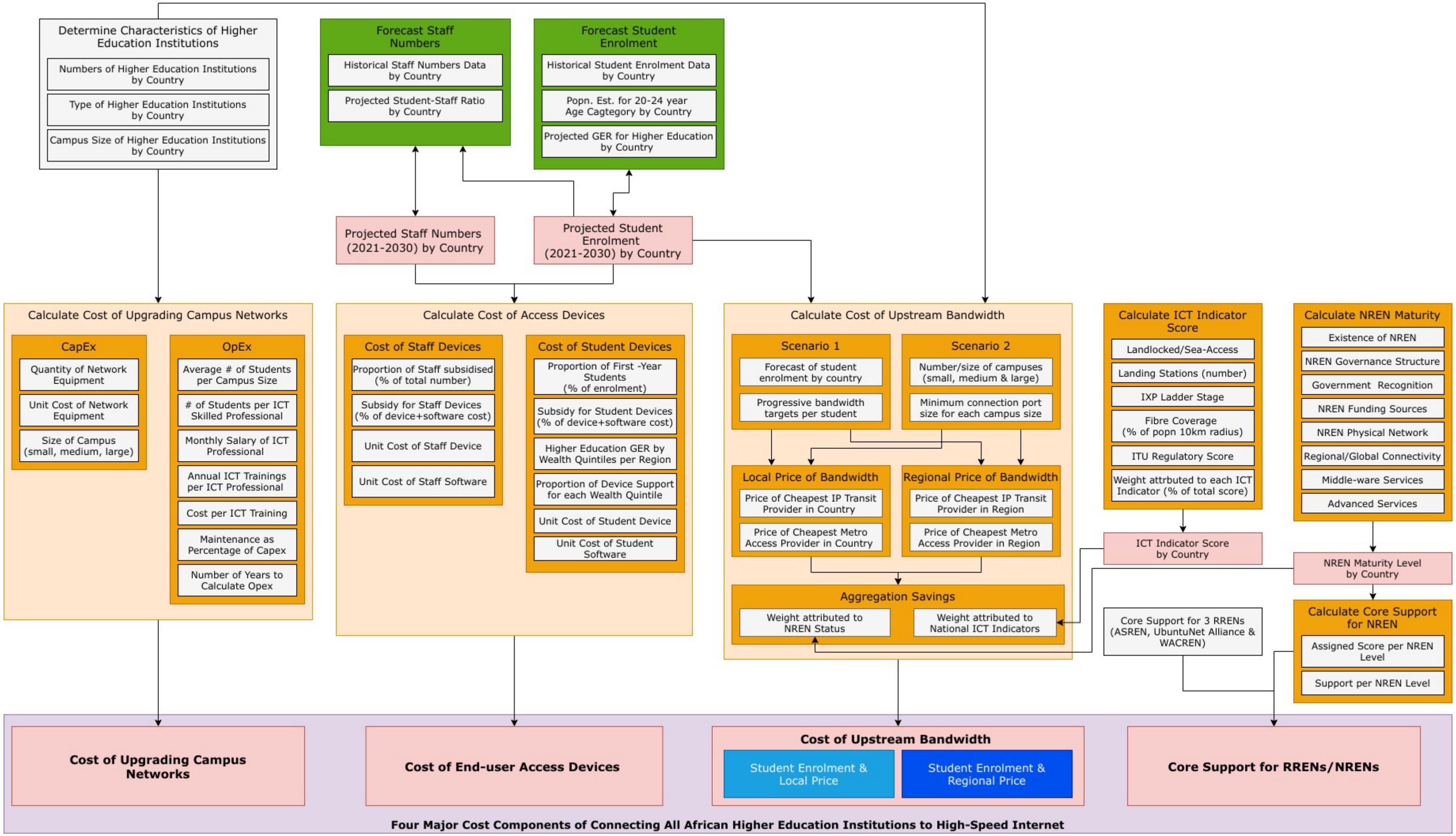


Figure 1: A schematic diagram to estimate costs for connecting HEIs in Africa

2.2 NREN Operational Stages

There are four progressive models for the connectivity for any HEI depending on the maturity of NREN, maturity of the telecommunications markets, extent of government support, and financial capacity of the institutions. The first two models are actually development stages while the last two can be considered as mature models:

i. Model 1: Connecting exclusively via Commercial Services Providers (CSPs);
ii. Model 2: Connecting via either CSP or NREN;
iii. Model 3: Connecting exclusively via NRENs
iv. Model 4: An advanced and hybrid model, connecting to both CSPs and NRENs separately. In this model, CSPs provide what has been historically regarded as commercial Internet, while NRENs and RRENs handle what has been historically regarded as REN traffic.

2.2.1 Model 1: Exclusive via CSPs

In this scenario, higher education institutions connect exclusively via commercial services providers (CSPs). This 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 higher education institutions 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.

The need to collaborate easily with universities all over the world and have easier access to the many REN opportunities and resources mean that Stage 1 is often an important starting stage because it creates the first value proposition for an Emerging NREN: aggregation to get bandwidth at lower costs, and tunnelling through commercial networks to reach other RENs.

2.2.2 Model 2: NREN or CSP

There will be a transition 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. NRENs at this stage are normally focused on connectivity services, support for technical capacity building among member institutions, and improvement of campus networks.

2.2.3 Model 3: Exclusive via NREN

As NRENs grow out of Stage 2, they offer to an increasing membership an increasing range of service among the traditional (NREN) services shown in Table 1. NRENs getting to this stage may be challenged by sustainability: adoption of services is a step behind the rolling out the services, the latter being a cost that may drive "connectivity" costs up above market levels before users appreciate the value. This makes the NREN seemingly uncompetitive, especially for institutions that are not very active in research.

Table 1: Traditional NREN services

Main 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, email 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.

It should be noted that in models 1, 2, and 3, and provided NRENs and RRENs do not transit commercial traffic, no distinction is made between "commercial" and "REN" traffic. Two major arguments stand against such distinction within most developing country contexts:

i. Sustainability considerations because general Internet access needs are still very dominant. Carrying what is historically termed REN traffic does not make for a sustainable business model without major government support. As an example, our in-depth country study indicates that RENU, the research and education network of Uganda, considered among the more mature NRENs in Africa, still derives 90% of its revenue from what would be termed "commercial internet."

ii. The absence of a local IXP and/or limited peering opportunities often make it cheaper to peer with commercial providers at locations external to Africa, which is best achieved through aggregation of all HEI traffic via regional RENs.

2.2.4 Model 4: CSPs for Commercial Traffic and NRENs for REN traffic

In this scenario, institutions connect to both CSPs (all "commercial" traffic) and NRENs (exclusive "REN" traffic) separately. This model requires various conditions to have been satisfied in the country:

- The telecommunications market is fully mature with universal broadband service;
- Competition in provision of broadband access has also matured to make such access affordable both at individual and institutional level;
- There is sufficient penetration of IXPs and local hosting of major databases, along with

low peering costs;

- All institutions can afford and sustain the technical environment and human resource; and
- The income from pure REN traffic and other services as well as government support is sufficient to sustain the NREN.

No single African country is anywhere close to meeting these preconditions yet. While the existence of Model 4 is recognised, it is not included in the costing analysis for the reasons given.

2.3 The Significance of the NREN Model for Upstream Connectivity

NRENs have proved to be the most viable model for bringing down costs quickly through aggregation and economies of scale in resource-limited environments. This is why most NRENs, certainly in Africa, have had their entry point business model as basic bandwidth aggregation to bring down the price and therefore increase bandwidth within the same resource envelope.

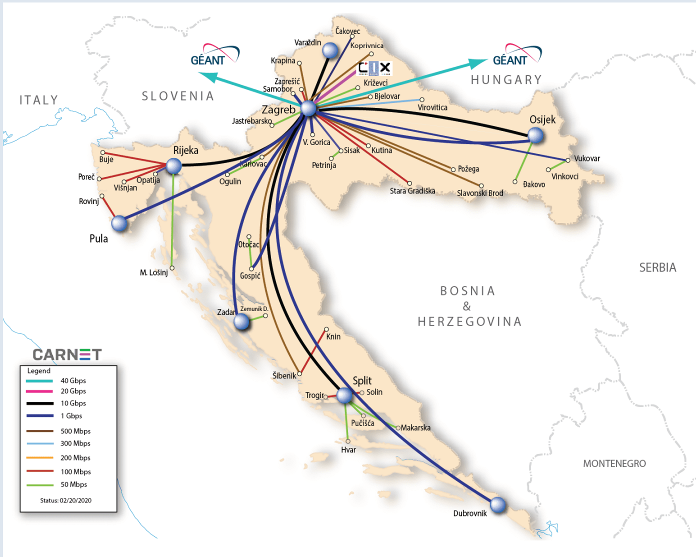
There are multiple categories of users of bandwidth in higher education. The vast majority of users consume bandwidth for learning, teaching and research, while administration and services staff rely on occasional access to the Internet, with intensive use of campus servers. Researchers constitute a third category of users. They need sustained but often temporary handling of vast volumes of data, either to transfer of large files or data generated by remote instrumentation. Connectivity via NRENs addresses the need for both access to commercial Internet and links to global research and education networks. NRENs can increase capacity for short periods of time when usage is expected to spike (such as access to instruments and when uploading, downloading or accessing large volumes of research data). A demonstration of the tailored capability of NREN connectivity was based on tests conducted during 2017, using large file transfers (100 Terabytes) on NREN networks and two commercial ISPs – all without any advance notification. This resulted in transfer durations of 1.4 days for the NREN links and 7.6 and 119.3 days via two different commercial ISPs.[14]

Beyond tailored connectivity, NRENs provide a wide range of compelling services as shown in Table 1. These are broadly defined as middleware (security, authentication and mobility, cross-institute federated support for national and international education and research), networked collaboration services (for e-Learning, e-Science and e-Research), and general support services including training, dissemination and project development. NRENs also connect to e-science resources such as telescopes, sensor networks, accelerators, and supercomputers.

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

Box I: Croatian Research and Education Network

The Croatian Research and Education Network (CARNET) provides a useful model to connect higher education institutions and also to international networks. The network provides access to schools, TVETs and universities across the country. Apart from managing and maintaining a national research and education backbone, it provides network security emergency response team (CERT) functions. CARENT provides schools with e-learning support, research and development and advancement of educational technology.



CARNET connects to the pan–European research network GÉANT via two 20 Gb/s link through neighbouring Bulgaria and Slovenia. In addition to access to commercial Internet through GÉANT, CARNET links to Internet service providers within the country through the Internet exchange of Croatia – CIX. Within Croatia, CARNET network connects larger and smaller Croatian cities at the mainland and several places on islands. Major university centres (Dubrovnik, Osijek, Pula, Rijeka, Slavonski Brod, Split, Zadar, Zagreb) are connected with speed ranging from 500 Mb/s to 10 Gb/s. In comparison, smaller centres are secured at speeds of 50 Mb/s up to 1 Gb/s. There is an exceptionally advanced infrastructure in Zagreb and Split where faculties and scientific institutions are connected to speeds up to 10 Gb/s. CARNET network also connects institutions from the primary and secondary education system at access speeds of 4 Mbps to 1 Gb/s. In Rijeka, Zagreb, Split and Pula CARNET connects different with its own built infrastructure.

Source: https://www.carnet.hr/en/

2.4 The Need for Country-level Higher Education Connectivity Strategies

Due to the often widely-varying state of the enabling environment and connectivity in African countries, there can be no one–size fits all approach to addressing the gaps. This means that 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.

Each country needs to assemble a high–level team drawn from the ministries responsible for higher education, the ICT sector, and finance; HEIs; the NREN where present; the ICT private sector; key development partners; and other stakeholders to map out these gaps and develop a unified plan for connecting their institutions. The general summary of tangible and intangible barriers that need to be addressed differently by different countries as shown in Figure 2 provides a good starting point in doing this.

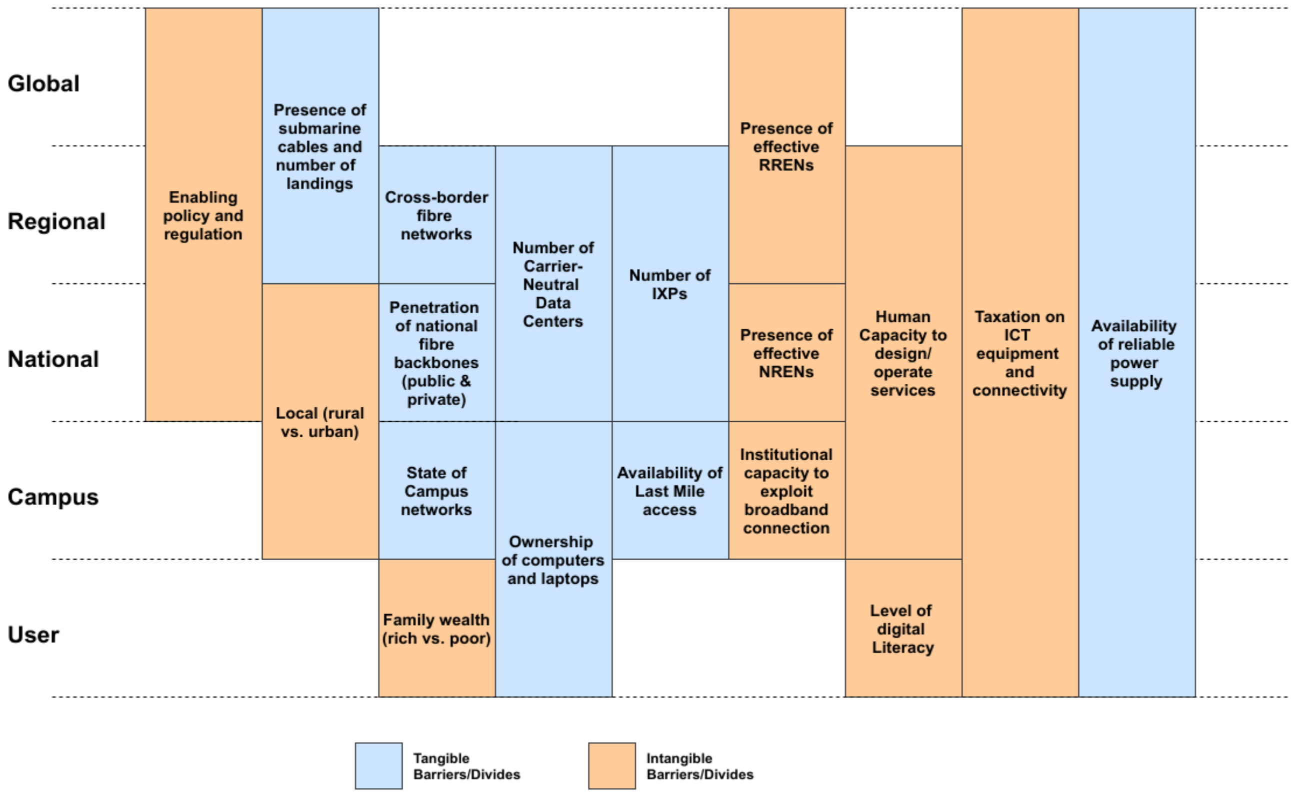


Figure 2: Tangible and intangible barriers for connecting HEIs

Source: KCL (From the Connectivity Gap Analysis Report)[15]

15 *ibid*

2.5 Recommended Targets and Timelines

Each country needs to meet minimum requirements for devices, campus and Internet connectivity to foster meaningful teaching, learning and research.

Table 2 gives the broadband targets as recommended in the first Report:[16]

Table 2: Progressive broadband targets

Year	Minimum Bandwidth	Remarks
2021 (target minimum)	≥ 0.2 Gbps @1,000	Translates to 1Gbps minimum for a campus of 5,000; and 10 Gbps for a campus of 50,000
2021 - 2025	≥ 2 Gbps @1,000	Translates to 10 Gbps minimum for a campus of 5,000; and 100 Gbps for a campus of 50,000. *This should be the minimum entry level for the WBG intervention*. It should be noted that the general aspirational target of most African NRENs by 2025 or earlier is 1Gbps per 1000 students, but this is heavily influenced by current challenges and limitations.
2025 - 2030	≥ 20 Gbps @1,000	Translates to 100 Gbps minimum 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.*

It is also recommended that:

i. **Computing devices:** 1:1 for both students and staff. All staff should own a laptop within the first year; and ownership for students 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, it means that all students would own a laptop by 2023 – this assumes 2021 as the first year of implementation. The acquisition models are discussed in Chapter 3.

ii. **Campus networks:** functioning campus networks with external connectivity of at least 2 Gbps per 1000 students, and ubiquitous and properly dimensioned broadband Wi-Fi by 2025. Immediate focus should be placed on promoting reliable and functioning campus networks over the next two years. Costing for upgrade to campus networks is presented in Chapter 4.

iii. **NRENs:** All countries should have functioning NRENs by 2023, even if some of them may be at Stage 1. Connecting higher education institutions should create opportunities for Model 3 by 2025.

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

16 *See Report 1: Connectivity Gap Analysis and Review of Existing Programs*

Table 3 gives the timeline for reaching different levels of individual access, broadband, and NREN maturity. Projections beyond 2025 are not given: 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.

Table 3: Prioritising 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 (80% support), and all staff (80% support)</td><td>Individual ownership for all first-year students (60% support)</td><td>Individual ownership for all first-year students (40% support)</td><td>Individual ownership for all first-year students (20% support)</td><td>Individual ownership for all students and staff</td></tr>
<tr><td>Campus network</td><td colspan="3">Build functioning campus networks across higher education institutions</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 2 Gbps per 1,000 students</td><td colspan="2">Start work towards 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 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 within the continent</td></tr>
</table>

Source: KCL

3. Access to Computing Devices in Higher Education in Africa

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 members need them to conduct research, teaching and collaboration with their peers around the globe; and administrative staff need them to support the overall learning environment.

The historical approach for universal access to computers for students at HEIs is computer labs; and both academic and administrative staff are increasingly provided with desktop and laptop computers. However, in addition to 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 towards one–to–one computing, which is being adapted across developed countries, with a full shift from computer labs.

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 learning platforms: the focus here is therefore transitioning to individual laptops. The benefits of connectivity can only be maximized when teachers and students have 1:1 access to computing devices. Shared devices make it difficult for students and staff to engage in teaching and learning process.

3.1 Laptop Access Models and Schemes

HEIs have adopted many models to ensure that devices are available to students and teachers. The most common models are:

- Allowing students and staff to bring their own devices (BYOD)
- Enabling ownership through an institutional scheme.

3.1.1 The BYOD Approach

The first seeming challenge of the BYOD approach is that, based on a global population approach, there are a 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)[17] and the model will work only for 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 which produce the overwhelming majority of students who get into HEIs through the competitive selection processes.

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

Where a BYOD approach is adopted, a robust Acceptable Use Policy (AUP) should accompany the BYOD scheme. Universities require to enforce requirements such as minimum specifications and security measures. The AUP should be extensive to cover technical practices such as network security and access control, data backups and retention, password management, mobile device use policies, and incident response as well as confidential data access, data transfer, data sharing, and encryption. Box II provides an example of a BYOD programme.

Box II: 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 cheque.
ii. Apply for a subsidy online. Once the application is approved, families will receive a subsidy code to apply to a laptop's online purchase.

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

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

3.1.2 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 programmes. Bulk purchase, if properly managed and negotiated, exploits economies of scale fully and could be linked to local start-ups for assembly and service. The management of such a scheme can also be out-sourced to suppliers based on negotiated prices to take the management and administrative load of the scheme off the institutions. Box III gives a specific example from Burkina Faso, and Box VI gives examples of access and subsidy models for staff and students based on institutional schemes from around the world.

Implementation and sustainability of institutional schemes can be a challenge, pointing to the need for good advance planning including stakeholder consultation. Box V 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 III: Burkina Faso Partial Subsidy of Student's Computing Device

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 IV: 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 higher education institution
ii. 50% from the university budget and 50% from research grant and personal funds
iii. Subsidised access to laptops paid by staff through loans

Student Laptop Subsidy Schemes

i. Free laptop scheme—free rotating laptop 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 laptops, which are bought on a discount basis.
ii. Laptop checkout program—laptop made available in the university library. Students use a library card to check out 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—laptop loan is applied to a student loan account
iv. Government partial subsidy (contribution) to the price of the equipment—Seychelles for example provides 3000 Rupees (USD 170) towards the purchase of computer, with the rest covered by students.[18]

Box V: Kenya's Quest towards One-to-One computing for Students

The Kenyan government has been pursuing different models for allowing students access to computers. The COVID-19 pandemic prompted 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 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

18 *http://www.egov.sc/documents/ICT_LaptopScheme_20140827.pdf*

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 Kenyata University of Agriculture and Technology has also experimented with a Taifa Laptop programme 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 scheme.

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.

3.1.3 Recommended Approach

It is recommended that to ease management and administration, only outright ownership approaches should be used—either BYOD (provided suitable acceptable use policies [AUPs] are developed and enforced); or subsidy schemes, ranging from partial to zero subsidy. It is a development truism that beneficiaries value and help with safeguarding the devices only when they have contributed to them—and it is therefore recommended that each staff member or student contributes in part or in full for their laptops. The specific recommendations are:

i. National level approaches should be used to guide institutions in developing and implementing laptop ownership policies.
ii. The scheme used, a combination of BYOD and partial subsidies, should be based on individual ownership of laptops by staff and students. It should be noted that even a BYOD approach can exploit the lower prices negotiated by consortia of institutions.
iii. WB support for laptops should assume that at portion of first year students can afford their own laptops, and the remaining fraction should make a contribution towards their device cost. It is however recognised that each country has to be examined on a case by case basis in order to determine how the support should be structured and phased out.
iv. Institutions should adopt and publicise policies that habituate acceptance that within five years, all entrants to HEIs will be required to own a laptop conforming to the institutional AUP as a condition for registration.
v. HEIs should ensure that by the end of the fifth year, there is a residual revolving fund that the minority of students who are established to lack the means can access a student-loan fund to own a laptop.

3.2 Estimating Laptop Costs

In order to estimate costs of computing devices, classroom devices, user software, and data storage, we used a forecast of the number of HEI 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. We used the exponential smoothing forecasting technique due to its key advantages including giving more weight to recent data and less weight to older data. That is, the weights decay exponentially as the data points go further into the far past. It also takes into account seasonality and trends in the datasets via additive error, additive trend and additive seasonality of the Exponential Triple Smoothing algorithm (to help in smoothing out minor deviations in past data trends by detecting seasonality patterns). This method generates the optimal forecasting parameters (or the dumping factors) by minimising the sum of squared errors of predictions. Consequently, exponential smoothing method gives reasonably accurate and therefore reliable forecasts.

Since the time series unit costs for computing devices are not readily available in Africa, we used average values of the unit costs for these devices (laptops and tablets and other devices such as classroom devices, data storage, software and graphics). The average costs of devices per users were obtained from a desk review, prices from Jumia the largest online marketplace for electronics, and fashion among others in Africa.[19]

Generally speaking, prices of devices are high in Africa due to high tax rates. The shortage of foreign currency, import tariffs and fees, high profit margins of vendors and other factors tend to increase the cost. In South Africa, where the market is more mature, a low–end laptop costs R5000 (USD 300). In Ethiopia where the market is restricted and involves high transactional logistics costs and other fees, the entry level laptops cost Birr 25,000 (USD 750). On Jumia, the prices tend to vary between these two extremes (Ethiopia and South Africa) with entry level laptops costing 40,000 KSH (USD 360) in Kenya, $12,000 Egyptian Pound (USD 600), 150,000 Nira (USD 400) in Nigeria and 225,000 FCFA (USD 400) in Senegal. The total cost of ownership of these devices is generally high because of the requirements of software, accessories and maintenance.

A European Union Survey on ICT in education in 2019 found that the average equipment cost per student per year in Europe varies between USD 107 and USD 176, depending on whether the device is shared among three students or one-to-one computing is adopted.[20] This includes the cost of a portable device and other essential tools for facilitating teaching and learning. The essential tools consist of interactive whiteboards, virtual learning environment and a basic suite of software for word processing, calculation, presentation and graphics.

Drawing on the EU work, and taking into account challenges that African universities face with investing and maintaining computing devices, we propose that both students and staff should own their devices. All staff should own a laptop within the first year; and ownership for students phased in through ensuring that all first-year students can secure personal laptops over a successive number of years starting in 2021.

We propose a predetermined scaling down of support, assumed to come from the World Bank. Support can start at 80% of the first-year students in the first year of implementation

19 *Jumia online market place www.jumia.com*

20 *Estimates are made on a price of tablet or laptop that ranges between USD270–$450 used by three students for three years*

and reduce by 20% year-on-year: 80%, 60%, 40%, 20%, and 0% over the next five years. This will also permit the phasing in of policies where students must come with their own computers. In addition, in line with the development truism that beneficiaries value assets only when they have contributed to the costs, we recommend that a minimum cost-share contribution of 20% of the cost of the device from each student.

It is evident from Table 4 that in countries where the devices costs are low such as South Africa students are expected to pay USD 300 per device, while the high-cost countries the price could double to USD 600. In both cases, the staff device cost is estimated to be between USD 450 to USD 600 per person, depending on the country. We recommend the lower working figure of USD 450 per user as economies of scale would bring costs down. Additionally, countries with high taxes on ICT goods, which is the noted cause of the wide price variations, should take the responsibility of either waiving or meeting the tax costs.

Table 4: Average device costs in 1:1 computing scenario

Type of device	Description	Estimated 1:1 computing per student (USD)
Portable devices	Laptop	270 – 450[21]
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.

In addition to the above, there is a need to purchase individual devices for researchers and students that participate in specified courses, such as rugged devices to be used for fieldwork in forestry and geology classes among others. Any scheme should also ensure that students with disabilities that need devices capable of supporting assistive tools and technologies are catered for: we estimate the cost of such devices to be less than 1% of the overall cost to higher education institutions, and have not factored them into the estimates.

The rollout of devices needs careful planning, including development of policies and responsibilities for device management, responsible use, digital citizenship, security, privacy and the management of loss and theft. Maintenance of many devices needs special consideration: HEIs need to deploy many competent technicians through direct employment or outsourcing to ensure that devices and applications work for staff and students smoothly to facilitate efficient learning, research, and administration.

To calculate the cost of devices, we have assumed that 80% of students are undergraduates that on average spend three years at the university, while 20% are graduate students who on average spend two years at the university. Consequently, one third of undergraduates in a given year are assumed to be first-years while one half of graduate students are assumed to be first-years at the start of any given academic year.

21 *Estimates are made on a price of laptop that ranges between USD270-$450 used by three students for three years.*

Assumptions for projecting costs for students and staff by country:

i. Used forecast of student enrolment and staff for each country for 2021 to 2025. See Table 29 for student details and Table 30 for staff details.
ii. 80% of students are undergraduate students who spend average three years at the university, 20% are graduate students who spend two years at the university.
iii. One third of undergraduates in a given year are assumed to be first-years while one half of graduate students are assumed to be first-years at the start of any given academic year. This results in a weighted average of 36.7% that need to acquire devices at the start of any academic year.
iv. We have included the full cost of first-year student devices between 2021 and 2025 in our calculation to provide the total cost. It is however recommended that there is a predetermined scaling down of support from the World Bank for student devices, which can be determined on a country-by-country basis.
v. All staff will get devices between 2021 and 2025. Staff devices are supported up to 100% and new staff are given new devices after recruitment;
vi. Average figures of USD 360 per student laptop and USD 525 for staff laptops including volume licences for operating systems and productivity suites of applications.

Table 5 provides a summary of the aggregate cost of equipping students and staff with laptops. Our estimates indicate the cost of equipping first-year students and all staff would USD 17.3 billion between 2021 and 2025.

Table 5: Cost of equipping students and staff with access devices (2021 to 2025)

Year	Forecast student enrolment	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

Table 31 in Appendix A: presents a summary of laptop costs by country.

4. Upgrading Campus Networks

4.1 Introduction

Campus networks are crucial, because all student and staff devices on campuses must connect through a local wireless or wired network before they can access the Internet or other academic and research resources. Usually, the campus network is the main bottleneck in the connectivity chain: no matter how fast the Internet connection is, individual access will be poor if the campus network is badly designed. This section discusses approaches and costs for improving campus networks.

The design and deployment of campus networks varies considerably across HEIs due to assorted factors including physical characteristics like the number of buildings, the distance between buildings, the presence of satellite campuses, as well as the number of end-users and network devices. Other factors to take into consideration during campus network improvement or design include providing clean power, better ventilation and air conditioning, and fire suppression systems.

Cabling is one of the most significant long-term investments that an institution will make during network deployment. The choice between different cabling options and the extent to which campuses deploy wireless network will also be a determinant in the design of a campus network.

Campus networks in many HEIs in Africa grew organically over time without attention to proper architecture and design. Most campus networks make heavy use of Network Address Translation (NAT) and firewalls that constrain their performance and make it hard for researchers and educators to explore innovative ways of teaching, learning and research. Providing high speed connectivity that actually benefits teaching and learning will require well-structured campus networks that are able to accommodate current and future user needs, and needs to be supported by skilled technical staff.

The cost of each campus network will depend on the complexity of its design, and the number of users and their computing and networking requirements. 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.

Monitoring is crucial for improving service quality and protection against viruses, spam and data theft. Management and monitoring therefore need to be integrated in the design. Campus network monitoring is typically accomplished via Network Operations Centres (NOCs) that also increase demand for higher skills. NOC technicians usually have significant work experience, specifically in network monitoring and the tools used.

With the departure from large computer labs, all campus networks need to be optimised 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. Access to wireless networks demands extensive use of frequencies. Campus wireless networks can operate in two different frequencies: 2.4 GHz and 5 GHz. Because the 2.4 GHz frequency has been around longer and does not require a licence (so longer as usage guidelines are followed), vendors tend to produce more and cheaper devices, easily creating congestion and interference in densely populated environments like dormitories where many devices communicate using the same frequency. 5 GHz is also unlicensed in some administrations (for example Uganda), but the licensing framework is not clear in many countries. The 2.4 GHz frequency offers better range and handles obstacles better compared to 5 GHz, but the latter offers much higher bandwidth.

Staffing and advanced skills are vital requirements for advanced campus networks. There is no globally agreed yardstick on the number of engineers required for operation of campus networks. Staff number scales based on the number of users, network devices, number of networks, security issues, complexity of routing.[22] In the private sector one engineer typically serves 200 to 300 users.[23] Higher education institutions need at least one engineer per 300 to 450 users. An institution of about 5,000 students would therefore need about 12 network engineers for support.

The multiple variables above make it evident that there is no one-size-fits-all model for campus networking, making it difficult to provide cost estimates even for a modest campus network. Each higher education institution needs to establish a budget for their campus network based on its unique setting and the characteristics discussed above.

4.2 Requirements for Deploying Campus Networks in Higher Education

Typically, universities in developed countries are expected to spend 1.5% to 2% of their budget on ICT staffing and day to day operations, with twice as much budgeted for equipment, bandwidth, software and other services.[24]

Campus networks require the following:

i. Equipment—this includes servers, access points, routers, switches, rack cabinets, cables, firewalls
ii. Wired Network (LAN)
iii. Wireless network
iv. On–campus storage and data centre

22 *https://verber.com/it-staffing/*
23 *https://www.auvik.com/franklyit/blog/tech-user-ratio/*
24 *Information Technology in Higher Education, Survey of Chief Information Officers, https://lbcio.org/wp-content/uploads/2011/01/LBCIO_2014_Survey_Final.pdf*

v. Identity management and access systems
vi. Network management and monitoring systems to enhance the reliability and security of network services for the user community
vii. Staff with diverse skills set.

4.3 Africa–wide Campus Network Upgrades and Deployment Models

Table 6 summarises the assumptions used for calculating the cost of upgrading campus networks across all African higher education institutions.

Table 6: Assumptions for calculating campus network upgrade costs in a country

Area	Assumptions
Student enrolment	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.
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: Interviews with different stakeholders, 2020

Table 7 provides a summary of the CapEx and OpEx for upgrading all HEI campus networks across Africa. The OpEx excludes bandwidth costs, which are handled in the next chapter.

Table 7: Estimates for upgrading all African HEIs campus networks (rounded to nearest 10)

Category of HEI	Number of HEIs	CapEx (USD, millions)	OpEx (USD, millions)	Total (USD, millions)
Institutions with less than 5,000 students (small campus)	6,870	10,060	12,530	22,590
Institutions with between 5000-15,000 students (medium campus)	260	700	1,100	1,800
Institutions with more than 15,000 students (large campus)	200	980	1,880	2,860
Total	**7,330**	**11,740**	**15,510**	**27,250**

Source: KCL calculations.

Table 11 shows summary estimates for upgrading HEI campuses at a country level while Table 32 in Appendix A: provides detailed estimates at the country level. Table 8 shows a summary of the estimates at the regional level.

Table 8: Summary estimates for upgrading campus networks by region (rounded to nearest 10)

WBG Region	CapEx (US$, millions)	OpEx (US$, millions)	Total (US$, millions)
East and Southern Africa	6,470	8,450	14,920
North Africa	1,680	2,330	4,010
West and Central Africa	3,600	4,730	8,330
Total	**11,750**	**15,510**	**27,260**

Source: KCL calculations.

OpEx covers five years (default period that can be modified in the model) and includes a maintenance component for the campus networks (15% for hardware and software costs). OpEx excludes bandwidth costs that are handled in the next section. Table 7 shows that OpEx (excluding bandwidth) and the CapEx are comparable, indicating that OpEx can be high on a long-term basis. Given the need for sustainability, this highlights the need for both higher education institutions and governments to budget these costs appropriately.

Small campuses account for 93.7% of all HEIs and 82.9% of the total cost of upgrading campus networks. Given that the average enrolment for small campuses can be low (e.g., 608 students per small campus in Uganda, and 1,481 in Mozambique) the small campus category can be refined into smaller categories and campus networks better dimensioned to reduce the cost of upgrading campus networks. Table 9 shows the number of small, medium and large campuses in Uganda and their accompanying proportion of the cost. Table 10 depicts the same institutions with the categories refined—mini campus (500 students or less), micro campus (500 to 1,500 students) and small campus (1,500 to 5,000 students), large campus (15,000 to 25,000 students) and very large campus (25,000 or more students).

Table 9: Distribution of small, medium and large campuses in Uganda

	No. of HEIs	**Average enrolment**	**% of HEIs**	**% of CapEx + OpEx**
Small (<=5000)	225	608	95.3%	87.5%
Medium (5001-15000)	7	7,753	3.0%	5.7%
Large (>=15000)	4	26,141	1.7%	6.9%
	236		100.0%	100.0%

Source: KCL

Table 10: Distribution of HEI campus sizes in Uganda

	Min enrolment	**Max enrolment**	**No. of HEIs**	**Average enrolment**	**% of HEIs**
Micro campus	0	500	150	163	63.6%
Mini campus	500	1500	56	872	23.7%
Small campus	1,500	5,000	19	2,824	8.1%
Medium campus	5,000	15,000	7	7,753	3.0%
Large campus	15,000	25,000	2	20,973	0.8%
Very large campus	25,000		2	32,000	0.8%
Total			236		100.0%

Source: KCL

Refining the categories shown in Table 9 as organised in Table 10 reduces the cost of upgrading campus networks for HEIs in in Uganda from USD 846 million to 574 million, a saving of 32.2%; in Côte d'Ivoire from USD 1,129 million to 711 million, a saving of 37%; and in Mozambique from 255 million to 238 million, a saving of 6.7%.. This highlights that countries with a larger proportion of small campuses can save on the cost of upgrading campuses networks by refining the categories to account for much smaller campuses and dimensioning their networks appropriately. More savings can be derived from the use of shared infrastructure like switching and data centres among micro and mini campuses that are geographically very close to each other. These potential savings have not been factored into the gross cost estimates for upgrading campus networks: while it was calculated for each of the case study countries to explore the potential impact, there is insufficient data for a continent-wide generalisation.

Table 11: Summary estimates for upgrading campus networks at all African HEIs by country

Country	Number of HEIs	CapEx + OpEx (USD, millions)	Country	Number of HEIs	CapEx + OpEx (USD, millions)	Country	Number of HEIs	CapEx + OpEx (USD, millions)
Algeria	105	628	Eswatini	28	96	Namibia	17	81
Angola	25	144	Ethiopia	140	642	Niger	16	67
Benin	49	187	Gabon	27	107	Nigeria	799	3,055
Botswana	53	196	Gambia	11	40	Rwanda	40	172
Burkina Faso	93	343	Ghana	275	978	São Tomé and Príncipe	5	16
Burundi	50	183	Guinea	53	189	Senegal	28	114
Cabo Verde	9	33	Guinea-Bissau	5	20	Seychelles	11	36
Cameroon	243	895	Kenya	1486	5,113	Sierra Leone	33	127
Central African Rep.	26	89	Lesotho	15	53	Somalia	125	447
Chad	20	69	Liberia	54	199	South Africa	487	1,828
Comoros	7	27	Libya	13	76	South Sudan	25	86
Congo	58	206	Madagascar	11	73	Sudan	139	611
Congo, Dem. Rep.	96	426	Malawi	56	203	Tanzania	494	1,676
Côte d'Ivoire	330	1,129	Mali	10	66	Togo	106	367
Djibouti	7	27	Mauritania	7	27	Tunisia	252	944
Egypt	195	938	Mauritius	14	50	Uganda	236	846
Equatorial Guinea	4	17	Morocco	412	1,429	Zambia	358	1,214
Eritrea	16	56	Mozambique	53	255	Zimbabwe	102	357

Source: KCL calculations.

Campus network design capability is an important factor in cost and sustainability; therefore, a concerted national effort should be made to improve campus network design. The Norwegian GigaCampus project provides a great insight into how a coordinated national campus network design and development effort can enable a country to reap the benefit in the long term. The Norwegian experience indicates that countries need between $1 to $3 million to support nation-wide effort to evolve with world-class campus infrastructure. This is expected to cost $94 million to cover all countries in Africa.[25]

Box VI: Norwegian GigaCampus Project

In 2005, in response to the Norwegian Ministry of Education and Research, the Norwegian Association of Higher Education Institutions 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 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, seminar 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 – 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 centre and communication rooms. This includes cabling, power, cooling as well as fire protection systems.

GigaCampus ran several national level procurement processes for ICT equipment for campus networks. Thirty agreements within ten 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 standardisation 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

25 *10 countries @ $3 million, 20 countries @ $2 million and 24 countries @$1 million*

5. Connecting Campuses Upstream

Countries have a wide range of options to connect campus upstream including through commercial service providers and NRENs. The bandwidth needs for higher education vary widely by country as summarized in Table 33. The higher education sector is one of the top consumers of higher-speed connectivity, therefore connecting higher education will have considerable impact on bandwidth usage on the continent.

5.1 Variation in Unit Price

We forecast student enrolment (in Table 29) and combine this with progressive targets (in Table 2) to estimate bandwidth requirements for each country. We consider the number of staff to be negligible compared to the number of students.

The overall targets are to achieve at least 2 Gbps per 1000 students by 2025 (to be provided for in the World Bank planning period ending 2023) and at least 20 Gbps per 1,000 students by 2030. Based on this, Table 12 shows the projected bandwidth requirements for the African continent on a regional basis using Student Enrolment, giving a total of 43.3 Tbps by 2025 and 506.8 Tbps by 2030.

Table 12: Projected bandwidth by region using Student Enrolment (2021, 2025 & 2030)

WBG Region	Projected higher education students (thousands)			Projected bandwidth requirements (Gbps)		
	2021	**2025**	**2030**	**2021**	**2025**	**2030**
East and Southern Africa	7,470	8,716	10,314	7,470	17,432	206,281
North Africa	6,314	6,897	7,607	6,314	13,795	152,147
West 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 3 shows two ways to determine the Unit Price (USD/Mbps/month). The unit price of bandwidth varies widely depending on distance from fibre network, local access and transit costs, the maturity of NREN, 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 Uganda. 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 higher education institutions are located at most 15 km from a provider’s PoP in a metro/urban area.

Source: KCL

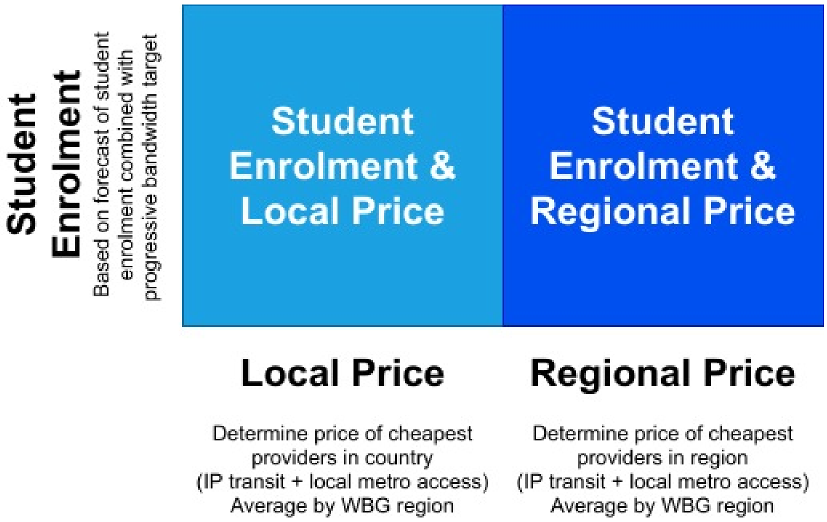


Figure 3: Matrix for determining bandwidth cost

Table 13 shows example rates from selected countries.

Table 13: Examples of IP transit and local metro access rates in selected countries

Country	Capital City	IP transit ($/Mbps)	Circuit	Metro access ($/Mbps)	Circuit	Region
Egypt	Cairo	23.68	10 GigE	4.38	GigE	Northern Africa
Ghana	Accra	7.13	10 GigE	3.11	GigE	West & Central Africa
Kenya	Nairobi	4.54	10 GigE	3.41	GigE	East & South Africa
Morocco	Rabat	73.13	10 GigE	4.23	GigE	Northern Africa
Nigeria	Lagos	5.17	10 GigE	0.69	10 GigE	West & Central Africa
South Africa	Cape Town	2.51	10 GigE	2.72	GigE	East & South Africa
Tanzania	Dar es Salaam	17.97	10 GigE	4.00	GigE	East & South Africa

Source: Telegeography, 2020

There are a number of countries for which there is no such data. To derive a unit price (USD/Mbps/month) for use across all countries, we calculate a regional average for countries using the WBG regions as indicated in the left-side of Table 14 and this is the price (Local Price) that we use for each country located within a particular region. Instead of using the cheapest provider rate in-country, an adjustment that uses the cheapest rates from within the region/vicinity can alter the upstream connectivity cost dramatically as indicated by right-side of Table 14 and this is the price (Regional Price).

Table 14: 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)**
North Africa	49.5	4.3	53.8	15.9	4.3	20.2
East and Southern Africa	48.8	3.8	52.5	10.5	3.8	14.3
West and Central Africa	50.3	1.9	52.2	2.4	1.9	4.3

Source: KCL calculations

5.2 Impact of Bandwidth Aggregation

In most countries in Africa, connectivity to higher education will primarily be provided by commercial services providers due to limited development of the National Research and Education Networks. This implies that all countries should accelerate the development of NRENs that aggregate demands of all users, provide services e.g., research and education connectivity, firewalls, security, content filtering and bring costs down at the later stages.

Source: GÉANT, NREN's the Economic Benefit

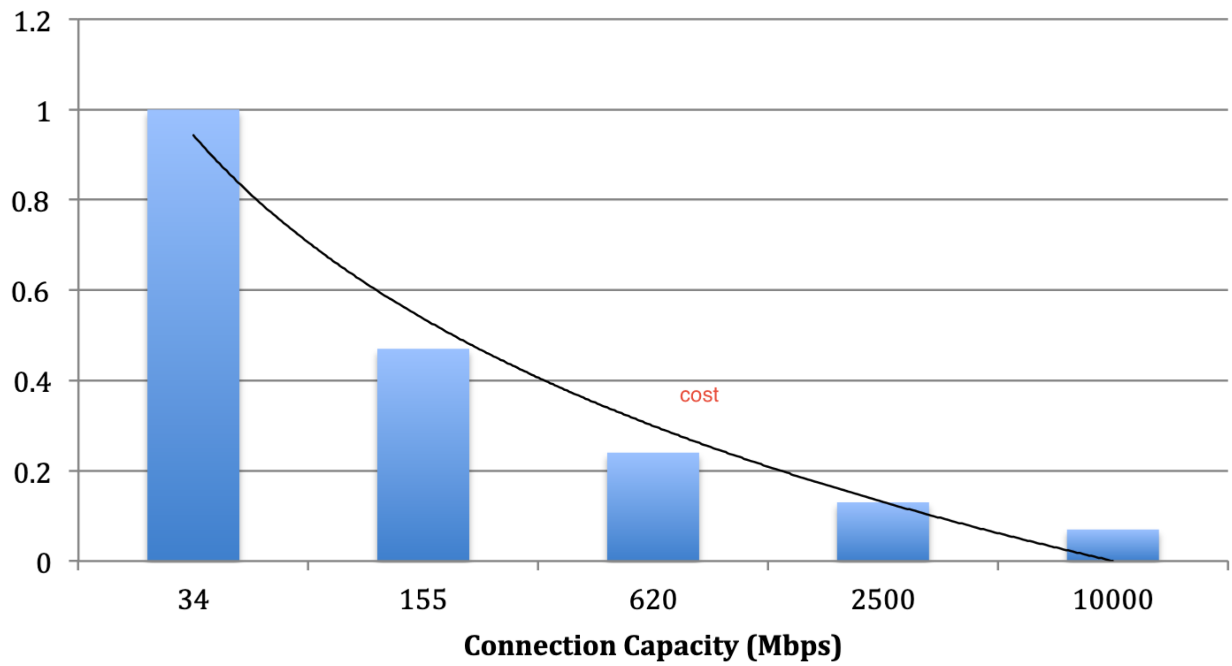


Figure 4: Relationship between cost and capacity of transmission

NREN-led procurement in Europe shows that bringing together demand, enable universities the increasingly high capacity needed for teaching, learning and research than having individual institutions separately purchasing connections. Procurement in Europe indicates that the cost per Mbps, for a 155 Mbps circuit is roughly half the cost, per Mbps, for a 34Mbps. Likewise, a 10Gbps circuit is a factor of fourteen cheaper per Mbps than an equivalent 34 Mbps.[26] The AfricaConnect projects have used a negotiated procurement procedure to ensure that fibre links, certainly on the marine side, are secured at costs comparable to the rest of the world. Using this approach, the best and final offers from bidders came down to less than 20% of initial bids – and also impacted the regional market costs.

The two most frequently used options for acquiring fibre access are leasing or obtaining a right of use contract.

An Indefeasible Right of Use (IRU) is a contractual arrangement with which an “IRU user” can unconditionally and exclusively use one or more fibres of the “IRU grantor’s” fibre network for an extended period, typically 10 to 25 years with a single payment up front. IRU provides complete use of a fibre line without any limitations for an extended period of time. The IRU contract defines detailed technical and performance specifications for the IRU fibres. The IRU user is solely responsible for repairing and maintaining the active/passive equipment that is connected with the IRU fibres.

IRU payment terms usually include:

- A lump–sum payment corresponding to the dark fibre construction cost and the use of the infrastructure for the IRU duration. This is the most substantial, often upfront fee.
- A periodic (e.g., annual) fee corresponding to the maintenance services provided to IRU user by the IRU grantor. This is usually fixed or slightly increasing, taking into account the country's inflation.

With leased fibre, the owner retains overall control over the fibre and provides the higher education institution with the ability to use a certain amount of capacity based on the lease agreement.

Currently, NRENs use four common options to connect to universities in Africa

- Purchasing IRUs from operators
- Leasing capacity from operators
- Purchasing dark fibre, where available on the market
- Building their own network segments, especially the last mile connection to member institutions where there is no viable commercial connection. This can be paid for either by the government, the institution or the NREN.

The NREN needs to connect each higher education campus network to a local aggregation Point of Presence (PoP), from where they often serve multiple customers and interconnect

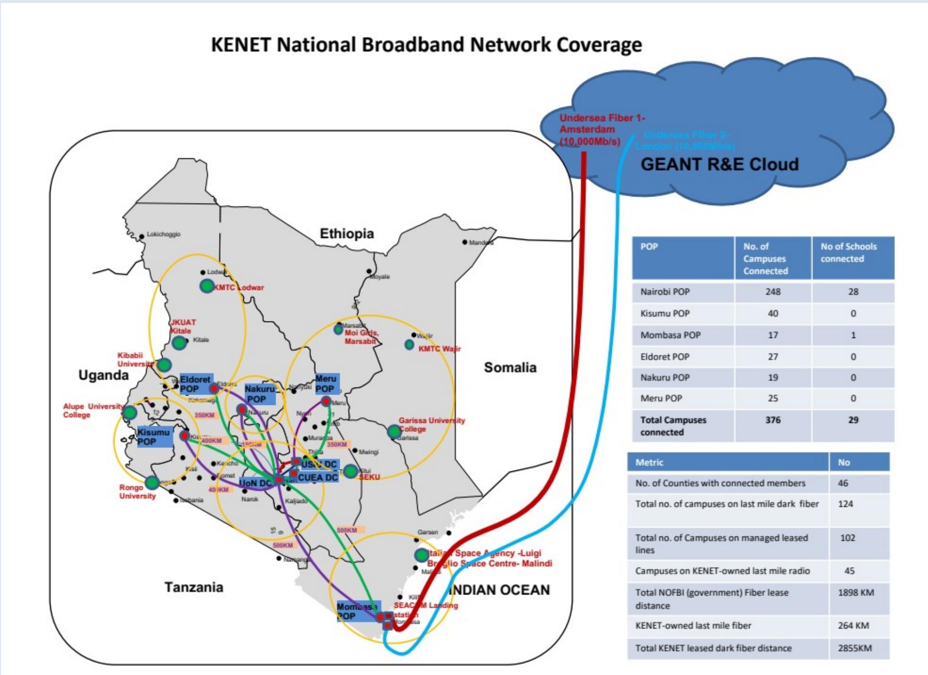
26 *GÉANT, NREN, the Economic Benefits, https://www.casefornrens.org/Resources_and_Tools/Document_Library/Documents/NRENs%20-%20The%20Economic%20Case.pdf*

multiple local campus networks. In urban towns, this last–mile connectivity may entail use of existing metro fibre networks, while in rural areas this often entails the NREN laying new fibre. From the local PoP, the NREN uses the national fibre backbone network to interconnect local PoPs spread across the country and back–haul traffic to a national PoP. At the national PoP, the NREN will interconnect various higher education networks, offer access to other NRENs through the RREN. Where an IXP exists, the NREN connects to this from their national PoP.

The Kenyan Education Network experience indicates that NRENs need to use the three fibre acquisition models based on the commercial conditions, the geographic location and available financial resources.

Box VII: KENET Using Multiple Models to Connect Kenyan Universities

The Kenya Education Network (KENET) has been using different models to connect universities in the country using fibre network since 2008. It had connected 135 of 360 campuses using fibre by 2020. KENET operates close to 3000 Km of fibre to connect universities.



KENET leases about 40 Gb/s of managed fibre from commercial operators like Liquid Telecom for both last mile and backbone links, 2960 Km of dark fibre primarily from government and has built over 264 Km of own last mile fibre to connect universities and research institutions leveraging government financing, donor funding, and contributions from member institutions.

Source: https://www.kenet.or.ke, 2021

In terms of cost, national aggregation will include the distance of each institution from an existing fibre network for last–mile connectivity, coverage and cost of metro fibre networks, coverage and cost of national fibre networks, amount of international Internet connectivity available for the country as well as the availability and costs associated with access to other essential components of the digital ecosystem like IXPs and carrier–neutral data centres.

To determine the potential savings that can accrue from bandwidth aggregation at each country-level, we use a combined weight of NREN indicators from the NREN survey and national ICT indicators collected during the Gap Analysis phase of the project.

5.2.1 NREN Indicators

NREN survey results collected during the Gap Analysis phase highlight a number of indicators relevant to higher education connectivity at the country-level. The most pertinent integrated into the cost model include:

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 (network [virtual or physical] 1 point, national POPs 2 points),
vi. Whether NREN has an Autonomous System Number (ASN) (1 point).[27,28] This facilitates routing within NREN network, exchange of routing information with other network operators and ability to directly peer with an IXP.
vii. Whether at least one institution or more has own ASN that can facilitate multi-homing (1 point),
viii. Whether any ASN has networks that they peer with (1 point),[29]
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 centre services, video conferencing, research management tools).

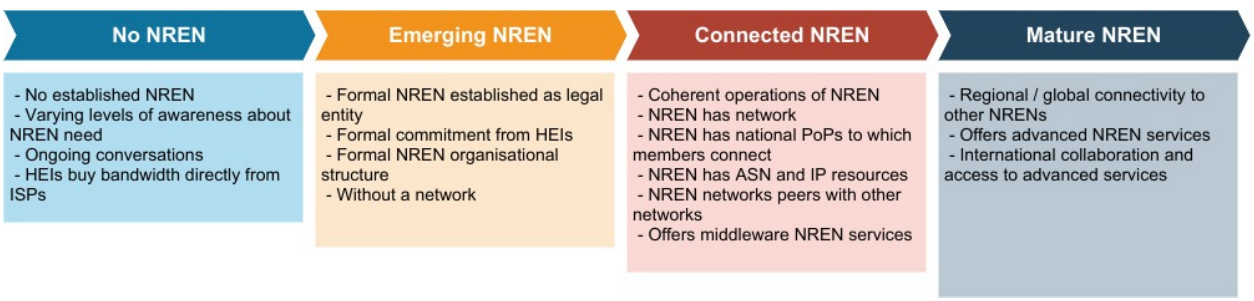


Figure 5: Stages of NREN development

Using a combination of Duncan Greaves' NREN Capability Maturity Model[30] and Mike Foley's

27 *AfriNIC is the regional Internet registry that allocates these for the African region, https://afrinic.net/asn*
28 *AfriNic ASN Statistics https://stats.afrinic.net/asn/*
29 *AfriNic ASN Statistics https://stats.afrinic.net/asn/*
30 *Greaves, D. (2009). An NREN Capability Maturity Model. https://www.casefornrens.org/Resources_and_Tools/Document_Library/Documents/NREN%20Capability%20Maturity%20Model%20(CMM).pdf*

levels of NREN development,[31] different African countries were organised into levels of NREN maturity, and scores given within each broad level. There are four broad groups summarized in Figure 5, that include:

i. No-NREN: no NREN, but varying levels of awareness about need and ongoing conversations.
ii. Emerging NREN: legal entity established, with formal organisational structure, but without a network.
iii. Connected NREN: has network of varying coverage, may have national PoPs to connect members, has ASN and IP resources that facilitate peering with other networks and offering middle-ware services, and
iv. Mature NREN: has high-speed regional (transit in Africa)/global (transit in Europe) connectivity to other NRENs and offering advanced services.

Table 15 depicts how the NRENs in different African countries can be categorized around these stages and how this affects the potential connectivity model, what actions need to be taken and the potential savings that can be derived from the resulting aggregation of demand.

Table 15: Classification of Connectivity in African Higher Education

State of NREN development	Countries	Predominant business models	Actions	Contribution to Saving via aggregation
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	Connect CSP	Ensure access to bandwidth to all higher education institutions (2 years) NREN development (3 years) Transition to full NREN model (5 years)	0% saving
Emerging NREN	Botswana, Burkina Faso, Burundi, Cameroon, Chad, Djibouti, Guinea, Liberia, Libya, Mali, Mauritania, Namibia, Niger, Sierra Leone, Sudan, Zimbabwe	Connection via CSP and NREN	Strengthening NREN Ensuring that higher education institutions are connected to adequate Internet bandwidth	30% saving

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

Connected NREN	Algeria, Benin, Cote d'Ivoire, DRC, Egypt, Ethiopia, Gabon, Ghana, Madagascar, Malawi, Morocco, Mozambique, Nigeria, Rwanda, Senegal, Somalia, Tanzania, Togo Tunisia, Zambia	Connection via CSP and NREN	Ensuring that higher education institutions are connected to adequate Internet bandwidth Provision of advanced services Transition to full-fledged NREN in three years	60% saving
Mature NREN	Kenya, South Africa, and Uganda	Exclusive NREN model	Provision of advanced connectivity and services	90% saving

Source: KCL calculations

5.2.2 National ICT Indicators

National ICT indicators collected during the Gap Analysis phase also include a number of indicators with a direct bearing on connectivity for higher education institutors at the country-level. The most pertinent integrated into the cost model include:

i. Whether country is landlocked or has access to the ocean, which allows direct access to submarine cables;
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;
iii. Internet eXchange Ladder Stage. Countries were categorized into 4 stages (see Table 16) depending on the number of IXPs and carrier neutral data centres they have as well as the interaction between these two important facilities;[32]

Table 16: Stages on 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	Angola, Burundi, Democratic Republic of Congo, Mauritius,

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

	IXP, presence of global Content Distribution Networks (CDNs)	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

iv. % Population within 10-km fibre coverage (reflects fibre network coverage of the country);
v. Regulatory score, which reflects the maturity of regulatory environment. It is based on individual country scores from ITU Global Regulatory Outlook 2020.

5.3 Cost of Connecting Campuses Upstream

Each broad group of countries needs different approaches to connectivity that we explore in the subsequent sections below.

5.3.1 Connecting No NREN countries to CSP

This model is can be used in countries with no research and education networking activity at the very beginning. In these countries, universities, colleges and TVETs purchase bandwidth directly from services providers. While prices from services providers tend to be lower in urban areas where operators have major infrastructure, cost can be extremely high for higher education institutions outside of major urban areas. This model of connection remains the most expensive for higher education institutions. The cost is expected to come down with the establishment of NRENs that aggregate connectivity for HEIs. It is therefore important that the development of NRENs goes a step ahead, or hand in hand with connecting higher education institutions in these countries.

Table 17: Bandwidth costs for No-NREN countries based on student enrolment and local prices (2025)

Country	Total (USD, millions)	
	Total No Aggregation Savings	**Total with Aggregation Savings**
Angola	178	116
Cabo Verde	18	11
Central African Rep.	18	15
Comoros	6	3
Congo, Republic	71	46
Equatorial Guinea	18	13
Eritrea	4	3
Eswatini	9	7

Gambia	15	9
Guinea-Bissau	23	18
Lesotho	16	10
Mauritius	24	10
São Tomé and Príncipe	2	1
Seychelles	1	1
South Sudan	90	76

Source: KCL Calculations

5.3.2 Connecting Emerging NREN Countries

This model works for universities that connect to service providers and NRENs separately. It works for countries where NRENs are young and emerging, but these countries need to move to full-fledged NRENs within three years. Universities purchase commercial Internet bandwidth from service providers separately, while also linking to NRENs for connecting to international research and education networks. In this mode, NRENs serve as a peering network for connecting campuses together.

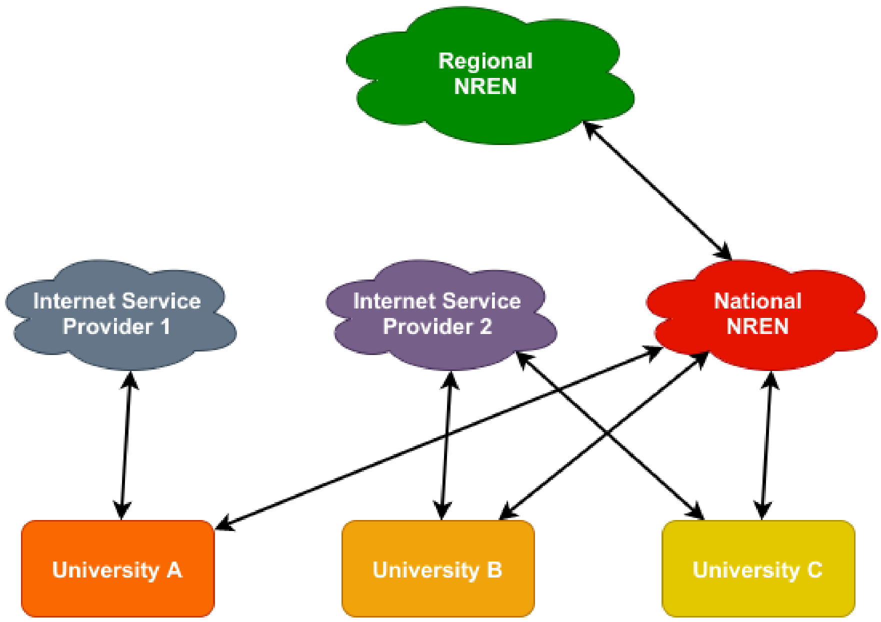


Figure 6: CSPs for primary connection with NRENs as peers

While this model makes policymakers and regulators that often refuse to provide NRENs with a Closed User Group licence and private service providers content, it creates a situation where universities rely on a costly connection. Because Universities have to manage two different connections – one for service provider and the other for NREN, management of the service becomes complex (see Figure 6) because good network design requires multi-homing in order to increase performance and reliability. This often means that universities need to obtain their own unique Autonomous System Number (ASN) and IP address space to effectively route their network traffic, pushing the envelope of limited technical capacity.

Table 18: Bandwidth costs for Emerging NREN countries based on Student Enrolment and Local Prices (2025)

Country	Total (USD, millions)	
	Total no Aggregation Savings	**Total with Aggregation Savings**
Botswana	33	19
Burkina Faso	188	115
Burundi	27	17
Cameroon	423	215
Chad	61	41
Djibouti	7	4
Guinea	201	108
Liberia	99	55
Libya	197	131
Mali	99	61
Mauritania	22	12
Namibia	35	18
Niger	87	55
Sierra Leone	95	55
Sudan	410	211
Zimbabwe	96	59

Source: KCL Calculations

5.3.3 NRENs as exclusive connection (Model 3)

For Connected NREN and Mature NREN countries, the NREN model is the most cost-effective approach to connect HEIs. In the NREN model, each participating institution connects to their NREN, which provides them with domestic and international connectivity to other institutions and the Internet, thus reducing the cost of coordination and transaction. When NRENs provide all connectivity, including internet service, it is more accessible for universities, because they manage a single connection.

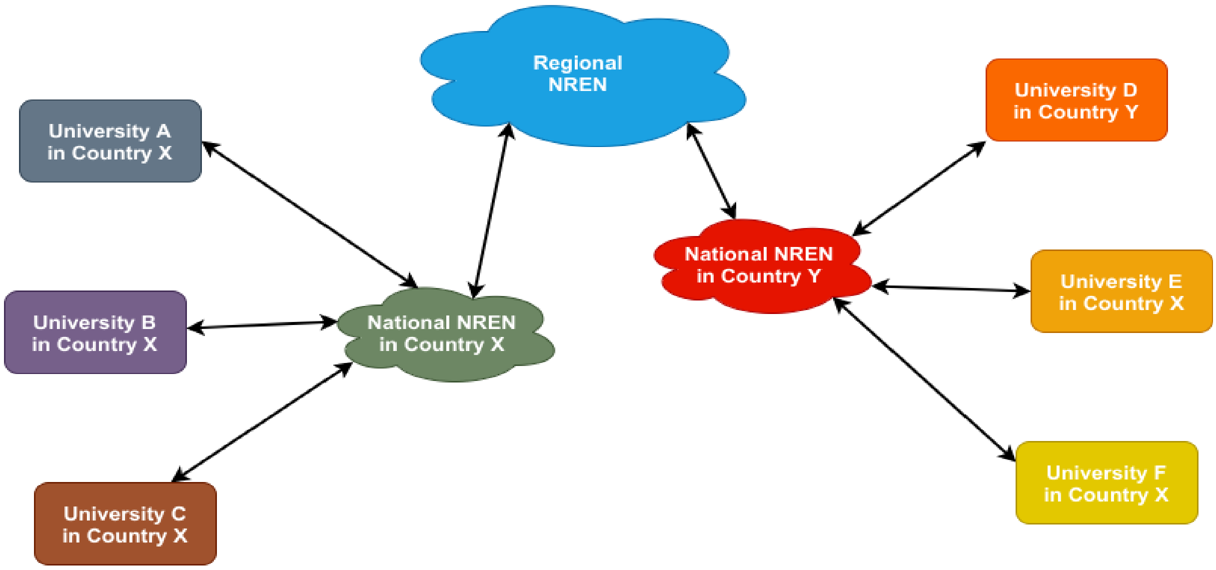


Figure 7: NRENs as primary connection

Table 19: Bandwidth costs for Connected NREN countries based on Student Enrolment and Local Prices (2025)

Country	Total (USD, millions)	
	Total no Aggregation Savings	**Total with Aggregation Savings**
Algeria	1,535	608
Benin	158	56
Congo, Democratic Republic of	285	104
Côte d'Ivoire	264	96
Egypt	2,394	758
Ethiopia	599	361
Gabon	18	6
Ghana	575	161
Madagascar	91	34
Malawi	26	11
Morocco	1,076	340
Mozambique	126	50
Nigeria	2,370	721
Rwanda	51	21
Senegal	208	61
Somalia	137	52
Tanzania	97	34

Togo	114	44
Tunisia	185	61
Zambia	108	50

Source: KCL Calculations

NRENs have proved to be the most viable model for bringing down costs quickly through aggregation and economies of scale in resource–limited environments. This is why most NRENs, certainly in Africa, have had their entry point business model as basic bandwidth aggregation to bring down the price and therefore increase bandwidth within the same resource envelope. Beyond the provision of access to commercial Internet and international collaborative research and education, NREN creates a platform for advanced research in network technologies at national levels.

Table 20: Bandwidth costs for Mature NREN countries based on Student Enrolment and Local Prices (2025)

Country	Total (USD, millions)	
	Total no Aggregation Savings	Total with Aggregation Savings
Kenya	594	78
South Africa	588	86
Uganda	149	41

Source: KCL Calculations

5.4 Strengthening and Sustaining NRENs

At NREN level the costs vary considerably based on the technology choice (fibre optics, wireless), the number of institutions involved, size of the institutions and their geographic location relative to fibre networks, bandwidth and quality of services requirements, and serviced offered by operators. Cost is also dependent on the level of NREN maturity.

The CapEx of an NREN includes initial network design cost, international and regional connectivity cost, the cost for purchase and upgrade of optical switching equipment and cost of last mile connections to campus networks as summarised in Table 21. 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. NRENs need a critical mass of human resources including engineers, application developers as well as communication and financial specialists. NRENs also need an ongoing budget for training and capacity building and support and upgrade of the network.

Table 21: CapEx and OpEx elements for different scenarios

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 Operations and maintenance
Engineering and contracts	Communication and outreach
Physical installation and inter–campus connection	Network services
	Overheads

Source: KCL

Discussions with NREN CEOs in Africa indicate that if HEIs get into long-term commitments with advance payments for connectivity, NRENs can in-turn use these resources to invest in the CapEx to build the necessary infrastructure to deliver the increased amounts of bandwidth. In addition, they indicated that they spend about 60% of their OpEx on connectivity-related expenses (e.g., network services, network operations and maintenance) and the remaining 40% on human resources and related costs. While NRENs can cover connectivity-related expenses from member bandwidth payments, they often struggle to cover core costs as well as costs related to ongoing capacity building for both internal staff and especially for the ICT support staff of member institutions. 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 ten years. As the cost of bandwidth is driven down, 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.

Assumptions:

i. Based on interviews with the NREN CEOs, NRENs spend about 40% of their OpEx on core costs (mostly human resource) and NREN development related costs.
ii. Countries are given support for core costs in inverse variation to their level of NREN maturity: Mature NREN countries receive the least support while No-NREN countries receive the most support.
iii. We have assumed support of USD 1 million per year to cover core costs for five years for Mature NREN countries. This increases by USD 0.5 million as the level of NREN maturity decreases until the No-NREN countries that we propose to support with USD 2.5 million per year over the same period. The list of countries and levels of support are presented in Table 22. It should be noted that this is a general approximation: in real terms, the smaller countries will need a lot less, and the larger countries a lot more.

Table 22: Support for Core Costs for African NRENs

State of NREN development	Countries	Proposed Support
No NREN	Angola, Cape Verde, Central African Republic, Comoros, Republic of Congo, Eritrea, Equatorial Guinea, Eswatini,	USD 2.5 million per country, USD 12.5 million per country over five years:

	Gambia, Guinea-Bissau, Lesotho, Mauritius, São Tomé and Príncipe, Seychelles, South Sudan **(15)**	**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 five years: **USD 150 million**
Mature NREN	Kenya, South Africa, and Uganda (3)	USD 1 million per country, USD 5 million per country over 5 years: **USD 15 million**
	Total	**USD 513 million**

Source: KCL

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.

5.5 Regional Upstream Connectivity Costs

Two or more countries need cross–border infrastructure to interconnect their national networks in order to be able to exchange Internet traffic. Such connections maybe terrestrial or subsea fibre networks with microwave and satellite increasingly phased out due to their limited bandwidth capacities. Cross–border infrastructure is even more important for the sixteen land-locked African countries that have to rely on their neighbours in order to be able to reach submarine cable landing stations located in countries with access to the sea.

A number of regional fibre carriers have emerged to provide terrestrial cross–border fibre networks inland to compliment the subsea cross–border networks that can only link countries with access to the sea. Some of these terrestrial providers include:

- Liquid Telecom covering East and Southern Africa
- Bandwidth and Cloud Services (BCS) Group covering Eastern Africa
- Hurricane Electric covering East and Southern Africa
- West Indian Ocean Cable Company (WIOCC) covers Eastern Africa
- Central African Backbone, funded by WBG covering Central Africa

A number of national IXPs have grown into regional connectivity hubs on the continent facilitating the exchange of regional traffic while attracting global networks and international content providers. These include:

- NapAfrica's IXP with PoPs in Cape Town, Durban and Johannesburg (South Africa)
- Kenya Internet Exchange Point (KIXP) with PoPs in Nairobi and Mombasa (Kenya)
- Internet eXchange Point of Nigeria (IXPN) with PoPs in Abuja, Kano, Lagos and Port Harcourt (Nigeria)

At the regional level, NRENs typical aggregate and keep African traffic local through Regional RENs (RRENs), Africa is covered by three major RRENs: the Arab States Research and Education Network (ASREN)[33] that connects North Africa but also includes members outside Africa; the West and Central African Research and Education Network[34] (WACREN), and the UbuntuNet Alliance (UA) that covers East and Southern Africa.[35]

National and regional networks procure intercontinental capacity from submarine cable operators. 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 had one cable landing, ten countries had two cable landings, six had three cable landings, and 10 had more than three cable landings creating more competition in this segment of the infrastructure ecosystem. The submarine cables have played a catalytic role in the build-up of terrestrial national and regional fibre networks to extend connectivity inland as well as national and regional IXPs to keep traffic local and improve content access. In turn, improvements in infrastructure have driven increase in demand for connectivity. This has resulted in the upgrade of existing and landing of new submarine cables (ACE, WACS, Main One, GLO–1, AST3, NCSIS, SAIL and SACS) on the West Coast, and the East Coast (EASSy, SEACOM, LION, TEAMS and SEAS) on the continent.

Submarine cables tend to be built and managed by consortia of public and private operators/entities driven by the need to access more and higher quality international broadband at lower cost. By investing from the onset, consortia participants get lifetime access to the cable as opposed to Indefeasible Rights of Use (IRU) that tend to last 5 to 20 years.

5.6 Strengthening and Sustaining Regional RENs

The three regional RENs, WACREN, UbuntuNet Alliance and ASREN aggregate national traffic and connect to international networks. Experience of the UbuntuNet Alliance summarized in Table 23 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 promotion of coordination among national research and education network).

Table 23: Cost drivers for UbuntuNet Alliance budget

Regional Research and Education Network	Cost Items (2020)

33 *ASREN website, http://asrenorg.net*
34 *WACREN website, https://www.wacren.net*
35 *UbuntuNet Alliance website, www.ubuntunet.net*

UbuntuNet Alliance (UA)[36] Number of countries connected: 10	CapEx investment in network costs (USD 1.1 million) Connectivity and network operation cost (USD 1.3 million) Human resource costs (USD 0.6 million) Coordination and other costs (USD 1 million) Total = USD 4 million

Source: UbuntuNet Alliance[37]

In Africa, RREN transmission costs are expected to be covered by member NRENs and through international support such as the EU funded AfricaConnect project; but, the three Regional Research and Education Networks 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 per year for NREN development over the next five years. This includes sensitisation workshop, short term consulting and NREN business plan design.
ii. RRENs spend USD 25,000 per country per year for training and promotion of Direct Engineering Assistance over the next five years.
iii. RRENs spend USD 700,000 each, annually to support critical mass of human resources including ICT engineers, application developers as well as communication and financial specialists for the next five years.

Table 24: Support for core costs for African RRENs

RREN	UA	WACREN	ASREN
Number of countries with membership region	24	22	10
Number of institutions	4,096	2,329	977
NREN development and promotion cost (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 cost (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.

36 *UbuntuNet Alliance members, https://ubuntunet.net/about/council-of-members/*
37 *Interviews with UbuntuNet Alliance management team*

5.7 Summary of Connection Costs

Table 25 compares the total bandwidth costs for all African countries based on Student Enrolment using both Local and Regional prices discussed in section 5. Besides underscoring the importance of a robust procurement process, the price comparison shows the importance of policy and regulatory reform and competition to lower broadband prices closer to those in developed countries and the significance of National Research and Education Networks.

Table 25: Annual bandwidth cost for all African countries by region using student enrolment (2025)

WBG Region	Total (USD, millions) using local prices		Total (USD, millions) using regional prices	
	Total no Aggregation Savings	**Total with Aggregation Savings**	**Total no Aggregation Savings**	**Total with Aggregation Savings**
East and Southern Africa	3,790	1,484	1,381	541
North Africa	5,386	1,899	1,929	680
West and Central Africa	5,143	1,973	614	235
Total	**14,319**	**5,356**	**3,924**	**1,456**

Source: KCL Calculations

Table 26 provides a summary of the different costs associated with connecting campuses upstream using the progressive bandwidth target of 2 Gbps per 1000 students set for 2025.

Table 26: Annual cost of connecting campuses upstream (2025)

Category	Cost (USD, millions) rounded to nearest 10	
	With Aggregation savings	**With no Aggregation savings**
Using Student Enrolment & Local Prices	5,326	14,319
Using Student Enrolment & Regional Prices	1,456	3,924
NREN core costs and NREN development related costs	103	
RREN core costs and NREN development related costs	5	

Source: KCL Calculations

6. Cost of Connecting African Higher Education

Table 27 sums up the cost elements for different components that make up the total cost of connecting all higher education institutions in Africa. These include the cost of equipping students and staff with access devices, designing and upgrading campus networks. The total costs are for five years starting with the first year of implementation, the initial assumed period being 2021 – 2025 inclusive.

Table 27: Summary of total 5-year cost of connecting all African higher education institutions to high-speed Internet (2021-2025)

Category	Cost (USD, millions)	Potential Sources of Funding
End-user devices		
Students and Staff	17,284	Government, development partners, students, institutions
Sub Total	**17,284**	
Upgrading campus networks		
CapEx	11,750	Government, development partners
OpEx	15,510	Institutions, government, development partners
Sub Total	**27,260**	
Cost of connecting campuses upstream		
	With Aggregation Savings	
Using Student Enrolment & Regional Price	**7,280**	Development partners, institutions, students
RRENs/NRENs development and support costs		
NREN core support and NREN development related costs	**513**	Development partners, government
RREN core support and NREN development related costs	**25**	Development partners, government
Total Cost Estimate (USD, billions)	**52**	**Using cost of connecting campuses upstream based on student enrolment and regional price**

Source: KCL calculations

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

It is also assumed that smart procurement strategies (e.g., benchmarking regional pricing) combined with procurement of long-term leases will be used to secure the best price advantage. Potential sources of funding include governments, development partners, students, and higher education institutions. Actual proportions will vary across countries depending on government funding priorities, development partner funding guidelines and the means of different stakeholders.

7. Conclusion and Summary

Connectivity is the foundation for teaching, learning and innovation in higher education. African higher education institutions need broadband access that is comparable with their peers in developed countries in ten years, with an initial goal of attaining at least 2 Gbps per 1000 students by 2025. This implies that every student and staff should have access to devices, campuses have the most advanced and secure networks capable of high-speed transactions with connection to the Internet and global research and education networks. Connecting higher education institutions require the development of National Research and Education Networks and state-of-the-art capacity at HEIs to manage the high-speed connection, applications and services.

We estimated that African countries need USD 52 billion over the five-year period 2021 – 2025 to achieve the goal of connecting higher education institutions, broken down into the key elements of end-user laptops (USD 17.2 billion); improving/establishing campus networks (USD 27.3 billion); connectivity for five-years (USD 7.2 billion); and NREN and RREN development/support (USD 538 million).

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. Modelling of the case study countries at this level (as provided for in the Cost Model) led to reductions of the cost of campus upgrading by 6.7%, 32.2%, and 37% respectively for Mozambique, Uganda. This potential reduction has not been factored into the gross estimated cost in the summary because the number of countries analysed is too small to be used as a basis for a reliable generalisation across the continent—but it does to point a significant potential reduction in the gross cost.

Potential sources of funding include governments, development partners, students, and higher education institutions. Actual proportions will vary across countries depending on government funding priorities, development partner funding guidelines and the means of different stakeholders. Part of the cost emanates from the high bandwidth tariffs in African countries, especially in nations that have made limited progress in promoting competition in the broadband market. Accelerated reform alone can ease the overall cost of connecting African higher education.

Coordination is an essential prerequisite to achieving higher education connectivity. Each country needs to assemble a high–level team drawn from the ministries responsible for higher education, and the ICT sector; HEIs; the NREN where present; the ICT private sector; key development partners; and other stakeholders to develop a unified plan for connecting its higher education institutions. A concerted national effort should be made to expand connectivity, accelerate online learning, improve campus network and promote NREN development.

Appendix A: Tables

Table 28: Number of African higher education institutions by country

Country	Type		Campus Size			Total
	Universities	TVETs	Small Campus (≤5k)	Medium Campus (5,001-15k)	Large Campus (>15k)	
Algeria	63	42	75	7	23	105
Angola	18	7	12	11	2	25
Benin	8	41	46	1	2	49
Botswana	8	45	49	3	1	53
Burkina Faso	18	75	87	4	2	93
Burundi	20	30	47	2	1	50
Cabo Verde	6	3	8	1	0	9
Cameroon	20	223	231	5	7	243
Central African Republic	1	25	25	1	0	26
Chad	10	10	19	1	0	20
Comoros	1	6	6	1	0	7
Congo	2	56	56	1	1	58
Congo, Dem. Rep.	52	44	78	12	6	96
Côte d'Ivoire	40	363	395	5	3	403

Djibouti	1	6	6	1	0	7
Egypt	54	141	161	11	23	195
Equatorial Guinea	1	3	3	1	0	4
Eritrea	7	9	15	1	0	16
Eswatini	5	23	27	1	0	28
Ethiopia	40	100	117	10	13	140
Gabon	8	19	24	2	1	27
Gambia	3	8	10	1	0	11
Ghana	55	220	265	5	5	275
Guinea	27	26	51	1	1	53
Guinea-Bissau	5		4	1	0	5
Kenya	73	1,413	1,442	35	9	1,486
Lesotho	2	13	14	1	0	15
Liberia	8	46	44	1	1	46
Libya	13	0	8	3	2	13
Madagascar	11	0	5	4	2	11
Malawi	26	30	53	2	1	56
Mali	6	4	5	3	2	10
Mauritania	3	4	6	1	0	7
Mauritius	4	10	13	1	0	14
Morocco	22	390	402	5	5	412
Mozambique	19	34	45	5	3	53

Namibia	3	14	12	4	1	17
Niger	9	7	14	1	1	16
Nigeria	171	628	737	35	27	799
Rwanda	12	28	33	5	2	40
São Tomé and Príncipe	1	4	5	0	0	5
Senegal	19	9	24	3	1	28
Seychelles	1	10	11	0	0	11
Sierra Leone	5	28	30	2	1	33
Somalia	44	81	117	7	1	125
South Africa	26	461	3	6	17	26
South Sudan	9	16	24	1	0	25
Sudan	52	87	115	15	9	139
Tanzania	47	447	486	5	3	494
Togo	8	98	103	2	1	106
Tunisia	32	220	241	1	10	252
Uganda	52	184	225	7	4	236
Zambia	63	295	350	7	1	358
Zimbabwe	21	81	98	3	1	102
Totals	**1,235**	**6,167**	**6,482**	**255**	**196**	**6,933**

Source: KCL calculations

Table 29: Projected student enrolment for 2021-2030 by country

Country	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Algeria	1,728,930	1,788,012	1,847,093	1,906,175	1,965,257	2,024,339	2,083,421	2,142,502	2,201,584	2,260,666
Angola	339,241	356,923	374,605	392,286	409,968	427,649	445,331	463,012	480,694	498,376
Benin	155,138	162,708	170,278	177,847	185,417	192,987	200,557	208,126	215,696	223,266
Botswana	66,648	69,192	71,736	74,280	76,824	79,368	81,912	84,456	87,000	89,543
Burkina Faso	160,353	175,553	190,754	205,954	221,154	236,355	251,555	266,755	281,956	297,156
Burundi	53,019	55,279	57,539	59,799	62,060	64,320	66,580	68,840	71,100	73,360
Cabo Verde	17,528	18,323	19,118	19,913	20,708	21,503	22,298	23,093	23,888	24,684
Cameroon	419,545	438,887	458,230	477,572	496,914	516,256	535,598	554,940	574,283	593,625
Central African Republic	18,098	18,723	19,348	19,973	20,598	21,223	21,848	22,473	23,098	23,723
Chad	60,397	63,210	66,023	68,836	71,650	74,463	77,276	80,089	82,902	85,715
Comoros	11,005	11,605	12,206	12,806	13,407	14,007	14,608	15,208	15,809	16,409
Congo, Republic of	68,772	72,431	76,090	79,749	83,408	87,067	90,726	94,385	98,044	101,703
Congo, Democratic Republic of	578,669	597,728	616,788	635,848	654,907	673,967	693,026	712,086	731,145	750,205
Côte d'Ivoire	272,215	281,814	291,412	301,011	310,609	320,207	329,806	339,404	349,003	358,601
Djibouti	12,462	13,283	14,103	14,924	15,745	16,566	17,386	18,207	19,028	19,848
Egypt, Arab Republic of	2,907,462	2,947,034	2,986,607	3,026,179	3,065,751	3,105,324	3,144,896	3,184,468	3,224,041	3,263,613
Equatorial Guinea	17,000	18,000	19,000	20,000	21,000	22,000	23,000	24,000	25,000	26,000

Country	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Eritrea	9,630	9,510	9,390	9,270	9,150	9,030	8,910	8,790	8,670	8,550
Eswatini	18,000	19,000	20,000	21,000	21,000	22,000	24,000	25,000	26,000	27,000
Ethiopia	1,239,330	1,273,871	1,308,412	1,342,953	1,377,494	1,412,035	1,446,575	1,481,116	1,515,657	1,550,198
Gabon	19,130	19,633	20,136	20,639	21,142	21,645	22,148	22,651	23,154	23,657
Gambia, The	13,674	14,614	15,554	16,494	17,433	18,373	19,313	20,253	21,192	22,132
Ghana	560,201	589,080	617,959	646,839	675,718	704,598	733,477	762,357	791,236	820,116
Guinea	195,708	205,824	215,939	226,055	236,170	246,286	256,401	266,517	276,632	286,747
Guinea-Bissau	23,000	24,000	25,000	26,000	27,000	28,000	30,000	31,000	32,000	34,000
Kenya	1,081,119	1,169,074	1,223,915	1,311,870	1,366,711	1,454,666	1,509,506	1,597,462	1,652,302	1,740,258
Lesotho	32,000	34,000	35,000	36,000	37,000	38,000	39,000	39,000	40,000	41,000
Liberia	94,191	99,704	105,216	110,729	116,241	121,754	127,266	132,779	138,291	143,803
Libya	227,000	235,000	241,000	248,000	252,000	256,000	259,000	262,000	264,000	264,000
Madagascar	172,410	181,774	191,139	200,503	209,868	219,232	228,597	237,961	247,326	256,690
Malawi	45,374	49,108	52,842	56,577	60,311	64,045	67,779	71,513	75,248	78,982
Mali	106,182	108,793	111,405	114,016	116,627	119,239	121,850	124,462	127,073	129,685
Mauritania	22,476	23,334	24,192	25,051	25,909	26,767	27,625	28,483	29,341	30,200
Mauritius	47,616	49,402	51,189	52,975	54,761	56,548	58,334	60,121	61,907	63,693
Morocco	1,193,879	1,239,757	1,285,634	1,331,511	1,377,389	1,423,266	1,469,143	1,515,020	1,560,898	1,606,775
Mozambique	247,711	258,411	269,111	279,811	290,511	301,210	311,910	322,610	333,310	344,010
Namibia	68,711	71,818	74,925	78,032	81,139	84,246	87,353	90,460	93,567	96,674

Country	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Niger	87,564	91,126	94,687	98,249	101,811	105,372	108,934	112,496	116,057	119,619
Nigeria	2,234,000	2,366,000	2,500,000	2,648,000	2,786,000	2,924,000	3,060,000	3,199,000	3,340,000	3,485,000
Rwanda	99,807	104,043	108,278	112,514	116,749	120,985	125,220	129,456	133,692	137,927
São Tomé and Príncipe	3,692	3,949	4,205	4,461	4,717	4,973	5,229	5,485	5,741	5,998
Senegal	206,814	216,094	225,375	234,655	243,935	253,215	262,495	271,775	281,056	290,336
Seychelles	1,580	1,750	1,920	2,090	2,260	2,431	2,601	2,771	2,941	3,111
Sierra Leone	93,000	97,000	102,000	107,000	112,000	117,000	122,000	126,000	131,000	135,000
Somalia	250,000	267,000	281,000	298,000	314,000	331,000	349,000	368,000	387,000	407,000
South Africa	1,250,025	1,275,464	1,300,903	1,326,342	1,351,780	1,377,219	1,402,658	1,428,096	1,453,535	1,478,974
South Sudan	170,000	180,000	188,000	198,000	208,000	219,000	230,000	241,000	253,000	266,000
Sudan	829,184	857,804	886,424	915,044	943,664	972,283	1,000,903	1,029,523	1,058,143	1,086,763
Tanzania	200,035	205,562	211,088	216,615	222,142	227,669	233,196	238,722	244,249	249,776
Togo	112,228	117,705	123,182	128,659	134,136	139,612	145,089	150,566	156,043	161,520
Tunisia	256,773	251,832	246,892	241,951	237,011	232,070	227,130	222,189	217,249	212,309
Uganda	293,914	305,943	317,971	329,999	342,027	354,056	366,084	378,112	390,140	402,169
Zambia	161,962	183,588	205,215	226,841	248,468	270,094	291,721	313,347	334,974	356,600
Zimbabwe	186,535	195,247	203,960	212,672	221,385	230,097	238,809	247,522	256,234	264,946

Source: KCL calculations

Table 30: Projected staff numbers for 2021-2030 by country

Country	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Algeria	68,203	70,714	73,225	75,736	78,246	80,757	83,268	85,779	88,290	90,800
Angola	15,000	16,000	17,000	17,000	18,000	19,000	19,000	20,000	20,000	21,000
Benin	17,571	18,658	19,745	20,833	21,920	23,007	24,095	25,182	26,269	27,357
Botswana	3,466	3,649	3,831	4,014	4,196	4,379	4,561	4,744	4,926	5,109
Burkina Faso	7,498	7,906	8,315	8,724	9,132	9,541	9,950	10,358	10,767	11,176
Burundi	3,890	4,090	4,290	4,490	4,690	4,890	5,090	5,290	5,490	5,690
Cabo Verde	1,814	1,895	1,977	2,059	2,141	2,222	2,304	2,386	2,467	2,549
Cameroon	10,055	10,556	11,057	11,558	12,059	12,561	13,062	13,563	14,064	14,565
Central African Republic	580	600	620	640	659	679	699	718	738	758
Chad	1,813	1,771	1,728	1,685	1,643	1,600	1,558	1,515	1,472	1,430
Comoros	312	321	330	339	348	358	367	376	385	394
Congo, Republic of	6,086	6,477	6,868	7,258	7,649	8,040	8,430	8,821	9,212	9,602
Congo, Democratic Republic of	41,738	43,433	45,128	46,823	48,518	50,212	51,907	53,602	55,297	56,991
Côte d'Ivoire	23,799	25,072	26,345	27,617	28,890	30,163	31,436	32,709	33,981	35,254
Djibouti	460	484	508	533	557	581	605	629	653	677
Egypt, Arab Republic of	133,000	135,000	137,000	138,000	140,000	142,000	143,000	145,000	147,000	148,000
Equatorial Guinea	750	790	820	860	890	920	950	980	1,010	1,040
Eritrea	927	971	1,016	1,060	1,104	1,148	1,192	1,236	1,281	1,325

Country	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Eswatini	1,644	1,804	1,929	2,089	2,213	2,373	2,498	2,657	2,782	2,942
Ethiopia	72,037	76,032	80,028	84,024	88,019	92,015	96,011	100,006	104,002	107,998
Gabon	840	860	870	880	900	910	920	930	940	950
Gambia, The	610	640	670	710	740	770	800	830	860	890
Ghana	19,818	20,790	21,763	22,736	23,709	24,682	25,655	26,627	27,600	28,573
Guinea	7,392	7,546	7,701	7,856	8,011	8,166	8,320	8,475	8,630	8,785
Guinea-Bissau	1,010	1,050	1,080	1,110	1,140	1,170	1,240	1,270	1,300	1,360
Kenya	28,771	30,845	32,919	34,993	37,067	39,142	41,216	43,290	45,364	47,438
Lesotho	1,251	1,294	1,338	1,382	1,425	1,469	1,513	1,556	1,600	1,644
Liberia	4,989	5,318	5,647	5,976	6,305	6,634	6,963	7,292	7,621	7,950
Libya	11,000	11,000	11,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Madagascar	6,658	6,942	7,226	7,510	7,795	8,079	8,363	8,647	8,932	9,216
Malawi	1,282	1,314	1,346	1,379	1,411	1,443	1,475	1,507	1,540	1,572
Mali	4,700	4,800	4,800	4,900	5,000	5,000	5,100	5,100	5,200	5,200
Mauritania	561	577	593	609	625	641	657	673	690	706
Mauritius	2,100	2,200	2,300	2,300	2,400	2,400	2,500	2,600	2,600	2,700
Morocco	38,103	38,949	39,796	40,643	41,489	42,336	43,183	44,029	44,876	45,722
Mozambique	18,119	18,470	20,233	20,585	22,348	22,700	24,463	24,815	26,578	26,929
Namibia	4,902	5,252	5,601	5,951	6,301	6,650	7,000	7,349	7,699	8,049
Niger	6,727	7,278	7,829	8,380	8,932	9,483	10,034	10,586	11,137	11,688
Nigeria	99,000	103,000	108,000	113,000	118,000	123,000	127,000	131,000	135,000	139,000

Country	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Rwanda	3,353	3,396	3,439	3,483	3,526	3,569	3,612	3,655	3,698	3,741
São Tomé and Príncipe	481	512	543	574	605	636	668	699	730	761
Senegal	7,560	7,840	8,121	8,402	8,682	8,963	9,244	9,525	9,805	10,086
Seychelles	69	70	71	72	72	73	74	75	76	77
Sierra Leone	4,100	4,300	4,400	4,600	4,800	4,900	5,100	5,200	5,300	5,400
Somalia	11,000	12,000	13,000	13,000	14,000	14,000	15,000	16,000	17,000	17,000
South Africa	55,000	56,000	57,000	57,000	58,000	59,000	59,000	60,000	61,000	61,000
South Sudan	7,500	7,900	8,200	8,500	8,900	9,300	9,700	10,100	10,500	11,000
Sudan	15,907	16,207	16,507	16,807	17,108	17,408	17,708	18,008	18,308	18,608
Tanzania	13,464	15,183	16,902	18,621	20,340	22,059	23,778	25,497	27,216	28,935
Togo	5,986	6,334	6,682	7,030	7,379	7,727	8,075	8,423	8,772	9,120
Tunisia	28,478	29,155	29,831	30,507	31,184	31,860	32,537	33,213	33,890	34,566
Uganda	8,827	9,108	9,389	9,671	9,952	10,233	10,514	10,796	11,077	11,358
Zambia	7,200	8,000	8,900	9,800	10,600	11,500	12,300	13,100	13,900	14,700
Zimbabwe	11,070	11,708	12,346	12,985	13,623	14,261	14,899	15,537	16,176	16,814

Source: KCL calculations

Table 31: Average Cost (USD millions) of equipping students and staff with laptops by Country (2021 to 2025)

Country	2021	2022	2023	2024	2025	Subtotal (Average) USD millions
Algeria	315	288	297	347	319	1,566
Angola	63	58	60	72	67	320
Benin	35	27	28	41	31	162
Botswana	13	11	12	14	13	62
Burkina Faso	30	28	31	38	36	163
Burundi	11	9	9	12	10	51
Cabo Verde	4	3	3	4	3	18
Cameroon	73	70	73	83	80	379
Central African Republic	3	3	3	4	3	16
Chad	11	10	11	12	12	55
Comoros	2	2	2	2	2	10
Congo, Democratic Republic of	117	97	100	129	108	551
Congo, Republic of	15	12	12	17	14	70
Côte d'Ivoire	57	46	48	64	51	267
Djibouti	2	2	2	3	3	12
Egypt, Arab Republic of	540	475	482	562	498	2,558
Equatorial Guinea	3	3	3	4	3	16
Eritrea	2	2	2	2	2	9

Eswatini	4	3	3	5	3	18
Ethiopia	239	207	212	263	225	1,147
Gabon	4	3	3	4	3	17
Gambia, The	3	2	3	3	3	13
Ghana	101	95	99	116	109	520
Guinea	35	33	35	41	38	182
Guinea-Bissau	4	4	4	5	4	21
Kenya	189	187	196	229	221	1,021
Lesotho	6	5	6	7	6	29
Liberia	18	16	17	21	19	91
Libya	43	38	39	46	41	207
Madagascar	31	29	31	36	34	162
Malawi	8	8	8	10	10	44
Mali	20	18	18	21	19	95
Mauritania	4	4	4	4	4	20
Mauritius	9	8	8	10	9	44
Morocco	212	199	206	235	223	1,075
Mozambique	50	42	44	57	48	240
Namibia	14	12	12	16	13	67
Niger	18	15	15	21	17	86
Nigeria	413	381	403	487	452	2,137
Rwanda	18	17	17	20	19	91

São Tomé and Príncipe	1	1	1	1	1	4
Senegal	37	35	36	42	40	190
Seychelles	0	0	0	0	0	2
Sierra Leone	17	16	16	20	18	87
Somalia	46	43	45	55	51	241
South Africa	231	206	210	244	220	1,110
South Sudan	31	29	30	36	34	161
Sudan	141	137	142	155	152	726
Tanzania	40	33	34	45	37	190
Togo	21	19	20	25	22	107
Tunisia	58	42	41	57	40	237
Uganda	52	49	51	58	55	265
Zambia	30	30	33	42	40	175
Zimbabwe	36	32	33	41	36	179
Total (USD millions)	**3,478**	**3,142**	**3,256**	**3,888**	**3,521**	**17,284**

Source: KCL calculations

Table 32: Detailed estimates for upgrading campus networks at all African HEIs by country

	CapEx (USD, millions)				OpEx (USD, millions)				Total (USD, millions)
Country	**Small Campus (≤5k)**	**Medium Campus (5,001-15k)**	**Large Campus (>15k)**	**Sub-Total**	**Small Campus (≤5k)**	**Medium Campus (5,001-15k)**	**Large Campus (>15k)**	**Sub-Total**	**CapEx+OpEx (excludes bandwidth)**
Algeria	110	19	114	243	137	29	219	385	628
Angola	18	29	10	57	22	46	19	87	144
Benin	67	3	10	80	84	4	19	107	187
Botswana	72	8	5	85	89	13	10	111	196
Burkina Faso	127	11	10	148	159	17	19	194	343
Burundi	69	5	5	79	86	8	10	104	183
Cabo Verde	12	3	0	14	15	4	0	19	33
Cameroon	338	13	35	387	421	21	67	509	895
Central African Republic	37	3	0	39	46	4	0	50	89
Chad	28	3	0	31	35	4	0	39	69
Comoros	9	3	0	11	11	4	0	15	27
Congo, Republic of	82	3	5	90	102	4	10	116	206
Congo, Democratic Republic of	114	32	30	176	142	50	57	250	426
Côte d'Ivoire	472	16	10	498	587	25	19	631	1,129
Djibouti	9	3	0	11	11	4	0	15	27
Egypt, Arab Republic of	236	29	114	380	294	46	219	559	938

	CapEx (USD, millions)				OpEx (USD, millions)				Total (USD, millions)
Country	**Small Campus (≤5k)**	**Medium Campus (5,001-15k)**	**Large Campus (>15k)**	**Sub-Total**	**Small Campus (≤5k)**	**Medium Campus (5,001-15k)**	**Large Campus (>15k)**	**Sub-Total**	**CapEx+OpEx (excludes bandwidth)**
Equatorial Guinea	4	3	0	7	5	4	0	10	17
Eritrea	22	3	0	25	27	4	0	32	56
Eswatini	40	3	0	42	49	4	0	53	96
Ethiopia	171	27	65	263	213	42	124	379	642
Gabon	35	5	5	45	44	8	10	62	107
Gambia, The	15	3	0	17	18	4	0	22	40
Ghana	388	13	25	426	483	21	48	552	978
Guinea	75	3	5	82	93	4	10	107	189
Guinea-Bissau	6	3	0	9	7	4	0	11	20
Kenya	2,113	93	45	2,251	2,630	146	86	2,862	5,113
Lesotho	21	3	0	23	26	4	0	30	53
Liberia	73	8	5	86	91	13	10	113	199
Libya	12	8	10	30	15	13	19	46	76
Madagascar	7	11	10	28	9	17	19	45	73
Malawi	78	5	5	88	97	8	10	115	203
Mali	7	8	10	25	9	13	19	41	66
Mauritania	9	3	0	11	11	4	0	15	27
Mauritius	19	3	0	22	24	4	0	28	50

	CapEx (USD, millions)				OpEx (USD, millions)				Total (USD, millions)
Country	**Small Campus (≤5k)**	**Medium Campus (5,001-15k)**	**Large Campus (>15k)**	**Sub-Total**	**Small Campus (≤5k)**	**Medium Campus (5,001-15k)**	**Large Campus (>15k)**	**Sub-Total**	**CapEx+OpEx (excludes bandwidth)**
Morocco	589	13	25	627	733	21	48	802	1,429
Mozambique	60	19	25	104	75	29	48	152	255
Namibia	18	11	5	33	22	17	10	48	81
Niger	21	3	5	28	26	4	10	39	67
Nigeria	1,080	93	134	1,307	1,344	146	257	1,748	3,055
Rwanda	48	13	10	72	60	21	19	100	172
São Tomé and Príncipe	7	0	0	7	9	0	0	9	16
Senegal	35	8	5	48	44	13	10	66	114
Seychelles	16	0	0	16	20	0	0	20	36
Sierra Leone	44	5	5	54	55	8	10	73	127
Somalia	171	19	5	195	213	29	10	252	447
South Africa	674	27	85	785	839	42	162	1,043	1,828
South Sudan	35	3	0	38	44	4	0	48	86
Sudan	168	40	45	253	210	63	86	358	611
Tanzania	712	13	15	740	886	21	29	936	1,676
Togo	151	5	5	161	188	8	10	206	367
Tunisia	353	3	50	405	440	4	95	539	944
Uganda	330	19	20	368	410	29	38	478	846

	CapEx (USD, millions)				OpEx (USD, millions)				Total (USD, millions)
Country	**Small Campus (≤5k)**	**Medium Campus (5,001-15k)**	**Large Campus (>15k)**	**Sub-Total**	**Small Campus (≤5k)**	**Medium Campus (5,001-15k)**	**Large Campus (>15k)**	**Sub-Total**	**CapEx+OpEx (excludes bandwidth)**
Zambia	513	19	5	536	638	29	10	677	1,214
Zimbabwe	144	8	5	157	179	13	10	201	357
Total	**10,060**	**700**	**980**	**11,750**	**12,530**	**1,100**	**1,880**	**15,510**	**27,250**

Source: KCL calculations

Table 33: Total cost for bandwidth requirements for all African countries by country (by student enrolment and local prices)

Country	Project bandwidth requirements (Gbps)			Project cost (2021) (USD millions)		Project cost (2025) (USD millions)		Project cost (2030) (USD millions)	
	2021	2025	2030	no Aggregation Savings	with Aggregation Savings	no Aggregation Savings	with Aggregation Savings	no Aggregation Savings	with Aggregation Savings
Algeria	1,729	3,931	45,213	1,350	535	1,535	608	4,413	1,749
Angola	339	820	9,968	148	74	178	89	542	271
Benin	155	371	4,465	132	47	158	56	475	169
Botswana	67	154	1,791	29	17	33	19	97	57
Burkina Faso	160	442	5,943	136	83	188	115	632	385
Burundi	53	124	1,467	23	14	27	17	80	50
Cabo Verde	18	41	494	15	9	18	11	52	31
Cameroon	420	994	11,872	357	182	423	215	1,263	642
Central African Republic	18	41	474	15	13	18	15	50	42
Chad	60	143	1,714	51	35	61	41	182	124
Comoros	11	27	328	5	3	6	3	18	11
Congo, Democratic Republic of	579	1,310	15,004	252	92	285	104	816	297
Congo, Republic of	69	167	2,034	59	38	71	46	216	139
Côte d'Ivoire	272	621	7,172	232	84	264	96	763	278
Djibouti	12	31	397	5	3	7	4	22	13

Country	Project bandwidth requirements (Gbps)			Project cost (2021) (USD millions)		Project cost (2025) (USD millions)		Project cost (2030) (USD millions)	
	2021	2025	2030	no Aggregation Savings	with Aggregation Savings	no Aggregation Savings	with Aggregation Savings	no Aggregation Savings	with Aggregation Savings
Egypt, Arab Republic of	2,907	6,132	65,272	2,270	719	2,394	758	6,371	2,018
Equatorial Guinea	17	42	520	14	10	18	13	55	40
Eritrea	10	18	171	4	4	4	3	9	8
Eswatini	18	42	540	8	6	9	7	29	23
Ethiopia	1,239	2,755	31,004	539	325	599	361	1,685	1,015
Gabon	19	42	473	16	6	18	6	50	18
Gambia, The	14	35	443	12	7	15	9	47	29
Ghana	560	1,351	16,402	477	133	575	161	1,744	488
Guinea	196	472	5,735	167	89	201	108	610	327
Guinea-Bissau	23	54	680	20	15	23	18	72	56
Kenya	1,081	2,733	34,805	470	62	594	78	1,892	248
Lesotho	32	74	820	14	9	16	10	45	28
Liberia	94	232	2,876	80	44	99	55	306	169
Libya	227	504	5,280	177	118	197	131	515	342
Madagascar	172	420	5,134	75	28	91	34	279	103
Malawi	45	121	1,580	20	8	26	11	86	37
Mali	106	233	2,594	90	56	99	61	276	170
Mauritania	22	52	604	19	11	22	12	64	36

Country	Project bandwidth requirements (Gbps)			Project cost (2021) (USD millions)		Project cost (2025) (USD millions)		Project cost (2030) (USD millions)	
	2021	2025	2030	no Aggregation Savings	with Aggregation Savings	no Aggregation Savings	with Aggregation Savings	no Aggregation Savings	with Aggregation Savings
Mauritius	48	110	1,274	21	9	24	10	69	30
Morocco	1,194	2,755	32,136	932	295	1,076	340	3,137	992
Mozambique	248	581	6,880	108	42	126	50	374	147
Namibia	69	162	1,933	30	15	35	18	105	54
Niger	88	204	2,392	74	48	87	55	254	163
Nigeria	2,234	5,572	69,700	1,901	578	2,370	721	7,412	2,255
Rwanda	100	233	2,759	43	18	51	21	150	62
São Tomé and Príncipe	4	9	120	2	1	2	1	7	4
Senegal	207	488	5,807	176	52	208	61	618	181
Seychelles	2	5	62	1	0	1	1	3	2
Sierra Leone	93	224	2,700	79	45	95	55	287	164
Somalia	250	628	8,140	109	42	137	52	442	169
South Africa	1,250	2,704	29,579	544	80	588	86	1,608	236
South Sudan	170	416	5,320	74	62	90	76	289	242
Sudan	829	1,887	21,735	361	186	410	211	1,181	608
Tanzania	200	444	4,996	87	31	97	34	272	97
Togo	112	268	3,230	95	37	114	44	344	132
Tunisia	257	474	4,246	201	67	185	61	414	138

Country	Project bandwidth requirements (Gbps)			Project cost (2021) (USD millions)		Project cost (2025) (USD millions)		Project cost (2030) (USD millions)	
	2021	2025	2030	no Aggregation Savings	with Aggregation Savings	no Aggregation Savings	with Aggregation Savings	no Aggregation Savings	with Aggregation Savings
Uganda	294	684	8,043	128	35	149	41	437	119
Zambia	162	497	7,132	70	33	108	50	388	180
Zimbabwe	187	443	5,299	81	49	96	59	288	175

Source: KCL calculations

Table 34: Total cost for bandwidth requirements for all African countries by country (student enrolment and regional prices)

Country	Project bandwidth requirements (Gbps)			Project cost (2021) (USD millions)		Project cost (2025) (USD millions)		Project cost (2030) (USD millions)	
	2021	2025	2030	no Aggregation Savings	with Aggregation Savings	no Aggregation Savings	with Aggregation Savings	no Aggregation Savings	with Aggregation Savings
Algeria	1,729	3,931	45,213	484	192	550	218	1,581	626
Angola	339	820	9,968	54	27	65	33	197	99
Benin	155	371	4,465	8	3	19	7	57	20
Botswana	67	154	1,791	11	6	12	7	35	21
Burkina Faso	160	442	5,943	8	5	22	14	75	46
Burundi	53	124	1,467	8	5	10	6	29	18
Cabo Verde	18	41	494	1	1	2	1	6	4
Cameroon	420	994	11,872	21	11	50	26	151	77
Central African Republic	18	41	474	1	1	2	2	6	5
Chad	60	143	1,714	3	2	7	5	22	15
Comoros	11	27	328	2	1	2	1	7	4
Congo, Republic of	69	167	2,034	3	2	8	5	26	17
Congo, Democratic Republic of	579	1,310	15,004	92	33	104	38	297	108
Côte d'Ivoire	272	621	7,172	14	5	32	11	91	33
Djibouti	12	31	397	2	1	2	1	8	5

Egypt, Arab Republic of	2,907	6,132	65,272	813	258	857	272	2,282	723
Equatorial Guinea	17	42	520	1	1	2	2	7	5
Eritrea	10	18	171	2	1	1	1	3	3
Eswatini	18	42	540	3	2	3	3	11	8
Ethiopia	1,239	2,755	31,004	196	118	218	132	614	370
Gabon	19	42	473	1	0	2	1	6	2
Gambia, The	14	35	443	1	0	2	1	6	3
Ghana	560	1,351	16,402	28	8	69	19	208	58
Guinea	196	472	5,735	10	5	24	13	73	39
Guinea-Bissau	23	54	680	1	1	3	2	9	7
Kenya	1,081	2,733	34,805	171	22	217	28	689	90
Lesotho	32	74	820	5	3	6	4	16	10
Liberia	94	232	2,876	5	3	12	7	36	20
Libya	227	504	5,280	63	42	70	47	185	123
Madagascar	172	420	5,134	27	10	33	12	102	38
Malawi	45	121	1,580	7	3	10	4	31	13
Mali	106	233	2,594	5	3	12	7	33	20
Mauritania	22	52	604	1	1	3	1	8	4
Mauritius	48	110	1,274	8	3	9	4	25	11
Morocco	1,194	2,755	32,136	334	106	385	122	1,123	355
Mozambique	248	581	6,880	39	15	46	18	136	54
Namibia	69	162	1,933	11	6	13	7	38	20

Niger	88	204	2,392	4	3	10	7	30	19
Nigeria	2,234	5,572	69,700	113	34	283	86	884	269
Rwanda	100	233	2,759	16	7	19	8	55	23
São Tomé and Príncipe	4	9	120	1	0	1	0	2	2
Senegal	207	488	5,807	10	3	25	7	74	22
Seychelles	2	5	62	0	0	0	0	1	1
Sierra Leone	93	224	2,700	5	3	11	7	34	20
Somalia	250	628	8,140	40	15	50	19	161	62
South Africa	1,250	2,704	29,579	198	29	214	31	586	86
South Sudan	170	416	5,320	27	23	33	28	105	88
Sudan	829	1,887	21,735	131	68	150	77	431	222
Tanzania	200	444	4,996	32	11	35	13	99	35
Togo	112	268	3,230	6	2	14	5	41	16
Tunisia	257	474	4,246	72	24	66	22	148	49
Uganda	294	684	8,043	47	13	54	15	159	43
Zambia	162	497	7,132	26	12	39	18	141	66
Zimbabwe	187	443	5,299	30	18	35	21	105	64

Source: KCL calculations