THE IMPACT OF NATIONAL RESEARCH AND EDUCATION NETWORKS ON THE QUALITY OF EDUCATION AND RESEARCH OUTPUT: A CASE OF ETHIOPIAN'S ETHERNET

by

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The Impact of National Research and Education Networks on the Quality of Education and Research Output: A case of Ethiopian's EthERNet

I declare that the above thesis is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

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Abstract

The rapid growth of universities in the Least Developing Countries (LDCs) is aimed at enhancing access to tertiary education, which has resulted in a sharp increase in the enrolment rate. However, the quantitative increase has been marred with a correspondingly continuous decline in the quality of education. This is attributed to a wide range of limiting factors mainly classified as institutional problems. Some of these problems include a shortage of resources, limited skills and incompetent human capital, lack of ICT infrastructure, and the ineffective use of existing ICT resources. These problems and others have adversely affected how national education and research network can improve research output and quality of education.

In this study, a survey, in the form of an exploratory quantitative research design is used. A descriptive non-experimental quantitative approach was also chosen, and a questionnaire was administered to approximately one hundred and seventy-two (172) participants drawn from twenty-nine (29) Ethiopian Public Universities. The results of the analysis show that the study variables namely NREN service for education, EthERNet, electronic device and research output have a significant and positive impact on the Quality of Education (QE) to differing degrees. Also, the study variables such as NREN service for research, high-performance computing, and remote computing facilities indicated that they had a significant and positive impact on Research Output (RO) to differing degrees.

The study explored the impact of EthERNet in improving the quality of education and research output by examining the existing network infrastructure and NREN services. The study employed the use of the Actor-Network Theory (ANT) to assess the existing network infrastructure and NREN services to determine that a reliable network can improve the quality of education and research output. Besides, Structural Equation Model (SEM) was used to identify the positive and negative factors that impact on the roles, relationships, and formation of quality of education and research output. Furthermore, a three-step design science approach was applied to propose and justify the theoretical framework, which is used as a base to develop a service portfolio and roadmap conceived to design the required NREN service for EthERNet.

This research contributed to the body of knowledge by finding the missing link between the quality of education and research outputs. From a theoretical perspective, the research contributed a theoretical framework by developing the construct and their measures that can be used in assessing the adoption and usage of technology. Furthermore, the study contributes to the literature by demonstrating an analytical process which could be used as a guide for future NREN service requirement to improve the quality of education and research output with the existing findings being used as a reference point.

KEYWORDS: National Research and Educational Network; Quality of Education and Research Output; NREN services; Higher Education; EthERNet; Actor-Network Theory; SWOT analysis; Structural Equation Modelling; Service Portfolio and Technology Road-mapping.

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Peer-Reviewed Publications and Other Research Output

This Doctoral Thesis is not a collection of published papers. The papers below were presented/published at research workshops and conferences/journals during the process of conducting this PhD thesis.

1. Bankole, F., Assefa, Z. and Africa, S. (2017) 'Improving the quality of education and research output in Africa; A case of Ethiopian education and research network (ethernet)', 10(24), pp. 31–51. *'International Journal of Applied Global Research', 4(2), pp. 45–52. Published by Intellectbase International Consortium, USA.*
2. Z. Assefa and F. Bankole, "The impacts of reliable networks to assist in improving educational quality and output of research. - A case of EthERNet Ethiopia," 2019 IEEE AFRICON, Accra, Ghana, 2019, pp. 1-8, doi: 10.1109/AFRICON46755.2019.9133805.

Conference Papers:

3. Zelalem, A. (2017). Infrastructure for Open Science Platform: A Case of Ethiopian Education and Research Network (EthERNet). *In Proceedings of the 10th Annual Conference of UbuntuNet Alliance: Pre-Workshop Towards an African Open Science Platform Infrastructure, Addis Ababa, Ethiopia, 2nd – 3rd November 2017*.
4. Zelalem, A. (2016). Current ICT Development in Ethiopia, a case of EthERNet. *In Proceedings of Future-Sat Africa: Future-Sat Africa Summit programme, Digital Horizons, Addis Ababa, Ethiopia October 18, 2016.*

Journal Publications (in preparation):

Assefa, Z, Bankole, F. and Africa, S. (2020) 'Application of Actor-Network Theory (ANT) to Depict NRENs Implementation in Higher Education', *submitted to be Published by IEEE TRANSACTIONS ON Computer Science*.

Work-in-Progress:

- Impact of High-Performance Computing (HPC) and Remote Computing Facility (RCF) for research output.
- NREN service portfolio to assist in improving the quality of education and research output.

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Acronyms and abbreviations

Abbreviation	Description
AAI	Authentication and Authorisation Infrastructure
AAU	Association of African Universities
ANT	Actor-Network Theory
AS	Autonomous Numbers
AVE	Average Variance Extracted
BYOD	Bring Your Own Device
C@ribNET	Caribbean NREN
CamREN	Cambodian Research and Education Network
CB	Covariance-Based
CBE	Competency-Based Education
CBR	Computer Business Review
CBS	Competency-Based Education
CFA	Confirmatory Factor Analysis
CKLN	Caribbean Knowledge and Learning Network
CPUs	Computing Power
CSGF	The Catania Science Gateway Framework
CSIRT	Computer Security Incident Response Team
CTO	Chief Technology Officer
DCI	Distributed Computing Infrastructures
DDoS	Distributed Denial of Service
DHCP	Dynamic Host Configuration Protocol
DL	Distance Learning
DNS	Domain Name System
DOI	Digital Object Identifier
DWDM	Dense Wavelength Division Multiplexing
ECAR	Educause Centre for Analysis and Research

EGI	European Grid Infrastructure
ENISA	European Union Agency for Network and Information Security
ESC	Education Strategy Centre
ESDP	Education Sector Development Program
ET	Ethio Telecom
ETC	Enterprise Technical Capabilities
EthERNet	Ethiopian Education and Research Network
FERPA	Family Education Rights and Privacy Act
GDP	Gross Domestic Product
GoF	Global Goodness of Fit
gTLD	Generic Top-Level Domains
GTP	Growth and Transformation Plan
HEAR	Haptic Enabled Art Realization
HEI	High Education Institutions
HPC	High-Performance Computing
IaaS	Infrastructure as a Service
IBM	The International Business Machines Corporation
ICT	Information and Communication Technology
IDC	International Data Corporation
IDP	An Identity Provider
IoT	The Internet of Things
IP	Intellectual Property
IPTV	IP Television
IS	Information Systems
ISO	The International Organization for Standardization
ISP	Internet Service Provider
ITC	Institute of Technology of Cambodia
ITU	International Telecommunication Union
IXP	Internet Exchange Points

LCCs	Least Connected Countries
LDCs	Least Developing Countries
LHECP	Lagos Higher Education Connectivity Project
LLDC	Landlocked Least Developing Country
LMS	Learning Management System
LTI	Learning Tools Interoperability
MCU	Multi-Conference Unit
MOE	Ministry of Education
MOOCs	Massive Open Online Courses
NGDLE	Next-Generation Digital Learning Environments
NKN	National Knowledge Network
NOCaaS	Network Operation Centre as a Service
NREN	National Research and Education Network
NUIs	Natural User Interfaces
OADR	Open Access Document and Data Repositories
OE	Open Education
OER	Open Education Resources
OPGW	Optical Ground Wire
OPP	Obligatory Passage Point
ORCID	Open Researcher and Contributor ID
OTN	Optical Transport Network
PaaS	Platform as a Service
PCI	Perceived Characteristics of Innovation
PLS	Partial Least Squares
PLS-PM	Partial Least Squares Path Modelling
PLS-SEM	Partial Least Squares Structural Equation Modelling
PoP	Point of Presence
PPPDS	Public Procurement and Property Disposal Service
R and E	Research and Education

RAS	Remote Access Services
RCF	Remote Computing Facilities
RRENs	Regional Research Education Networks
SaaS	Software as a Service
SAML	Security Assertion Mark-up Language
SAMR	Substitution, Augmentation, Modification and Redefinition
SCM	Social Constructivist Model
SCOT	The Social Construction of Technology
SDG	Sustainable Development Goal
SDN	Software-Defined Networking
SEM	Structural Equation Modelling
SERENATE	Study into European Research and Education Networking as Targeted by eEurope
SOA	Service-Oriented Architecture
SOC	Service-Oriented Computing
SOMA	Service-Oriented Modelling and Architecture
SPM	Service Portfolio Management
SPOCs	Small Private Online Courses
SPSS	Statistical Program for Social Scientists
STI	Science and Technology Innovation
STIM	Science, Technology, and Innovation-Supporting Mechanism
SWOT	Strength, Weakness, Opportunity, and Threat
TEIN3	Trans-Eurasia Information Network
TRM	Technology Road Mapping
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
URL	Uniform Resource Locator
VDI	Virtual Desktop Environment
VIFs	Variance Inflation factors

VLC	Virtual Learning Campus
VLE	Virtual Learning Environment
VOs	Virtual Organizations
VPN	Virtual Private Network
VRCs	Virtual Research Communities
WDI	World Development Index
WSIS	World Summit on the Information Society
ZAMREN	Zambia Research Education Networks

Chapter 1: Introduction to the Study

This chapter provides an overview of the impacts of National Research and Educational Networks (NRENs) on education and research at institutions of higher education. Some of the topics that are addressed briefly in this section include the background and orientation of the study, problem statement, research questions, research objective, study's significance, study's scope, study's limitations, nature of the study, ethical considerations and summary of the findings. It also contains an outline of the rest of the chapters.

1.1. Research Background

Based on a report presented by UNESCO on the projected advances in science by 2030, many of the least-developed countries (LDCs), including Ethiopia, have increased access to higher education in the last few decades by establishing new universities (MHRD, 2016). Evidence shows that the number of higher education institutions in Ethiopia expanded radically from two universities in 1977 to 34 in just over two decades, with another 11 universities to be opened shortly (Ashcroft and Rayner, 2011). As a result, the enrolment rates at tertiary educational institutions have continuously been on the rise.

However, the quality of education seems to have been adversely affected by the high rate at which new universities are opened and higher student enrolments (Adamu and Addamu, 2012). One possible reason for this negative result is that the demand for more resources, such as libraries, laboratories, Information and Communication Technology (ICT) and other factors, is exacerbating the existing shortage of funds and qualified instructors (Salmi, Sursock and Olefir, 2017). Thus, it has been difficult to provide high-quality educations while increasing research outputs simultaneously. However, a study in developed countries has shown that the socio-economic development of a nation can be sped up significantly because of the presence of an efficient national research and education network (Bankole and Assefa, 2017).

National Research and Education Networks (NRENs) present limitless prospects for improving the quality of learning and support sound research outcomes (Yaver *et al.*, 2016). The Ethiopian

NREN, EthERNet (Ethiopian Education and Research Network) have been established to alleviate the shortcomings mentioned above by interconnecting research organisations and educational institutions within the country. Typically, EthERNet provides a local, national anchor through which campuses within that country interconnect. Its reach then extends to the regional level through the Regional Research and Education Networks (RRENs), which then also link the various regions to the more extensive global network. Thus, the system allows connections on national regional and global scales (Bankole and Assefa, 2017).

Overall, the usage of an NREN is likely to result in better qualitative standards for education, learning and research. Some of the benefits associated with high qualitative standards include enhanced sharing of resources, such as digital libraries, amongst senior professors as well as the unconstrained flow of information, information resources and tools to higher education institutions. The NREN infrastructure is also expected to allow researchers, professors, and students to collaborate effectively with their counterparts across the globe via shared resources and information using dependable and timely electronic systems. It is suggested that the NREN service portfolio and a roadmap for EthERNet could provide the necessary services for Ethiopian public higher education institutions in a centralised, private, cloud-based setup, irrespective of their locations (Cho, Yoon and Kim, 2016). The National Research and Education Network (NREN) has a vast potential to improve the quality of education and research (Saay and Norta, 2018). EthERNet was established purposely to interconnect research and education institutions within the country. Typically, EthERNet has recognised to serve as a national backbone for the connected campuses and further interconnects other backbones at a regional level to develop the Regional Research and Education Network (RRENs) backbones, which, in turn, connects on a global scale (Bankole and Assefa, 2017).

The study focuses upon demonstrating how the constructs of ANT can aid in the comprehension and understanding of NREN service requirements and functionality in Ethiopian higher learning institutions. It highlights the primary actors in the processes, those actors that are characterised as fundamentally necessary for successful NREN operation in institutions of higher learning. Furthermore, the study develops a theoretical framework and evaluates the links between the actors and their associated processes. The research also investigates the challenges to the effective use of

EthERNet. It addresses the possibility of using this medium to enrich the educational quality and research outcomes within the Ethiopian system of higher learning. A significant study outcome is an EthERNet roadmap and NREN service portfolio that can be given to member institutions to improve educational quality and research output.

1.2. The Orientation of the Study

Generally, the socio-economic strength of a country is heavily dependent on the success of its educational system (Ozturk, 2011). Similarly, a country's competitiveness is established by the strength of its higher learning systems (Serdyukov, 2017). This probably explains why they're an increase in the demand for higher education across the globe has been. Existing studies have associated the increase in the need for higher education with the projected growth/expansion of 100 million students from the year 2000 to over 250 million around the globe by 2025 (Jones 2018). Moreover, most institutions of higher learning and their government continue to seek innovative approaches to enhance access to higher learning programmes, as well as improve quality to boost their competitiveness (Serdyukov, 2017).

Over the last few decades, unprecedented growth has been witnessed in the expansion of the tertiary education sector (Teal, 2011). The increase has resulted in substantive direct and indirect economic influences that have caused multiple effects to be realized in many areas, including human capital, research initiatives, trading activities, and innovation, among others (Holmes, 2013). In general, there have been numerous substantive benefits that have been realized from the perspective of individual and regional economies. Statistics presented on enrolment indicates that there will be a growth of +0.6 million enrolments in the next decade (Djurovic, 2018). From a global perspective, this analysis anticipated that tertiary enrolments would surpass 21 million between 2011 and 2020, resulting in a focused growth of 1.4 per cent (British Council, 2012).

The role of innovation is mainly dependent on the success of individuals, institutions, and economies (Edler and Fagerberg, 2017). The authors indicate that this element is vital for the expansion and fulfilment of new ideas. However, universities are the primary centres for innovation and the general development of knowledge (Segarra and Arauzo, 2008). In line with this, 76% of all primary research initiatives are undertaken at universities around the world. (Gasevic, Kovanovic, Joksimovic and Siemens, 2014). Hence, universities are fundamental in the advancement of industrial processes and technological growth and expansion. Research and innovation are increasingly interdisciplinary, inter-institutional, and international, generating vast amounts of data. Besides enlarging interdisciplinary collaborations, these fields continue to link institutions locally and internationally (Mansell, 2013). Science has benefited from increased data sharing, which has allowed specialisations to flourish (Castelli, 2012). Defying geographical and physical limitations, many scholarly communities have engaged in joint research initiatives since the institution of Virtual Organizations (VOs) has resulted in network platforms for contemporary communication and information sharing (Danesh, Raahemi, Kamali and Richards, 2013).

Higher education aims to furnish students with skills that are relevant for successful performances in workplaces and communities and in solving life's challenges (Aşkun and Yildirim, 2011). This has continuously remained unchanging for many centuries. However, the world around universities and institutions of higher learning has witnessed constant transformation to remain relevant and enhance their enrolment rate (Casidy, 2014). It is worth noting that expectations of education have significantly risen, exerting more pressure on higher education, and learning to satisfy the growing demands. With the depletion of existing resources for educational changes, calls for new models have focused on experiences for students and the stimulation of innovative and entrepreneurial skills to meet higher educational goals (Guerrero, Urbano, Fayolle, Klofsten and Mian, 2016). Amidst these changes, institutions are relying heavily upon Information and Communication Technology (ICT) to facilitate the security and management of finances, learning and research (Sharma, 2011). Hence, ICT professionals must develop a full understanding of the challenges involved in the educational processes to create systems that can adequately present solutions to the existing problems affecting individuals, institutions and various sectors within modern communities (Brown, Dehoney and Millichap, 2015).

Higher education aims to furnish students with skills that are relevant for successful performances in workplaces and communities and in solving life's challenges. However, the world around universities and institutions of higher learning has undergone constant transformations and, with these transformations, the expectations for education have risen significantly, exerting pressure on higher education. With the depletion of existing resources for educational changes, calls for new models have focused on experiences for students and the stimulation of innovative and entrepreneurial skills to meet higher educational goals. Amidst these changes, institutions are relying heavily upon ICT to facilitate the security and management of finances, learning and research. Hence, ICT professionals must develop a full understanding of the challenges involved in the educational processes to create systems that can adequately present solutions to the existing problems affecting individuals, institutions and various sectors within modern communities (Brown, Dehoney and Millichap, 2015).

Furthermore, higher education is a vital investment that aids in the development of capital for communities and various economic sectors. Thus, institutions of higher learning, in addition to teaching, developing and disseminating knowledge and equip students with the techniques needed to acquire using such knowledge, it is expected from them to create significant human capital resources (Fadaee, 2008). The sustainability of the global economy, along with its welfare is very dependent on the creation, development, transfer, and sharing of knowledge (Zakaria and Kaushal, 2017). At no point can any state or region remain a consumer of new knowledge without engaging in its production. In the process of this creation, universities become pivotal societal elements for bridging the innovation gap through teaching and research (Välimaa and Hoffman, 2008). Despite healthy economic growth rates in the 1990s and 2000s, unfortunately, many African and Asian countries are producing fewer inventions and innovations today (Zanello, Mohnen and Ventresca, 2016).

There is an outstanding and overwhelming entrepreneurial and innovative spirit among people in these regions. For example, consider the re-invention of many aspects of mobile banking in Africa. Therefore, the lack of such courage cannot be blamed for the deficit in new patents. Instead, the gap is due to limited resources for technological transfers at universities with significant financial limitations. The international development community bears part of this responsibility for failing to encourage African governments to prioritise and invest in higher learning (Eicker, Haseloff and Lennartz, 2017). The number of young Africans expected to enter the job market every year is approximately 11 million. In addition to increasing their awareness of the value of Intellectual Property (IP), these individuals must have their new and vibrant ideas supported for innovation to succeed (Baah-Boateng, 2016). They must also be equipped with the skills that are relevant and necessary for performance and innovation.

With the emergence of the digital revolution, universities experience a heightened ability to 'go global' and reach an unlimited global audience, which has primarily resulted in the emergence of Massive Open Online Courses (MOOCs) (Hew and Cheung, 2014). The rise of MOOCs has corresponded to the acquisition of digital devices, such as smartphones and tablets, thus increasing the extent to which people can access digital information. Furthermore, the current 'digital native' generation is very techno-savvy, leading to increased networking (Hall and Keynes, 2011). Predictably, the coming years will see many developments in higher learning that will allow increased access to education through quality MOOCs. However, on-campus education will remain critical to university education, especially for practical courses (Bralić and Divjak, 2018). At the same time, universities will have to continue evolving to achieve quality deliveries that satisfy educational expectations.

For researchers and academicians, collaboration and sharing of data have become real, and many of them now use web-based platforms to share their research outcomes with the global academic community. Other researchers can then build on such primary research, improve upon it, and use it for innovative purposes, thus providing solutions to the numerous challenges facing humanity (Juan, Daradoumis, Roca, Grasman and Faulin, 2012).

1.3. Statement of the Problem

Ethiopian public universities that have numerous satellite campuses spread over a vast geographical region have been continually confronted with a shortage of resources, amongst other problems, mainly due to the small qualified human capital pool (Derbew, Animut, Talib, Mehtsun and Hamburger, 2014). Hence, appointing instructors with the necessary qualifications is quite impossible at most of the Ethiopian public universities. The absence of competent and qualified instructors, especially in newly opened institutions of higher learning, is made more acute by the lack of skilled ICT people and the ineffective use of existing ICT resources (Tibebu, Bandyopadhyay and Negash, 2010).

Research on scientific journal articles appearing in the global SciMago and other global databases has indicated that African universities have the lowest number of journal submissions as a group (Tijssen and Kraemer-Mbula, 2017). African universities contribute barely 1% of the global research output, creating the necessity for more research, innovation, and international sharing of information with other parts of the world. This small contribution has been mostly attributed to the absence of the necessary tools and skills a research community needs to improve research quality and output (Amir, Duermeijer and Schoombee, 2018).

Globally, there has been very little research addressing the potential effects of NREN on research and education in higher education within the context of developing countries. Some of the benefits that have been highlighted from the implementation of NREN from global perspective include improved connectivity, enhanced communication, and the provision of high-value services that can improve teaching and research outcome (Kashefi *et al.*, 2018). Most of the existing research has emphasised the challenges affecting the uptake of NREN services among African universities, such as the absence of robust network infrastructures, insufficient ICT budgets, bureaucratic hurdles and the autonomy of the institutions, among others (Abbott, 2017). While examining the challenges facing the implementation of NREN, they have entirely failed to address the comprehension and understanding of NREN service requirement. Therefore, this research seeks to understand how NREN services could have impacted the research outcome and the quality of education using the proposed theoretical framework and the ANT model, which emphasizes on the benefits and relationship of different actors to promote the effective transfer of resources within a network. Additionally, it was noted that developing country has not been able to come up with NRENs service portfolios and roadmaps that can be implemented and have practical utility in the higher education sector. There is also a need to fulfil the aspirations of the SDGs (Sustainable Development Goals) for education set by the governments of developing countries.

1.4. Research Questions

Based on the problems identified above; the primary research question is presented, along with its associated secondary sub-questions based on the Actor-Network Theory (ANT), to guide the theoretical research framework.

The primary question guiding this research is: What are the impacts of National Research and Education Networks (NREN) on the quality of education and research outputs? Moreover, how should NREN services provided by EthERNet be developed into a service portfolio and an EthERNet roadmap be created so that effective and efficient services can be implemented to enrich the educational quality and research output in Ethiopian higher education institutions?

The secondary questions are.

1. How have significant drawbacks influenced institutional networking and the use of EthERNet in Ethiopian institutions of higher learning?
2. How have EthERNet services impacted the quality of education and research output at Ethiopian institutions of higher learning?
3. How have the positive and negative factors influencing the actor-networks relationship with a view of enriching the educational quality and the research outputs at Ethiopian higher education institutions?
4. To what extent do end-users need NREN services in Ethiopian public higher learning institutions to enrich the educational quality and research outputs, and to develop a service portfolio and roadmap for EthERNet?
5. To what extent has the concept of ANT supported the comprehension of NREN service requirement in Ethiopian institutions of higher learning?

1.5. Aims of the Research

The research work is to present what ANT is and how it can influence the quality of higher education and research output using EthERNet as a reliable technology tool for the study (Carroll, 2018).

The primary aim of this research is to investigate the impact of NREN services to improve the quality of education and research output among Ethiopian higher education institutions. Three main aspects which form the focus of the study include the NREN services required by the end-users, challenges encountered using the network, and the impacts of using the EthERNet. These aspects are critically examined to develop a service portfolio and roadmap for EthERNet, which can enrich the standards of education and the research output at Ethiopian institutions of higher learning. This is expected to enhance the role of the EthERNet by promoting the realisation of its goals thus increasing the possibility of collaboration between Ethiopian researchers and their local, national, and global peers in stimulating the socio-economic development of Ethiopia and beyond.

The objectives of this research are to.

1) Investigate the services required by researchers and educators within the Ethiopian higher learning system to enhance educational quality and research output.
2) Find out the main challenges faced by Ethiopian higher education institutions with regards to their network, and in using EthERNet to enhance educational quality and research output.
3) Assess the impacts of reliable networks to improve on educational quality and research output.
4) Examine both positive and negative factors that influence relationships of actor-networks that enrich the educational quality and research output at Ethiopian higher education institutions.
5) Assess how Actor-Network Theory (ANT) constructs can be employed in understanding NREN service requirements in Ethiopian institutions of higher learning.
6) Find out how EthERNet can provide the services that can be used to address the issues of quality of education and research output within Ethiopian higher education and to develop an NREN service portfolio and roadmap.

1.6. Significance of the Study

The study contributes to the existing literature in several ways. It intends to propose a theoretical framework as the base for the research, which leads to assist in developing a service portfolio and roadmap for the effective use and implementation of NREN services at EthERNet. The study will rely on identifying the services required by researchers and educators at Ethiopian public higher education institutions, assessing the challenges faced while using the network and the impacts of using EthERNet to enrich the overall quality of the processes of teaching, learning and research output. Furthermore, the research aims to define the required services that can be provided by EthERNet to end-users and to measure the preparedness of member institutions in the use of EthERNet. The findings and insight from the study will have the potential to help ICT policymakers, regulating bodies and other stakeholders locally, nationally, and internationally to utilise the framework.

In particular, it is hoped that carrying out the research and analysis will result in a makeable contribution to theoretical and managerial perspectives by enhancing relationships between quality of education and research output using the Actor-Network Theory (ANT) model. ANT is used to identify the required NREN service, their relative importance, and their relationships. The study also evaluates the positive factors, as well as the negative factors that influence and affect the quality of education and research output at Ethiopian higher education institutions. In general, this research provides new insight concerning the use of the NREN to improve educational quality and the research outputs in the higher education sectors of developing countries. The study proposes an NREN service portfolio and roadmap for the effective use and implementation of the model at EthERNet that can be used by other countries with similar contexts.

1.7. Scope and Context of the Study

This study concentrates on the impact of NREN services on the quality of learning and research output in Ethiopian institutions of higher learning. Those aspects that impacted on the reliable networks that were examined include NREN services needed by the end-user, the challenges, and the impact of EthERNet in Ethiopian institutions of higher learning. Based on the input from the user, this study develops a practical service portfolio and roadmap for the service that should be provided by EthERNet. However, the study was limited to a specific NREN context. Therefore, future research needs to consider evaluating the proposed theoretical framework's applicability to multiple NREN contexts.

This study concentrates on the impact of the NREN services on the quality of learning and research output in Ethiopian institutions of higher learning. In the last few years, African universities have solely focused on admitting more students with a view of increasing access to higher education to many. However, they have ignored to invest in more workforce and resources, which can support high education quality and research outcome. Ethiopian institutions of higher learning have been confronted by these challenges and how they can improve the quality of education and research outcome. These have impacted on the reliable networks in terms of NREN services required by the higher education academic staffs, researchers and students, the challenges, and the impact of EthERNet in Ethiopian institutions of higher learning. Based on the input from the higher education institutions end users, the study was limited to developing a service portfolio and roadmap that was meant to improve on research collaboration and the quality of education. Therefore, future research needs to consider evaluating the proposed theoretical framework's applicability to multiple NREN contexts.

1.8. Nature of the Study

In this study, an exploratory quantitative research design was used, where a questionnaire was employed for the collecting of data regarding the NREN services that end users would like to have in Ethiopian public higher education, the challenges faced using the network and EthERNet, and the impact of EthERNet on improving the quality of education and research output. This is deemed appropriate to increase the chances of gaining views from many respondents within the shortest time and rapidly evaluate their responses.

A theoretical framework is proposed using a three-step design science approach and validated through exploratory quantitative study at the higher education institutions in Ethiopia grounded on the ANT model. After the identification of the services and resources required by the end-user together with the challenges encountered, SEM-PLS methods were used to evaluate the applicability of the theoretical framework, which is used as the base for developing an NREN service portfolio and roadmap for EthERNet.

During the selection of the research participants, purposive sampling was employed in selecting knowledgeable individuals from Ethiopian public higher education population. The researcher targeted educational researchers, scientists, and educators from Ethiopian Public Universities, but did not restrict the size of the population. The outcome of the research was presented graphically with the help of the Statistical Program for Social Scientists (SPSS v24). Additionally, WarpPLS 6.0 was used to examine the formative latent variables that were initially theorized in the study.

1.9. Thesis Structure

This study is composed of seven chapters, as depicted in Figure 1. 1.

Chapter 1: This presents a background to the current study by focusing on specific areas such as the statement of the problem, the research questions, the significance of the study, limitations of the research, and a summary of the methodology. In this case, NREN services are considered to enhance the quality of education and facilitate research collaboration among researchers. However, some institutions seem to have failed to understand NREN services can be used to address resource challenges, especially African universities.

Chapter 2: This presents the literature review analysis and deals with the review of related work by providing comprehensive coverage of theoretical knowledge in higher learning and the state of research, in Africa in general and in Ethiopia in particular. Additionally, it deals with NRENs and the services provided by them for end-users, SWOT analysis, and service portfolio and technology road mapping. Subsequently, an evaluation of ANT is made alongside the philosophies and ideas that support it, as well as its supportive theory's translation. Also, ANT's relevance, as well as its implication on ICT research, is described in detail. Barriers, challenges, and the impact of NREN on the improvement of the study and education sector are explained to justify further the development of the NREN service portfolio and roadmap.

Chapter 3: This provides an analysis and exposition of the theoretical framework used. It opens with an explanation of education and research actor involvement in the processes of higher learning and roles, as well as the impacts of ICT on higher learning. This includes the institution of actor-networks, as well as the review of the elements that affect the formation and functioning of the outlined actor networks. It then proceeds to present the theoretical framework at the same time as it derives and discusses the research hypothesis.

Chapter 4: Here, the approach and research methodology of the study is presented. It encompasses the approaches used in research, the strategies employed in the study, the research design, the techniques of data collection, the methods of data analysis, the validity and reliability, the ethical considerations made and the conclusion.

Chapter 5: This presents the analysis of the data, which is gathered using questionnaires. It includes the presentation of results and findings in graphical form. The validity and reliability of the results are also discussed.

Chapter 6: This provides a discussion of the research findings deduced from the analysis of the data to the research questions posed in the thesis and links these questions with the literature review where applicable.

Chapter 7: This presents and discusses the proposed NREN service portfolio and roadmap for EthERNet.

Chapter 8: This concludes by giving recommendations following on from the finding of the study and suggests directions for future research based on the study.

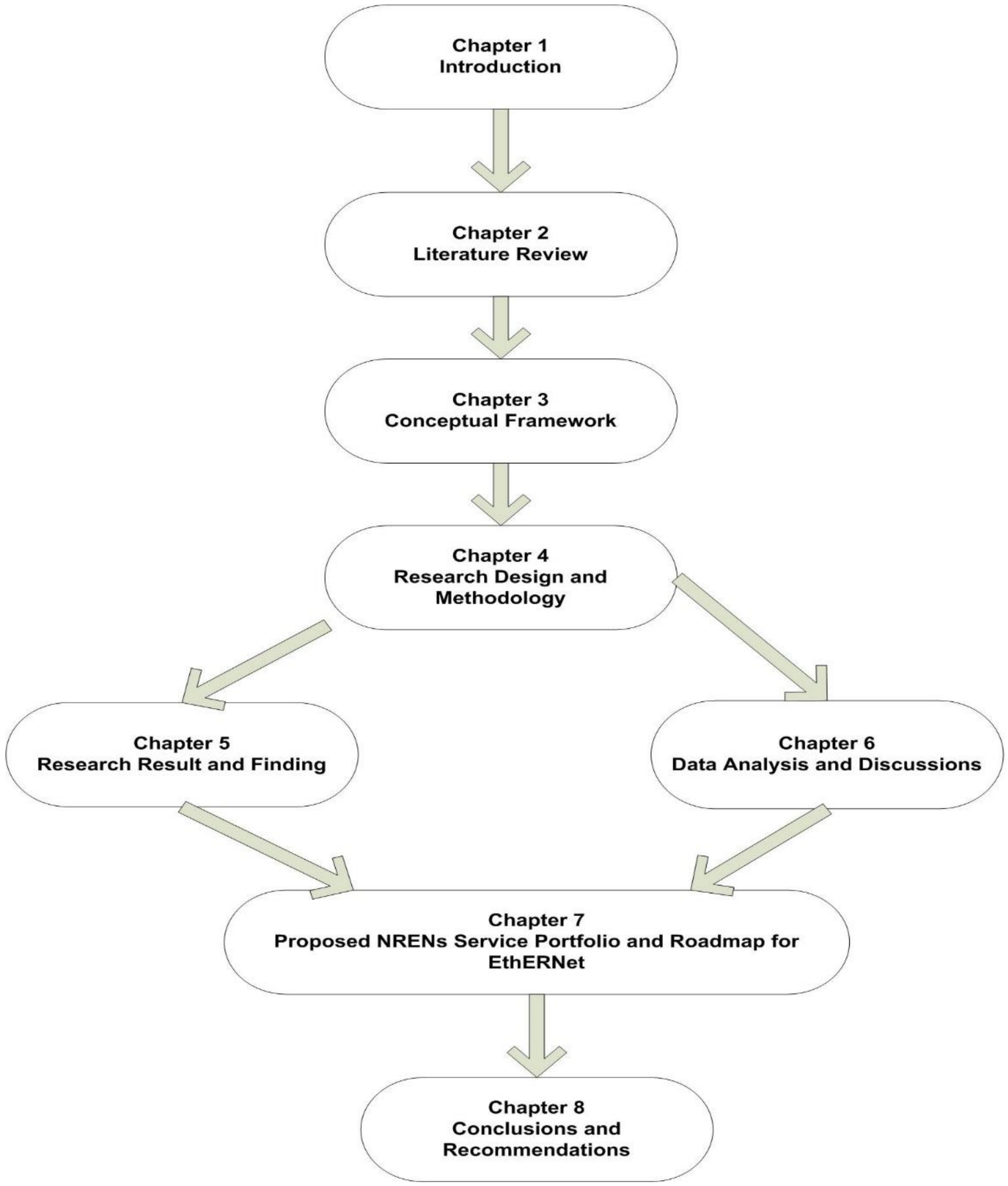


Figure 1. 1: Thesis structure

1.10. Summary

This chapter introduces the ideas that NREN has an opportunity to provide services to enhance the quality of education and facilitate research collaboration for Ethiopian researchers, and that there is a need to understand better how NREN services can be used to address resource challenges. Research questions and objectives were initially identified that could be used to know how NREN services can address some of the problems faced in higher learning institutions. This exploratory quantitative study is grounded on the ANT model, which emphasizes on the association between the actors and their networks. The outcome of this study is expected to offer a service portfolio and roadmap model that can impact on the implementation of the EthERNet in higher learning institutions. The next chapter presents a review of existing literature on the current state of higher learning and research institutions, and the extent to NREN service have impacted on their core activities.

Chapter 2: Literature Review

This chapter presents a review of related work and its relevance on the impact of NREN services on education quality and research output. Relevant journals, research articles, dissertations, reports, policies, and books were consulted to form a meaningful section. The sections that are presented include the current state of higher learning and that of research in Africa and Ethiopia, evaluation and relevance of ANT as well as its supportive theory, different NRENs services that are offered together with the barriers, the impacts on educational quality and research outputs. Each of this section is discussed as follows:

2.1. Current State of Higher Learning and Research Institutions in Africa

According to an outlay of Agenda 2063 presented by the African Union Commission (AUC) in the year 2015, the strategy for Africa renaissance and developmental advancement was agreed upon by all the African Union members 2013. One of the visions in the Agenda was that at least 70 per cent of all high school graduates would join tertiary education and pursue subjects related to sciences and technology. This means that the gross enrolment ratio is expected to double the current global average enrolment of 32 per cent and more than eight times the current Sub-Saharan African enrolment (African Union Commission, 2015).

However, despite the enhanced enrolment of students in most African education systems, the establishment and development of infrastructure and improvement of educational quality are still wanting. There have been numerous calls for African governments and universities to invest in extensive training of teachers, improve pedagogies and establish infrastructural provisions. Additionally, there have been notable challenges, which have been associated with access to higher education in most parts of Africa. A report presented on the State of Education in Africa (The Africa-America Institute, 2015) indicated that the need for the education systems to satisfy these challenges by increasing opportunities for qualified secondary education graduates, as well as for the significant portions of populations that are eager to access tertiary education (De Wever, Vanderlinde, Tuytens and Aelterman, 2016).

Consequently, most universities in the Sub-Saharan African countries have been mandated to enrol more students. There has been an increase in the number of students who have enrolled for tertiary education from 200,000 tertiary students in 1970 to over 4.5 million in 2008 (UNESCO, 2010). Despite this extraordinary growth, Africa's gross enrolment ratio has still adversely lagged the rest of the developing world. Because funding has not been kept at pace with the enrolment growth rate, it is not surprising that the low quality of education offered has presented an enormous challenge. Some of the challenges facing the growth of higher education and the related falling of its quality include depreciating standards of educational training for teachers, limited infrastructural provisions for universities, inflexible admission criteria in institutions of higher learning, and minimal opportunities for credit transfers from one university to another (Bloom, Canning and Chan, 2015).

Additionally, research output from Africa remains quite low when compared with global trends and expectations (Kolk and Rivera-Santos, 2018). Although there has been a rise in outputs from African institutions with a reported increase from 21,000 in 2008 to 33,300 in 2014, signifying an increase from 2% to 2.6% of Africa's share of the world's publications. However, the fraction is still small when compared with global research output that increased from 1,029,271 in 2008 to 1,270, 425 in 2014. Besides, most of Africa's publication outputs are dominated by a few countries; South Africa was leading the chart with 9,309. Others are Gabon (80), Cameroon (31), Kenya (30), Congo (24), Uganda (20), Rwanda (12) and Ethiopia (9). Furthermore, Africa's research output is primarily dominated by the life sciences and agriculture field, with little from the physical sciences, engineering, technology, and mathematics field (Blom, Lan and Adil, 2015).

2.2. Current State of Higher Learning and Research Institutions in Ethiopia

There have been rapid transformations, as well as growths of higher learning in Ethiopia over the last decade, with an increased number of universities and student enrolments. From 2004 to 2016, the number of public higher education institutions increased from 8 to 36, and the number of private higher education institutions reached five universities and 107 colleges. With an ambitious plan to become a middle-income economy by 2025, the Ethiopian government has heavily invested in research and education, because the economic growth that is moving towards industrialisation and service economies from agriculture demands different skills and new knowledge sets (Salmi, Sursock and Olefir, 2017). Subsequently, this remarkable expansion has created opportunities for the rapid increase in intake capacity. The total enrolment in undergraduate programs in both government and private higher education institutions increased hastily and reached 778,151 by 2016. The total admission in second-degree programs in Ethiopian higher education reached 37,152 by 2015. However, the gross enrolment rate has not improved by the same proportion; it is still at 10.4% (Salmi, Sursock and Olefir, 2017).

Despite massive resource allocations to higher education, universities still report insufficient supplies of text and reference books, laboratories, workshop equipment and access to ICT facilities (Bankole and Assefa, 2017). This concurs with the view that the state of higher education in Africa is wanting even though it has experienced unprecedented growth from many perspectives (Inglehart, 2018). In Ethiopia, the universities are endowed with inadequate infrastructural facilities, limited financial resources and funding, out-dated pedagogical and curricular situations, poor ICT infrastructure, and under-stocked libraries, among others. Due to these reasons, the graduation rate is low among regular undergraduate students (Woldegiyorgis, 2017). This could be attributed probably to the reduction in the quality of higher education being offered in Ethiopia (Yirdaw, 2016).

To improve the quality of higher education, several initiatives have been implemented including harmonising curricula for all the undergraduate programs, adopting a modular approach for course delivery to enhance active learning, opening institutional Quality Assurance Offices at each university, equipping libraries, laboratories and implementing ICT infrastructure (Tadesse, Manathunga and Gillies, 2018). Usually, the quality of higher education and learning has slowly been dependant on, and supported by, qualified, well trained, and adequately motivated faculty at universities (Shirani, Nasr, Rouhollahi and Khalili, 2016). However, the unfortunate situation in Africa is that even leading universities have few such professionals, and these have limited graduate achievements, which subsequently limit the level of knowledge imparted to students, thus limiting the generative ability of the latter to produce new ideas and innovations (Burnett, Rickard and Terekhov, 2018).

According to Ethiopian Higher Education Proclamation 650/2009, research and community service are the second and third missions of all institutions of higher learning in Ethiopia apart from teaching (Abebe, 2015). The main target of universities is to generate research and produce competent graduates. However, financial support for research is low. For example, in 2011/12, the research allocation of all universities accounted for only 1% of their total budget (Kahsay, 2017). The Ethiopian Higher Education Proclamation has relied on higher learning institutions to conduct research, generate, and transfer knowledge and technologies that can be used by industries and enterprises. Article 4 of the Ethiopian Higher Education Proclamation number 650/2009 states that one of the objectives of higher learning institutes, among others, is encouraging research activities with a substantive focus on the growth of knowledge and technological skills transfer inconsistency with the country's pressing needs and demands. Moreover, the proclamation in article 24(1) urges universities to focus on the developmental needs and requirements of the country alongside education while conducting research and technology transfer (Abebe, 2015).

The universities in Ethiopia have numerous young academic staff employees who can do research and contribute to technology transfer immensely; however, various weaknesses have been encountered including shortage and depletion of senior staff from universities; the available young staffs who work in the universities are equipped with a shallow level of scientific skills. Other challenges that have been encountered include poor research infrastructure, poor integration of teaching and research, inadequate deliberation/report of research output based on the time plan given, weak linkage of research findings to the community, a mediocre potential for universities to solve problems of industry and poor university and industry linkage (Kahsay, 2017).

2.3. Education and Training in LDC

As per the UN report, the enrolment rates in secondary, vocational, technical, and tertiary education have been increasing from year to year. This has led to the development and enhancement of skills that are required for employment. Significant issues that continue to exist in leading LDCs include mixed educational qualities, as well as limited and minimal access to education by marginalised groups in the societies. Even though the enrolment rates of the tertiary educational establishments are increasing, the quality of education is deteriorating due to the reasons mentioned above (Alonso, 2015).

2.3.1. Science, Technology, and Innovation in LDC

The state of science, developmental technology and scientific innovation are pathetic in the LDCs (World Bank, 2014). In 2011, the expenditure by the majority of the LDCs on research deemed as a developmental element was almost zero, when considered as a percentage of the GDP. For instance, Ethiopia allocated only 0.6% of its GDP to research to enhance development (Tigabu, 2017). Additionally, the meagre number of science-literate citizens in LDCs contributes to the limited output and generation of scientific knowledge and skills, their distribution, and application in solving challenges. Therefore, in the majority of LDCs, applicable localised development of consciousness is minimal; thus, there is a need to allocate enough resources to increase research and development outputs (Alonso, 2015). Noting that the improvement of skills and technological know-how is relevant to the performance of any economy, Ethiopia is taking steps to ensure the achievement of this in its learning system. This is being done by incorporating technology and skills development within the country's developmental policy. The support for this is anchored in the Educational Sector Development Program IV for 2011-2015, in which the country established 70:30 ratio of academic study intake in favour of sciences against humanities. The government of Ethiopia attempted to improve the state of science courses in the education system through the introduction of enhanced quality curricula for mathematics and sciences in both Primary and secondary schools (Tadesse, Mengistu and Gorfu, 2016). The expansion of technological, scientific, mathematical, and engineering courses requires more demanding infrastructural and financial input compared to those of humanities and social sciences. These requirements can only be achieved with the corresponding information of necessary financial resources to enable facilitation and implementation, which are almost always inadequate. This necessitates the need for government involvement to enhance the realisation of quality results/outputs (Alonso, 2015).

As per MHRD (2016), LDCs still play a marginal role in the Science, Technology and Innovation (STI) activities arena, including research spending, the publication of articles/citations in peer-reviewed journals, and in taking out patents, compared with the countries that lead in scientific research and innovation. This produces the result that, even after combining all the patents produced in the LDCs, the total still falls way below that of many individual developed countries. Evaluations indicate that ignoring this gap and leaving it unaddressed will not only worsen the state of effective production but also leave LDCs at the bottom of the global economy in terms of production and economic development. For LDCs and their people, it will be challenging to eradicate the widespread poverty, evade unfavourable structural constraints that continue to affect the economies, and achieve significant and sustainable development without substantial investment to boost the productive capacities of research in science and technology for innovation (MHRD, 2016).

2.3.2. LDC and the use of ICT

The definition of Least Developed Countries (LDCs) indicates that these are low-income nations that are struggling to achieve sustainable development. Currently, the UN has designated 48 countries as LDCs depending on socio-economic growth and human development indices. These countries display the lowest scores across the world in both categories of ratings (Loewe and Rippin, 2015). The majority of the LDCs are continuing to struggle with growing inequality, inadequate creation of productive employment and decent jobs, unchanging state of manufacturing GDP, consistent un-productivity across the economies, the simple realities of pervasive poverty, and steady states of vulnerability to sudden economic shocks (Alonso, 2015).

Some of the main positive developments in LDCs regarding ICT are access to ICT, especially mobile cellular penetration and broadened subscriptions to Internet provision that are continuously improving from year to year. However, speeds vary from country to country. According to the development indicator of the World Bank, in 2013, the mobile cellular penetration of the LDCs was 56 per cent, but in 2014, the percentage increased to almost 64 per cent; however, in Ethiopia, the penetration had only reached 31.6 per cent by then (The World Bank, 2014). In contrast to the mobile penetration, the Internet subscriptions in LDCs countries reduced during the same period, for instance, there was a realisation of an average increase in the number of subscribers to the Internet in the LDCs. This resulted in an increase from a previous 7.8% to 8.6% between 2013 and 2014**.** This indicator: however, for Ethiopia was only 2.9 per cent. In support of this, International

Telecommunication Union (ITU) qualified 42 countries as the “world’s Least Connected Countries (LCCs),” among those 34 are LDCs (Union Internationale des télécommunications, 2015).

2.4. National Research and Education Networks (NRENs)

Based on a report produced regarding NREN institutions in 2010, it was noted that the presence of a robust National Research and Education Network (NREN) could have a significant impact on the social and economic development in a country (Yaver *et al.*, 2016). To understand how this happens, it is essential to evaluate how research and education institutions serve as the primary consumers of numerous national public services such as communication and labour resources. As such, NREN is tasked with the mandate of providing the required communication programs such as Internet infrastructures and computer facilities to all institutions registered in the country with the educations board. These institutions are not limited to higher-level universities but include all institutions of learning such as public libraries, high schools, and heritage sites. To a certain extent, NRENs are a branch under the government that could also offer the networking services to government departments and healthcare institutions that have adopted high-tech service delivery strategies using Information Technology. This means that NREN serves as the linking medium for various institutions so that the users can access materials from the other institutions without too much hassle as exemplified by the positive results in countries that have adopted the NREN concept (Yaver *et al.*, 2016). As education continues to lead through various innovations that include online classes and e-research, NRENs has provided the best platform for interdisciplinary collaboration between different institutions using a communications network system built by ICT experts (Taylor and Abbott, 2015). Identifiable characteristics of an effective NREN can be noted on the focus put on security and protecting users’ privacy, high-speed connectivity, and access to the information database of all institutes in the network collaboration. This makes it easy for students and researchers to acquire data for support services that would be costly without the NREN (Osazuwa, 2011).

Education and Research institutes should be connected and with their counterparts globally to resolve complex research problems that require cooperation and access to materials that are limited or costly for all institutions to invest in. This culture of teamwork and the ability to share information selflessly among peers is a positive personality trait that is cultivated in young students during higher education training. In the year 2011, the World Summit on the Information Society agreed on a specific framework that would be used to define NRENs: “a specialised Internet service provider dedicated to supporting the needs of the research and education communities within a country” (Mulhanga, Lima, Massingue and Ferreira, 2014). This implies that it will be administered to provide support for a high-speed backbone network; often offering dedicated channels for individual research projects.

While there is continuous development in the NREN world in different aspects, the concept of NREN version 2 (NREN v2) is becoming a popular point of discussion, which is more than just connectivity. Hence, NREN v2 is beyond connectivity and will be the worldwide platform for the research and learning institutions, taking the place of a specialised Internet Service Provider (ISP). The main idea behind the NREN v2 platforms is that the education and research institutional goals are beyond connectivity, they use NRENs to work together in a collaborative environment to solve their everyday challenges and to develop new technologies for shared use within the NREN world (Yaver *et al.*, 2016). To qualify and be able to transform from NREN to NREN v2, the new version should be able to alter: from the primary medium of collaboration between institutions to a typical instigator of partnerships without the direct involvement of the institution’s resources, from knowledge carrier to the knowledge multiplier, and change the institutions from one that only provides communication services to an engaged community actor. As such, the NREN v2 will create an environment where the most complex and sophisticated research institutions are intertwined with institutions from different remote locations to help in providing high-tech services that are unavailable in the small-scale sectors (Yaver *et al.*, 2016).

Typically, there is a single NREN in each country. However, there is no unique structure that has been used to model all the NRENs found in the independent countries available (Kashefi, Taylor, Abbott, Anagnostou, Tessa, Oaiya, Barry and Alline, 2019). Yaver *et al.* (2016) attributed this variation to the influence of the existing local conditions such as organisational and ownership (governance) dissimilarities. Despite these variations on the model used, Yaver *et al.* (2016*)* also noted that most NRENs possess the same characteristics as illustrated earlier. For instance, NRENs can be separately incorporated as a government department (which is the case for the Ethiopian

NREN, organised under the Ministry of Science and Higher Education) or operated by third parties (just like the case of the Kenyan NREN) under contract. The European model of NREN has been widely adopted by Colombia and some countries in Africa. The model utilizes one NREN that coordinates and partners with regional and local networks in ensuring proper information transfer.

Furthermore, the illustration from the European model indicates that the NREN adopts a hierarchical approach in which the national backbone exists at the topmost, followed by the regional networks, metropolitan area networks (MAN), and the individual local campus network (LAN) at the lowest level. In this case, users within the system are at liberty to request services from any level of the NREN. According to the model, it is possible that traffic congestion would mostly occur at the lowest level due to the high number of users and requests made (Yaver *et al.*, 2016). The model is shown in Figure 2. 1.

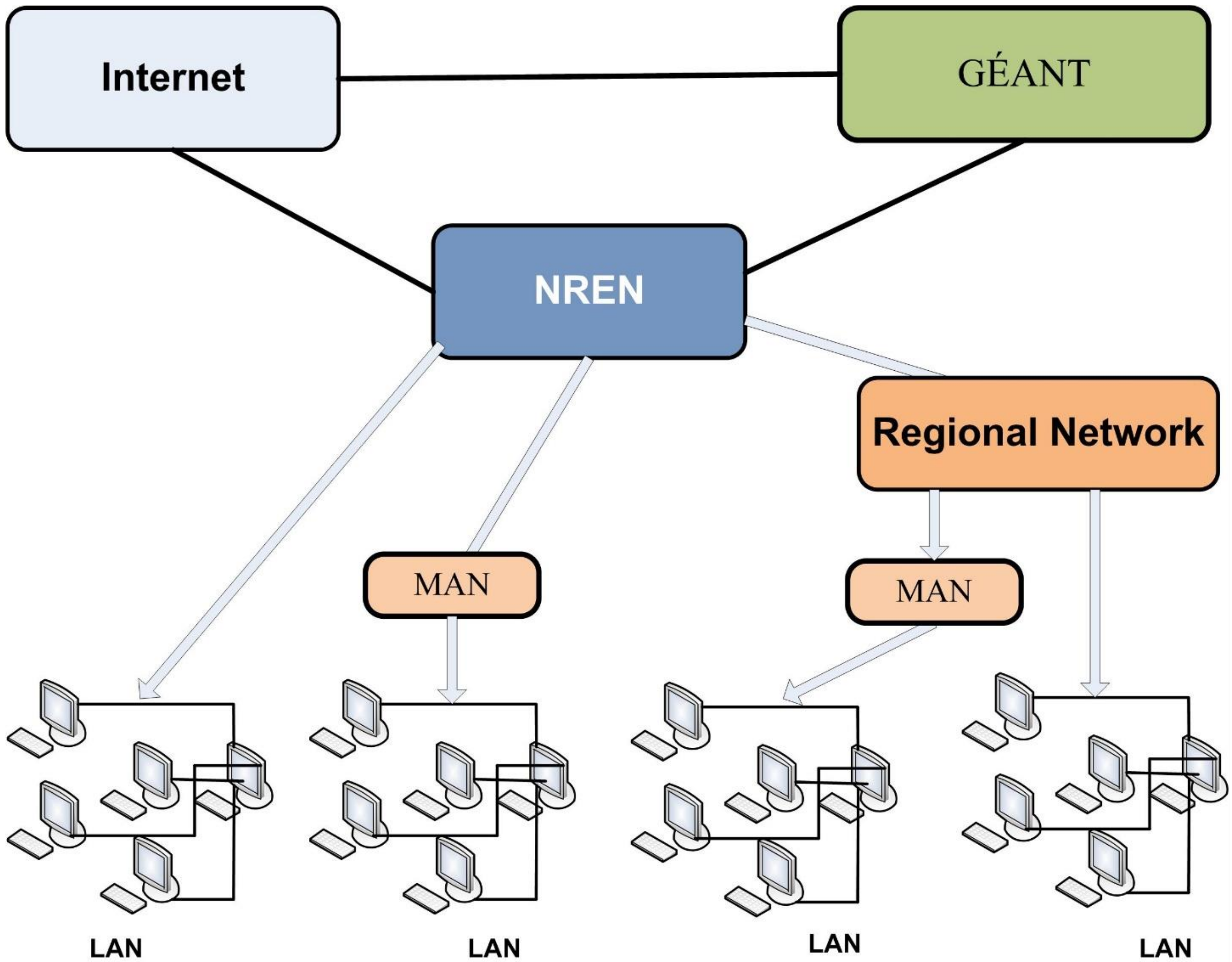


Figure 2. 1: The NREN model adopted in Europe (Yaver *et al.*, 2016)

2.5. NRENs in the Least Developing Countries (LDCs)

The main objective for the creation of NRENs in any country is to create an organisation responsible for the collaboration between higher education institutions and research organisations. This means that they are responsible for implementing programs that will enable communication between individuals in different campuses with minimal bureaucratic processes. Attaining this high level of trust between organisations is achieved through implementing authorisation checks and mutual trust in the integrity of the process.

According to the U. N's Technology Bank for the Least Developed Countries, there are nearly 110 NRENs registered in different countries, with a mere 16 registered in the least developed countries.

This has been attributed to the costly fibre optic materials required to install an efficient communication network between institutions. When the governments in LDCs realise the potential benefits that can be accrued through the creation of NRENs, there will be an increase in the quality of education. NRENs differ from commercialised Internet Service Providers, as the chief characteristic of NRENs is the interconnection of different organisations to share information.

The Science, Technology, and Innovation-Supporting Mechanism (STIM) was created to aid LDCs to enhance the national reputation of Information Technology facilities through grants issued to develop and improve technologies required for sustainable development in the education sector. The development driven STIMs include a policy document that encourages local technological research studies while maintaining an environment that is favourable to international organisations to invest in the technological sector in a specific country. A collaboration between STIM and NRENs in the least developed countries will immensely improve how students and researchers share information across the networks. Despite the economic and social challenges in LDCs, it is crucial to commend the countries that have successfully implemented NRENs such as Uganda and Zambia, which faced the additional difficulty of being landlocked. While the process took many years before the national and international institutions could use the NRENs efficiently, these nations celebrate the benefits from the restructuring of research projects in their respective countries (Kunda & Khunga, 2015).

In Ethiopia's case, on the one hand, the country has been successful in the creation of EthERNet, which can enable Ethiopian researchers, scientists and educators to collaborate and work together with each other and with colleagues from global institutions as they intellectually struggle to resolve complex issues meaningful for the betterment of Ethiopian society. On the other hand, nations have relied on the regulatory environment and international investments to support the successful implementation of the NRENs. Makoni (2016) indicated that interrelationships between NRENs among African nations could rapidly enhance the progress of achieving the expected benefits. A notable example is the UbuntuNet regional network, which was established between Kenya and South Africa to support collaborations and sharing of data among researchers in the two countries (Makoni, 2016).

2.6. Ethiopian Education and Research Network (EthERNet)

The government of Ethiopia commenced EthERNet in 2001 as an Ethiopian NREN (National Research and Education Network) and a member of UbuntuNet Alliance, which is a local association of NRENs in East and Southern Africa. It initially focused on the development of ICT infrastructure for public universities to share educational resources locally and globally and on providing tele-education and telemedicine that enabled the delivery of many types of training, classes and meetings (Bankole and Assefa, 2017). EthERNet was initiated as a tool for local higher education institutions and research organizations to work simultaneously together in projects that would improve the level of project performance in the country. The high-speed connections meant that peers could communicate irrespective of the geographical location of their respective organizations, whether they were within the Ethiopian borders or in other countries. The main drive was to help address and overcome the critical shortages of resources in many higher education institutions in Ethiopia.

A critical reason that enables EthERNet to play such a role in carrying all network traffic of Ethiopian higher education is the government-funded a project, which cost more than $60 million, to deliver fast and reliable networking services to the thirty-six public universities and institutes of technology across different regions of the country. The newly built EthERNet functions separately from the existing commercial service provider (Ethio Telecom) network and delivers 10 Gbps bandwidth connectivity between the universities, as shown in Figure 2. 2.

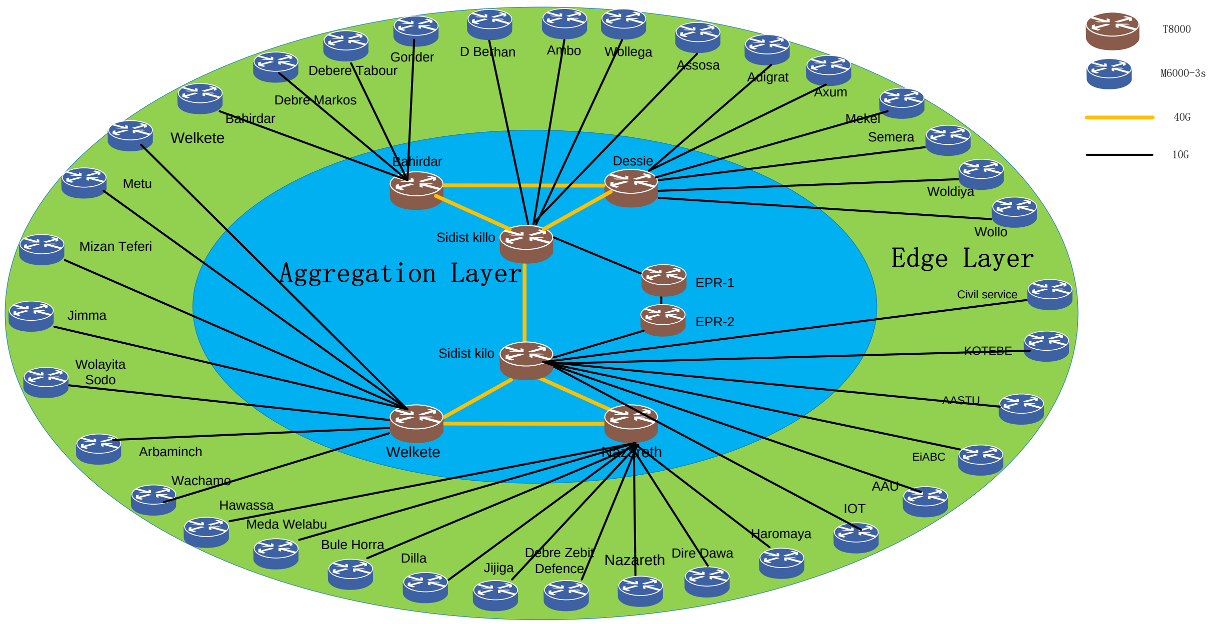


Figure 2. 2: Existing EthERNet IP Backbone Architecture (Bankole and Assefa, 2017).

As indicated in Figure 2. 3, the optical fibre backbone has been built on highly reliable Optical Ground Wire (OPGW) on Ethiopian Electric Power high voltage lines. There are also aggregation rings in the north, south and central part of the country based on 40Gbps bandwidth. An Exchange Point/Internet Gateway has been built at the EthERNet Data Centre located in Addis Ababa to join with neighbouring NRENs (SudREN, KENET, SolmaliREN) and ultimately to connect to UbuntuNet, GÉANT, Internet2 and all other global research and education networks.

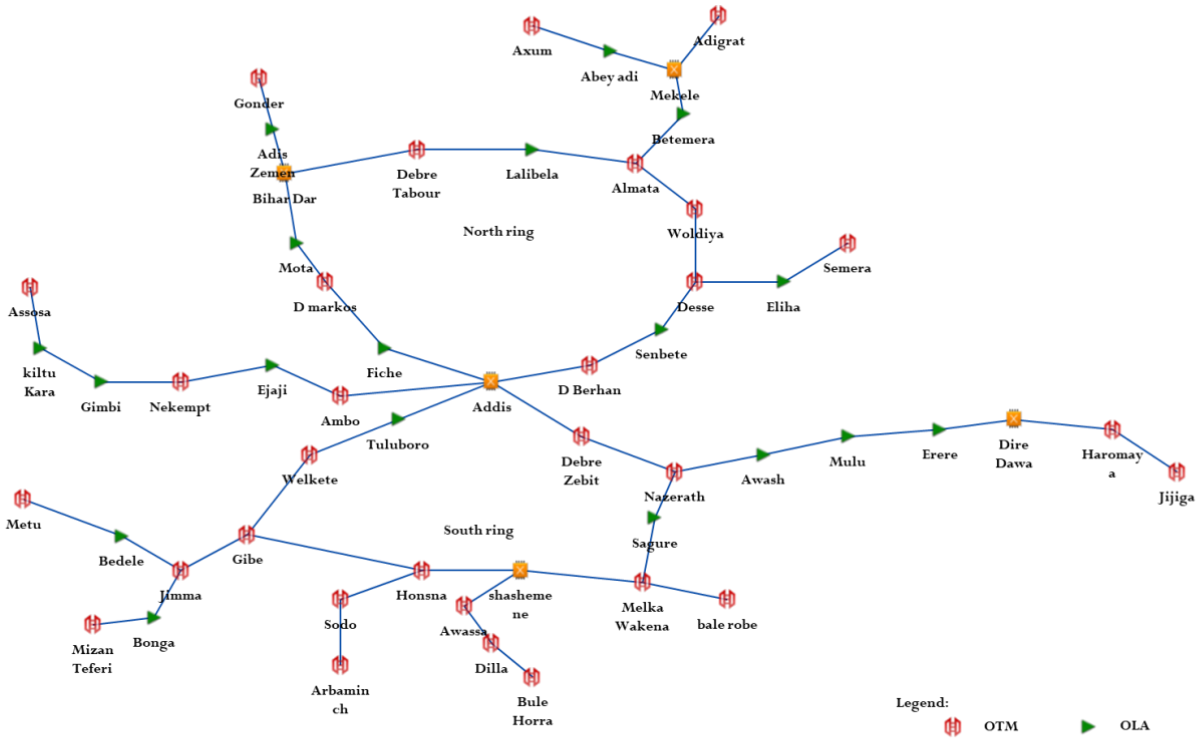


Figure 2. 3: Existing EthERNet Optical Network Architecture (Bankole and Assefa, 2017)

Apart from the other critical issues that have been observed; the existing ICT infrastructures in Ethiopian higher education supports NREN services poorly. EthERNet is not yet connected to the global research education network. Furthermore, the absence of ICT facilities supporting researcher and education hinder the exchange of viable educational material between members. The lack of a strategic roadmap and reference architectural framework to provide NREN services restricts the provision of quality education and research at Ethiopian higher education (Cho, Yoon, and Kim, 2016). By improving the efficiency and effectiveness of EthERNet, to provide all the necessary service for its end users, Ethiopian researchers and professors would be able to work with their counterparts across the globe to resolve global issues and help the development of projects within Ethiopia.

2.7. What Services Can NRENs Provide to End Users?

According to GÉANT (the pan-European data network for the research and education community), periodical assessments are made, to know the services which are provided by NRENs across the globe and to identify their member institutions and the plans they have. A questionnaire was sent, and data collected during the 2016 NREN Compendium survey. The Compendium of NRENs in Europe recently released a policy statement that analysed the different features and benefits of NRENs in conjunction with GÉANT, using specific case studies on countries that have successfully installed the NRENs and provide services to end-users (Taylor and Abbott, 2016). The services are categorized into three. These are Network Services, Security, Trust & Identity and Cloud and Collaboration Services.

2.7.1. Network Services

Globally, the basic operations of universities lie in the facilitation of appropriate and reliable academic education consisting of teaching, research, and community service (Cloete, Maassen and Bailey, 2015). Through ICT, the provision and access to information anywhere and anytime, as well as opportunities for networking and communications for knowledge sharing, participation, and lifelong education, are guaranteed (Asabere, Togo, Acakpovi, Torgby and Ampadu, 2017). Developed nations in the world have made significant applications of ICT in their daily activities. Such development is, however, relatively slow in developing countries such as Ghana. In developed nations, these new technologies and approaches are having a positive impact on education. Higher education in developed nations has made significant progress in improving the applications of ICT and use them for their teaching, learning and research activities. The development is, however, relatively slow in developing countries like Ethiopia. Research has shown that, in developed countries, these new technologies and approaches are having a positive impact on education. Through the connection of tertiary institutions, NREN has provided a means of researching the increase of Internet bandwidth, enabling researchers to collaborate by providing ICT resources (Mkandawire, 2013).

Another use of ICT is to seek advice from experts. Lecturers assist students on a specific problem in their area of study. Online teaching, learning and research are famous for all categories of students and lecturers because its nature is usually asynchronous. Asynchronous methods allow students to engage with a wide variety of courses when it is suitable for them, i.e. communication can take place between students and other participants at any time. Furthermore, asynchronous methods provide instructional content for students, which serve as a guide during the teaching process (Clark and Mayer, 2016).

Below are the most common core network services provided by the GÉANT Association (Alberto *et al.*, 2016).

1. **Network Infrastructure: Dark Fibre** - means unused optical fibre network built using fibre leased or purchased to reduce costs of laying the cables again. There is a need for NREN to set up their dark fibre through leasing or purchasing. Among the reasons for an NREN to acquire their private dark fibre include the rapid roll-out of new services by holding spares and installing transponders based on demand projections, the ability to automate service restoration, integration into the NREN's own network operations systems, and potentially new functionality developed for community requirements.
2. **Network Services -** NRENs deliver a broad portfolio of services to meet user needs. As ever, IP (both IPv4 and IPv6) remains at the core of the NREN service offering. The next most common network services are layer two virtual private networks (L2 VPN), lambdas, Distributed Denial of Service (DDoS) mitigation, IP Trunks, Network peering refers, Network Performance Monitoring, SDN and Wi-Fi. The majority of the European NRENs offers these.

2.7.2. Security, Trust, and Identity

Security, Trust, and Identity are elements within the NREN used to provide essential services that the users require while using the different applications in an NREN network. These include:

1. **Security Services**

Security is considered as one of the crucial elements that ought to be integrated into the NREN's organisational mission statement. This, and it to the increased incidences that have been cited in media reports. Various reports and news show an increasing number of cases of hacking and insecurity-related activities across different applications that require networked media, using viruses and Distributed Denial of Service attacks. As the security landscape expands with ever-increasing challenges such as the use of Bring Your Own Device (BYOD) schemes and the Internet of Things, NRENs are keen to improve security services and risk management within their organisations. They are also aware that they should assure clients that the possibility of attacks is minimised, and that risk mitigation approaches are adopted to protect the privacy and theft of ideas. The majority of NRENs have performed or plan to conduct regular risk assessments, have a devoted Chief Information Security Officer, have security measures, adherence to rules and regulations and have a risk management framework (e.g. ISO 27001, ISO 27005 and OCTAVE). A majority of NRENs are also increasing security training, seeking support from a variety of training providers to help expand the security skills base of staff. According to the NREN Compendium survey, NRENs identified many network securities threats during 2016, with the most significant risks coming from Large-scale DDoS attacks and Critical vulnerabilities, such as Heartbleed.

2. Trust and Identity

The deployment of federated access and national identity federations for research and education has enabled NRENs to explore new service delivery models. This has also included areas that, until a few years ago, were not the core business of NRENs. As a result, NRENs have expanded their boundaries to think about widening trust and identity strategies to make service offerings more sustainable and attractive to NREN users.

The trust and identity activity within GÉANT and the NRENs encompass the following areas:

- Development of new technology and policy features to make federated access possible for e-Science communities.
- Digital certificate services, such as the Trust Certificate Service.
- Operations of international infrastructures, such as eduGAIN and eduroam, and related inter-federation services and monitoring tools.
- Operations of national identity federations.
- Support of policy harmonization and best practices across identity federations.

For a long time, security was typically associated with, and defined as, the means to protect the network from undesired access and consumption. NRENs were pioneers in creating many of the earliest incident response teams. With the broader use of digital identity, security has now grown also to encompass security incidents in identity federations and eduGAIN.

This means that students and researchers can access the databases of all the institutions in the NREN collaboration with the same credentials that they use to access the local network, without the need for double registration. If a student wants to access the database of a university in another country, the student simply must connect and log in with the same log in details, thus removing the need to travel to access the said material. This phenomenon is termed “a Community of Practice”, which promotes the virtues of sharing and a framework founded on trust between peers not to misuse the access given to them. Some of the programs that enable this feature include the Certification Authority Services and Identity Federation Services, depending on the nature of the collaboration. The former refers to access provided for local communication channels while the latter allows access to institutions within the same federation. “Federations” is loosely used to refer to eduroam services within the same consortium that has separate entities. Education roaming involves cooperation between research institutes and the education industry to provide Internet access to users without the need to pay. This seamless access is possible via a technical architecture and many policy agreements that enable eduroam participating institutions to trust the result of the authentication of a user that takes place at the user’s home organization. The authorization process for users accessing other institutions is the obligation of the network being used by the user, meaning that eduroam is the safest way of securing NREN networks, surpassing the security protocols used to protect Wi-Fi hotspots in crowded areas.

Eduroam is built on one of the most secure encryption and authentication standards in existence today. Its security exceeds by far typical commercial hotspots. The first application of the eduroam technology was tested in Europe, before quickly being adopted by other countries and research institutes, to a current total of 89 territories worldwide, as shown in Figure 2. 4. There are also other emerging pilot locations where eduroam is deployed as a hierarchy of national eduroam federations; GÉANT represents the services of eduroam for countries that have adopted the technology in Europe (eduroam.org).

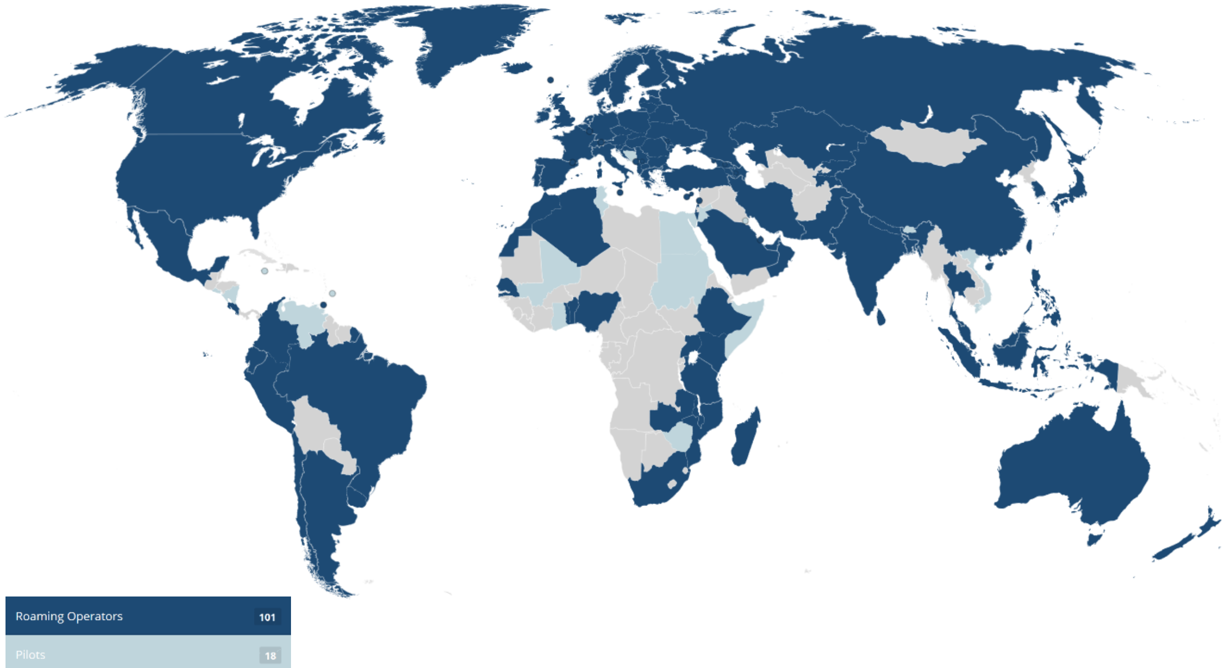


Figure 2. 4: Eduroam Territories Worldwide (GÉANT, 2018)

Identity Federations - Identity federations simplify inter-organizational access to web resources, by allowing users to access, with one login, resources offered by participating organizations in the identity federation. Identity federations (and eduGAIN, built on national identity federations) are built on the standardized SAML protocol and focus primarily on providing trusted, web Single Sign-on using SAML. These are increasingly seen as part of the core service portfolio of NRENs globally and are an important distinguishing factor from commercial services in their approach to privacy.

The main characteristics of identity federations are:

- Authentication of the user always takes place at the user's home organization (identity provider). The identity provider authenticates users while ensuring that only a limited amount of necessary personal information about the user is shared with the services.
- Users are required to provide their details to their local institution, which then provides them with login details. These registration details can then be used to access all the databases of the institutions using the same federation network.

Service providers offer services to users authenticated by the identity providers, minimizing the amount of user management service providers must do.

Currently, 69 territories worldwide and emerging pilot locations are using identity federations as depicted in Figure 2. 5.

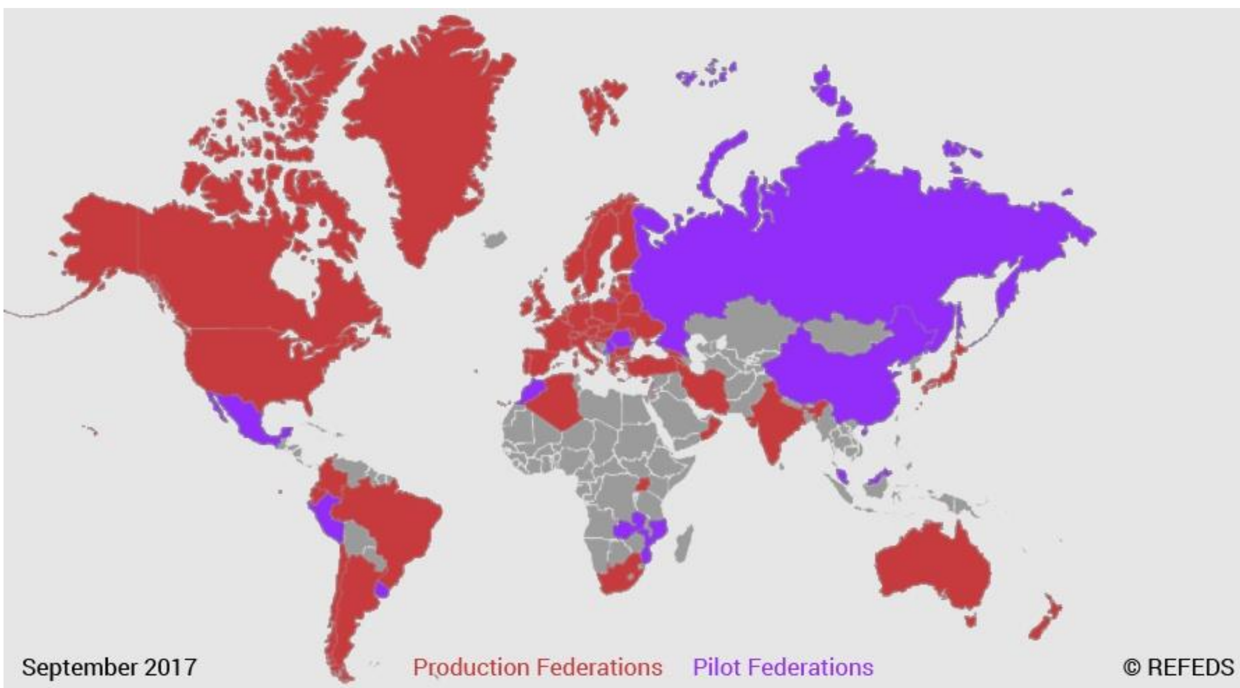
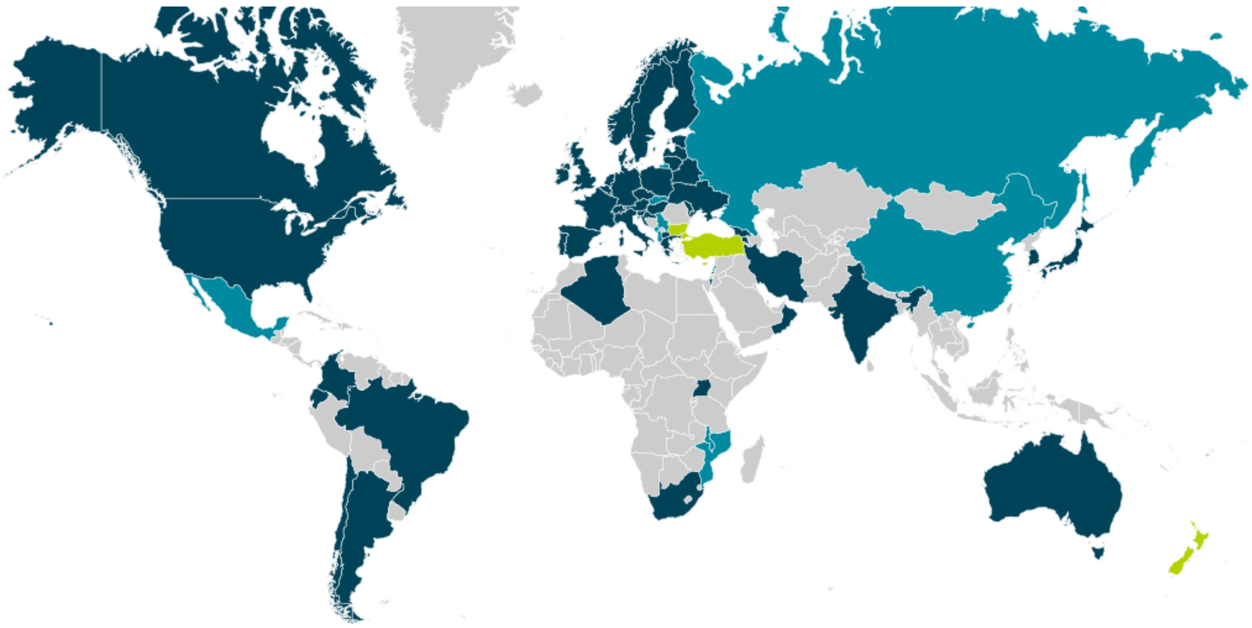


Figure 2. 5: Identity Federations Operators Worldwide (Hämmerle, 2017)

eduGAIN – Research and education are becoming increasingly borderless. The purpose of the eduGAIN infrastructure and the accompanying inter-federation services is to enable users from one federation to access services from other federations. The eduGAIN service has now achieved critical mass has been almost universally adopted by established research and education identity federations worldwide, as depicted in Figure 2. 6. It is widely recognized that eduGAIN is the foundation to enable federated access globally, and there is keen interest among the eScience community to use it extensively (edugain.org).



eduGAIN World Map - ■ eduGAIN ■ Joining ■ Candidate

Figure 2. 6: eduGAIN Global Footprint (GÉANT, 2017)

When a user is provided with certified federated access, it means that they are guaranteed the right to access the materials within the NREN that their institution is a member of, or possibly the right to access other resources across other NREN networks. There is no fear of unauthorized access since the degree of protection at this point is the best in the world. This has made it easy for institutions and Communities of Practice to organize them regionally and within international federations in beneficial collaboration patterns.

Some of the standard federation services rendered using these approaches include the following (Colmenero *et al.*, 2016):

- Access to everyday use software, remote sensors, and high-performance computing.
- Catalogue structures and document sharing.
- Collaboration platforms.
- E-learning tools and web portals.
- Library services.
- Mailing-list subscription facilities.
- Science gateways.
- Software permits.
- Streaming video portals.
- Video- and web-conferencing.
- Webshops for a range of academic services.

2.7.3. Cloud and Collaboration Services

In 2016, 70% of NRENs offered various types of cloud services to their consumers, compared to 56% in 2015. Within the commercial sector and R and E, the take-up of cloud services has been slower than anticipated, due to concerns over data protection, privacy, and security. These issues are still being a concern to 62% of respondent NRENs, demonstrating the need to deliver secure and trusted services.

Collaboration services are crucial to ensuring the connection between researchers and educators alike, using services such as videoconferencing and virtual learning environments to bridge the geographical divide.

Cloud storage is the most common service provided by NRENs, with 62% currently delivering or planning to provide cloud storage in the next 12 months. However, Infrastructure as a Service (IaaS) (general-purpose cloud computing services) is or will be, offered by 61% of NRENs, indicating that these two service types are, and continue to be, vital to the Research and Education sector. Software as a Service (SaaS) and Platform as a Service (PaaS) complete the standard service portfolio for the majority of NRENs.

According to the responses from the survey, most NRENs follow a 'build' rather than a "buy" model for commodity services, such as Storage, PaaS and IaaS, with a significant majority of NRENs opting to "build" these services on behalf of their users. Significantly, Software as a Service (SaaS) is principally a package that NRENs purchase. This is likely to be due to the full range of software solutions required, and the lack of skills to support such a variety in a cost-effective manner (Gajin *et al.*, 2015).

According to the GÉANT Association (2014), some of the conventional apparatus that are used to ensure practical cooperation between users in a Community of Practice include:

1. **Collaboration and Support Service**

Online communication and collaboration are crucial to research and education. Peers and the staff of institutions depend on eLearning services and video conferencing to study and share. This is a quickly evolving area, and GÉANT is working to sustain NRENs as they nurture innovation for their societies. Many services were discussed as part of the NREN Compendium survey, including videoconferencing, WebRTC, cloud solutions, unified communications, and e-learning initiatives.

Videoconferencing - It has become clear that NRENs consider videoconferencing services strategically crucial for their business. The penetration of centrally managed videoconferencing services into the community has been stable for years now, with around 60% of NRENs offering such a service to their constituencies. However, there is a significant change in the way users prefer to consume such services. The focus has shifted from traditional MCU-based videoconferencing rooms and room-based systems to dynamically created virtual meeting URLs that can be accessed via popular web browsers directly from desktops or mobile devices. At least 65% of the NREN solutions now provide web-based access (mostly via downloadable browser plug-ins) to their videoconferencing rooms.

WebRTC Technology - With the advent of the standard-based WebRTC (mobile-based and web-based open source applications used for real-time communication) technology, more and more vendors' solutions provide "clientless" access to their conferences, which means that no clients or plug-ins must be installed on the end-user devices to connect to the virtual meeting rooms. There is a significant interest in the NREN community to invest in and deploy such native web real-time communication solutions: 40% of them already have WebRTC support, and another 30% are planning to have this feature in place very soon.

Unified Communications and VoIP - Most of the NRENs still do not find it strategically essential or economically beneficial to invest in the unified communications space. Country-specific and European regulations on the voice market, traditionally dominated by legacy telecommunications providers, are still not changing in favour of the NRENs, despite the strong lobby of Internet giants, such as Google and Microsoft. This leads to the current situation where only 24% of NRENs are active in the VoIP services arena (a decreasing trend compared to 2012). The use of GÉANT's global NRENum.net telephone number mapping service has also plateaued in Europe, with the only driving forces now coming from Latin America and Central Asia. The foreseeable convergence between Unified Communications and WebRTC-based videoconferencing solutions (i.e. the broader Skype for Business movement) is yet to be seen.

2. Multimedia and e-Learning

Three areas of service development have improved the e-learning landscape, which includes:

Virtual Learning Environment (VLE) - The definition of the VLE service type covers the web collaboration tools that allow the webcasting of slide-based presentations with voice, video, chat, and notes features, typically incorporated for many session attendees. Such popular solutions include Adobe Connect and Cisco WebEx. This service type shows significant growth. Penetration of these services grew 12% in the last five years, to 42% in 2016. The average number of 10 000 virtual rooms per month, optionally streamed and recorded – across the community is already significant. Adobe Connect still dominates, but the community is looking for alternative solutions based on the HTML5 and WebRTC standards.

Content Management System - Around 30% of NRENs provide multimedia content management systems. In the 2016 NREN Compendium survey, 10 GÉANT NRENs reported in total 93 000 objects to be stored, which represents 180 TB of data. A large portion of these is aggregated by the GÉANT eduOER service that aims to make Open Education Content searchable and located across the connected repositories.

e-Learning Support - Supporting education is one of the core missions of an NREN. According to the latest 2016 survey, 12 GÉANT NRENs already have a Learning Management System (LMS) platform, and another 5 NRENs are planning to deploy one. As a result, a joint European GÉANT effort is foreseen. The preferred platforms are mostly open-source solutions, such as Moodle and Mahara, which have LTI (Learning Tools Interoperability) standard-based interfaces.

3. Networked Research Resources

e-Science refers to a section in research lifecycles where the integration of ICT facilities is incorporated to improve the theme of innovation, quicker computing, and analytical tools in different spheres of research. When an organization has a myriad of e-Science tools, it is referred to as e-Infrastructures that can be used across various institutions that are within a given NREN network in each region or colleagues from international institutions. Students and peer researchers can access the e-Infrastructures of any institution within the NREN network if they have credentials that are acceptable across different access portals or the Identity Federation and Certification Authorities. Users can use services that are not within their home network. The e14Africa and the Science Gateway Demonstrator for Africa are the best examples of e-Infrastructure networks that are used explicitly by research institutes carrying out projects in the environment sector. In collaboration with the European Grid Infrastructure, the Science Gateways project introduced new programs that their users could use in aiding the research projects on-going in the institutions of research.

The key areas in which NREN networks can help, in the provision of services, include the following:

- Computing power (CPUs) and services.
- Cloud computing and high-performance computing.
- Science gateways.
- Sensor services.
- Software services.
- Storage as a service.

After the introduction of cloud technology, various NRENs have already adopted the technology to avoid the extra costs that are incurred through outsourcing the service provision to an external business entity. While it is possible to enter into agreements with the service providers, the element of creating a free environment for researchers to carry out test-studies is limited if there are regulations provided by the service provider.

4. Support Services

This section lists the essential facilities that are part and parcel of the support services that the NREN networks offer, other than the primary role of networking systems. These are services that are either for profit or do not aid the sharing of resources:

- Training, Dissemination and Project Development Support

A common feature among many NRENs is the provision of separate critical functions that the member organizations can use that does not explicitly involve the use of networked channels. These services are reflected as extra features that are used for guidance or consultation when the users do not know specific elements within the education sector or research projects.

A good example is the provision of training and development programs that the users can use remotely or organize as a seminar for teams to attend at specific places. The benefit of this is that it offers exposure to new members, and the advertising of these services can help identify the communities and regions that will benefit most from their provision.

- Brokerage and Professional Services

The other service is the provision of experts to work in collaboration with the member institutions to promote quality and link up services to other members within the network. The top executives in various NRENs have connections in each member institute that can be expertly used by introducing the members to each other depending on the strengths and weakness of the members. For instance, if one organization is looking to introduce online classes, the NREN can help by acquiring the required licence to carry out this program. Another service provided in this section involves the acquisition of resources and facilities used in communication networks. In the past, NRENs were only required to help in the acquisition of facilities that are used within the network; however, this has expanded to include the purchase of materials that the institutions can use to upgrade the networks within the organizations. The mandate of NRENs also transcends the maintenance of the facilities used within the NREN network.

- Software development

The task of NREN also involves innovation and the creation of new applications or upgrading current frameworks that will help users efficiently take advantage of the features in the NREN. The possibility of protecting the owner of a new piece of software is provided for while open-ended applications are also accepted into the system.

- Massive Open Online Courses (MOOCs)

MOOCs are courses that are offered on the Internet without specific target consumers; instead, these courses encourage any interested parties to register and begin the classes. These classes take advantage of course materials used in the past, such as video tutorials or past conversations between the tutor and the students to provide sufficient learning material to the registered attendants. The nature of access to MOOCs is open-ended while there are categories available for students looking for different options. A good example is the Small Private Online Courses (SPOCs). While NRENs are specifically engaged in the provision of these classes, they offer advice on the best technologies that can be used to create these programs at minimal costs to the member universities and research institutes.

2.8. Actor-Network Theory

The history of ANT is based on the 1980's attempts within the sociological research science departments and the French philosophy studies to simplify the understanding of any scientific element through focusing on the associations related to the given element (Fenwick and Edwards, 2019). This theoretical framework gained prominence in other sociological subjects as it yielded positive results in the test cases (Rydin and Tate, 2016; Lukka and Vinnari, 2017). According to Shim and Shin (2016), the Actor-Network Theory is likened to a social glue that serves the purpose of bringing togetherness in society through various connectors without the need to specify a single factor as the instigator of the collaboration. As such, the ANT provides a connection for linking independent elements in a restructured association with the minimal peculiar movement.

There is a need for straight sets of connections that create a network and are reshaped in a manner that propagates action in the selective elements (Lukka and Vinnari, 2017), such that the users can know the nature of connections between actors in a single network and the nature of connections between actors in different networks. The creation of ANT involves the following four elements; actors that can exist separately or as a group of actors that symbolize a single unit in the network (Isma'ili, Li, He and Shen, 2016). The term actor does not specify the user, as specific sources of instruction for the network to carry out, since actors can include items such as ideas or program software (Latour, 2017).

The next component is the nature of the relationship that is created between the different actors in the system to enable the transfer of resources in the network. According to Del Chiappa and Baggio (2015), some of the links created often involve money transfers, information sharing, communication channels, and linkages between two actors within the system. The next element is the network itself, an embodiment of an entity in the system that offers a mediation platform for the actors (Feldman, Pentland, D'Adderio and Lazaric (2016). Lastly, the need to cause an action depending on the instructions given by the actors or an agency is crucial to ensure efficiency within the ANT.

According to Van der Duim (2017), ANT programs are initiated to evaluate the creation of relationships between different actors, the objectives for creating that relationship, what the responsibilities of the members are, and the interactions between users and other non-human actors to create a stable network. The non-human actors referred to above include computer programs and the natural environment. It is essential to acknowledge how a network of different features can effectively come into realization and learn from the information obtained. According to Zach and Hill (2017), ANT programs are identified by two main features; the nature of the association between the actors and how the actors are restructured to create an active network. Any action that occurs within a network is a combination of various events initiated by the elements that are interpreted in various ways by the independent actors to create a single network for carrying out the specific instruction. This ability to integrate the activities occurring within the network to transform the ideas of the actors is initiated in several different ways. Bankole and Assefa (2017) argue that a relationship between two or more actions is combined by a single mediator in the network that brings together the relevant facilities required to accomplish the specified action. As such, the resultant action is a sum of the instructions issued by the actors and not restricted to the directive from the human components in the system (Khodadadi and O'Donnell, 2017).

Thus, the use of the term collective in an ANT differs subtly to differentiate the concept of togetherness among actors and the execution of a command or an idea using all components (Van der Dium, 2017). This means that the dictionary definition of collective as a group of individuals coming together is replaced by the definition of an action that arises from a collaboration between actors (Dyson, Grant, and Hendriks, 2015). The criteria of definition are based on the relationships that exist between the actors and not the number of participants in the network. According to Van der Dium (2017), the relevance of this definition is based on four essential elements: 1.) creation of a network can be done and repeated many times depending on the requirements of a project, 2.) networks serve the purpose of interlinking two actors depending on the type of action, 3.) ANT assigns the responsibilities in the network on the human actors within the system and 4.) the translator items on ANT play the role of identifying changes that lead to the execution of a project (Khodadadi and O'Donnell, 2017).

The emergence of the ANT was attributed to the attempt at deconstructing the myth that only pure technical and pure social relations can exist. This is entirely false considering the existing associations between independent entities that are either human or non-human (Isma'ili, Li, He and Shen, 2016). A study conducted by Pentland, D'Adderio and Lazaric (2016) concluded that the affirmation of relational effects on the treatment of human and non-human entities is dependent on binary dualisms that are guided by the existence of a social and a natural object or a subject and an object. Examples of such binary relationships include an individual/group and the local/global associations. As such, the concept of ANT is renowned for redefining the scope of traditional structuralism in which humans were considered as the primary source of interpretation in a network. This argument led to the removal of perceiving actors from different levels, instead of promoting a topological view of both human and non-human actors (Permana, Chrisnawati and Hasibuan, 2018). In such a case, no actor is superior to another; in fact, all the elements in the sociological phenomena have to acknowledge the relationship they have with other actors (Rydin and Tate, 2016). ANT applies different principles that define how the configuration of items in any heterogeneous or semantic relationship works, furthermore, different principles guides the choice of its main actors (Belicia and Islam, 2018).

The first principle is referred to as "Agnosticism" as a reference to the unbiased nature of choosing the actors in a network (Alasuutari, 2015). The second principle alludes to the adherence to a generalized symmetry where the application of impartiality in the first principle must guarantee that equal chances are offered for both human and non-human actors (Hockett, 2017. The purpose of the second principle is to ensure that there is sufficient evidence to show why a given course of action is chosen while ignoring other options that are perfectly acceptable within the network. Equality is a virtue that is aimed at protecting the rights of all parties while acknowledging the importance of the different roles played by each actor (Isma'ili, Li, He and Shen, 2016). The third principle relates to the need for an environment where free association is encouraged and that the independent actors are provided with avenues to create theoretical divisions depending on geographical locations, cultural norms, or social characteristics (Hockett, 2017). According to Latour (2017), there are various types of hybrid relationships existing in the modern world in which the actors base the relationships on standard social, technological, or natural features rather than a purely single phenomenon (Hockett, 2017). The free association principle is essential in an ANT to reduce the effects of superiority, complexity and demands by actors to be treated with privilege in comparison to other actors. In such a situation, during the execution of a task, there is no assumption from either human or non-humans about the outcome during a study (Alasuutari, 2015). Actor-networks are made up of independent associations that come together to create a single network (Belicia and Islam, 2018).

According to Born and Barry (2018), the judicious use of ANT as a tool for studying the nature of associations between actors was initiated due to aspirations to comprehend how the theoretical and methodological foundation of networks is possible when the actors are entirely dissimilar in features. The study was further advanced by Iyamu (2015), who was investigating the impact of the different features between humans and non-humans on the successful integration of a network. The researchers concluded the relevance of the type of actor was insignificant compared to the critical role of having a seamless relationship combining the strengths of the actors.

According to Belicia and Islam (2018), the prominence of ANT was based on the ability to restructure different networks into an identifiable pattern that has each actor prominently represented within the network. This study showed how networks could be created, the resources required to maintain given types of networks, and how different networks react in the presence of other networks. Figure 2. 7 gives a visual representation of the requisite mechanics for the creation and maintenance of a network (Belicia and Islam, 2018).

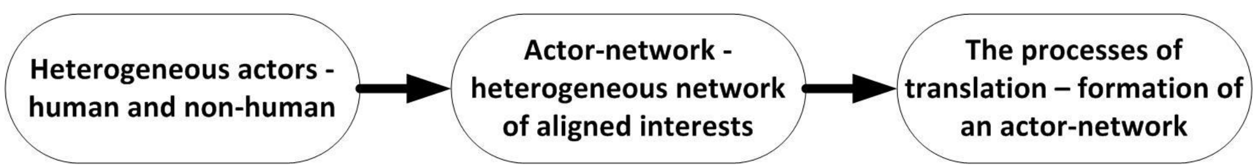


Figure 2. 7: ANT Three-Part sourced from Belicia and Islam (2018).

According to Groening, Sarkis and Zhu (2018), ANT can also be defined as a process that includes the translation of ideas from different actors or the execution of commands in a network to accommodate enrolment. In a similar study, Belicia and Islam (2018) claim that actors end up engaged with systems through the procedure of interpretation. Additionally, the interpretation happens as actors have experienced when endeavouring to achieve the objectives of their networks, as the underlying project or content is changed through association.

According to Van der Duim (2017), the procedure of interpretation alludes to arrangements, illustration and exclusion among actors, elements, and locations. It includes the redefinition of these elements to convince the actors to act as per the prerequisites of the system. These redefinitions are frequently engraved in the crossover actors that help and look after systems. The purpose of curiosity for the current investigation explains how the procedures of interpretation are utilized by actors to accumulate different actors, who are in some cases quite disparate, and to persuade them that they have an average premium that connects and relates them to each other. The interpretation comprises characterizing parts and depicting a circumstance (Van der Duim, 2017). According to van der Duim, Ren and Thór (2013), interpretation refers to various ways of changing over/changing heterogeneous actors such that they are comparable with the end goal that one on-screen character might be supplanted by another or to improve the in the dark confining or making an interpretation of system elements to a single square while maintaining their disparities. In ANT, a human or non-human on-screen character can make its essence felt separately by alternate actors. A performing artist can, from numerous points of view, in any case, additionally be identified as a "black box", the substance of this remark is that users should avoid too much worrying (Isma'ili, Li, He and Shen, 2016).

As indicated by Walton (2013), to accomplish unwavering associations and an objective overview, the members must set an OPP (Obligatory Passage Point) to divert all benefits in a single route. This will make a black box with the goal in which interpretation procedures are executed naturally and are never discussed bit by bit. Hsbollah, Simon and Letch (2016) claim that the OPP is a hub that fills in as a middle person between actors, systems, or system segments. The OPP is robust when it practices control over actors' assets and can guarantee responsibility for the achievement of the network. According to Isma'ili, Li, He and Shen (2016), the procedures of translation can be partitioned into segments, as shown in Figure 2. 8.

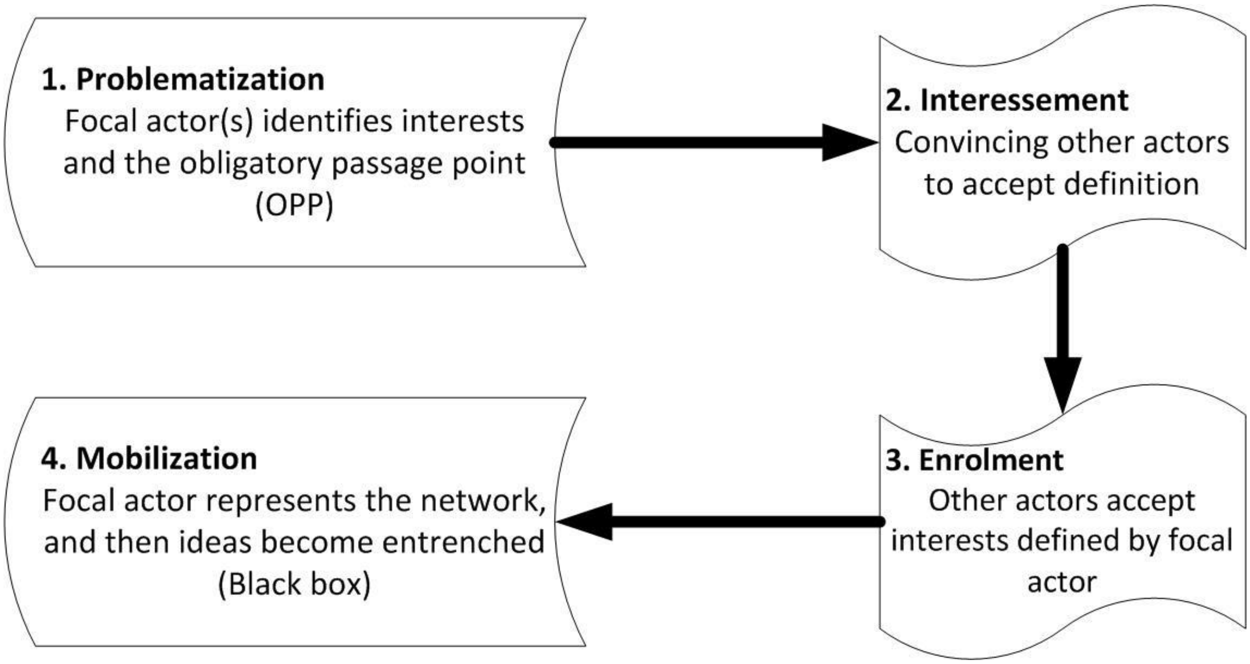


Figure 2. 8: The Translation Phase Process (Isma'ili, Li, He and Shen, 2016)

2.9. Translation Process

Colarič-Jakše (2015) indicated that the procedure of translation comprises a sequence of progressive developments, changes, and redefinitions. These activities are utilized to explain the methods through which power is ascribed and negotiated. It also attempts to dissolve the classic dualism of technical and social, as the characteristics of all enrolled actors are derived from their relative value within an actor-network. Along these lines, translation is viewed as a verb, which implies change and the likelihood of equality between human or non-human actors in a system. Actors that are unequivocally adjusted through the procedure of interpretation each offer an enthusiasm for the responsibilities of their counterparts and the construction of robust collaborations among themselves. According to Iyamu (2015), the procedure of interpretation is useful when a system of adjusted interests is made possible.

Interestingly, delicately adjusted elements require constant supervision of their relationships or else they may fail to coordinate. Issues to do with the arrangement of interests between the actors in a system are called trials by strength (Hsbollah, Simon and Letch, 2016). An example of this includes re-understanding and re-portrayal during the regeneration of effects and role-playing in institutions (Sánchez, 2016). According to Groening, Sarkis and Zhu (2018), the procedure of translation can be separated into four categories, which are depicted in Figure 2. 8 and detailed in the ensuing sections.

2.9.1. Problematization

This refers to the efforts of actors in defining the scope of an issue to evaluating what constitutes a problem and how solutions can be implemented, to remove the problem, within a network. It is also essential to account for the human and non-human actors that are directly linked to the problem so that a solution to the problem will offer direct benefits to these actors (Torres-Delgado and Palomeque, 2014). The composition of an OPP is thus dependent on the ability to define the problem question and the responsibilities of the actors regarding the focal actor. As such, it is always correct to assume that the involvement of different actors in a network is based on divergent interests such as financial transactions or environmental issues (Lindle *et al.*, 2003). All the entities in a network will have trust in the focal actor to define the scope of the problem and the relevance to the other actors in a cooperative manner (Torres-Delgado and Palomeque, 2014).

2.9.2. Interessement

Interessement identifies with the association of different actors in settling the recognized issues (Jeannerat and Crevoisier, 2016). It alludes to the moves and procedures made by the focal/central actor to guarantee different actors acknowledge the suggested answer for the issue, as well as the parts allocated to each member (Torres-Delgado and Palomeque, 2014). In this way, a necessary stage in the production actor-networks shows a competitive edge over other networks. The central actor may need to persuade different actors to show the advantages of joining this system rather than others (Snijders, Blumstein, Stanley, and Franks, 2017). According to Torres-Delgado and Palomeque (2014), along these lines, accomplishing interessement necessitates the central actor to identify all characteristics that will reveal an answer for a recognized issue, and how it might realize other actors. As can be seen, the most vital part is that of the central actor, who persuades collaborations of actors to be intrigued by partaking in the resolution of an issue.

2.9.3. Enrolment

Another element of translation is defined as a sequence of standard transactions, power and trickeries that go with interessement and that help systems of actors to prevail with regards to accomplishing their objectives (Alasuutari, 2015). Enrolment is when actors end up associated with a system and naturally exists if interessement was fruitful (Van der Duim, 2017). And also, selecting themselves, actors likewise show others their definitions and systems, with the goal that they are urging others through enlisting actors. Subsequently, as per Snijders, Blumstein, Stanley, and Franks (2017), central actors will work to coordinate the said actions towards the solidification of different networks of securities. Therefore, central actors can fortify collusions already framed that must have been accomplished via prior arrangements (Snijders, Blumstein, Stanley, and Franks, 2017). Enrolment refers to significant procedures during the translation practice due to the achievement of actor-systems relying upon causes that add to the development of connections inside the network.

2.9.4. Mobilization

As per the Jude, Kajura and Birevu (2014) study, mobilization is the fourth element of translation, and it is the stage amid, which the proposed answers for a specific problem receive an acknowledgement, leading to an arrangement of a much bigger network without actors, shaped through a few actors working as representatives for others. Wollschlaeger, Sauter and Jasperneite (2017) stated that the forerunner would arrange a sequence of apparent connections to carry out the maintenance of the network. Torres-Delgado and Palomeque (2014) claimed that this phase of research may never come to full realisation and could be faulty if realized. As a rule, a change will compel a step back to one of the prior phases of translation. The above clarification gives the impression that ANT is unpredictable and includes a wide range of ideas, including actors, systems, and the components of the procedure of translation.

The following section addresses the pros and cons of ANT.

2.10. Pros and Cons of ANT

2.10.1. Pros of ANT

ANT is a valuable tactic used to assist experts with understanding the multifaceted nature of the real world (for instance the intricacy of business entities), and the dynamic responsibilities of non-human actors in these unique situations. This helps comprehend how human actors' reaction is initiated given collaborations between heterogeneous members in a network. According to Hsbollah, Simon and Letch (2016) and Saunders (2014), ANT gives a focal point through which the responsibilities of natural (non-human) elements can be viewed in the creation of standard practices.

2.10.2. Cons of ANT

Ambrose, Eadson and Pinder (2016) proposed that ANT features are depicted through selective highlighting on contextual research and data gathering, prompting circumstances where experts account for the observed features and that complex component, such as qualities and standards, are not acknowledged. This hypothesis was scrutinized by Doolin and Lowe (2016) for neglecting to offer some methods for separating human and non-human actors. In any case, the reason for rational thoughts on social and environmental elements as symmetrical is to help depict the actor-network and does not insist that all actors must be dealt with similarly, nor that the unique relationship between elements is comparative. Some benefits of building a system depend on the type of relationship amongst members and any controls. Furthermore, since different systems impact each system in an actor-network, the process of clarifying existing complications of the system is made very hard. Torres-Delgado and Palomeque (2014) portrayed ANT as excessively graphic, having hidden contrasts, and tending to create focused, managerial research that defines the scope of the most crucial issues. Rydin and Tate (2016) recognize that it can be hard to characterize organizations within a network while preserving regulatory standards. ANT has additionally been blamed for missing political connections that can help improve the political arena. French (2019) remarked on the absence of familiarity with political motivation in various ANT research projects. Ordinarily, the decision of which actor to take after is assumed to be the responsibility of the expert, who may settle on the wrong choice.

Ambrose, Eadson and Pinder (2016) commented that in books, the ANT wording is puzzling. For instance, the procedures of translation, the human aspect of translation and registration are altogether utilized interchangeably to allude to ANT. The ANT is reproached by Bilodeau and Potvin (2016) for being exceptionally graphic and its failure to achieve point by point recommendations of how actors ought to be seen, and their aggregate activities evaluated and translated. Benjamin and Potts (2018) were critical of the idea that ANT is utilized together with other hypothetical methodologies and translation.

2.11. The ANT Technique

Various approaches have been established to understand human and their manner of interaction with organizational technology. A conventional theory that pays close consideration to the complexity is 'the Socio-Technical System (STS)' that is comprised of a system or organization with the technical component; like its IT structure, and social aspects, and is regarded valuable in specifying the function of the system (Cresswell *et al.,* 2010). However, one of the popular theories that are found on the STS principle is Act-Network Theory (ANT). ANT is an acronym for actor-network theory; a theoretical framework of the social-related theory that assumes the existence of a shifting relationship between the environment and nature. The theory is of the assumption that no other form of relationship exists outside this, while the level of all the actors in the same (Montenegro and Bulgacov, 2014).

Furthermore, the theory believes that observed analysis should be carried out to describe the activities of its actors (Montenegro and Bulgacov, 2014). It gives meaning to a working theory by understanding its active players and the interaction amongst them (Montenegro and Bulgacov, 2014). In ANT theory, an actor denotes the origin of action irrespective of its status, human or non-human. However, an actor cannot function all by itself, it needs the support of other actors, more so, in patterns that permit the actor to act possibly. ANT is, therefore, of the opinion that technology arose from social interests, and it can shape social processes (Cresswell *et al.,* 2010). ANT sees the world as a body of networks that include ideas, things, ideas, and humans. All these networks are usually referred to as actors within the network (Elbanna, 2009). The logical connection amongst all the active players in a network is the primary activity in an ANT system

(Cresswell *et al.*, 2010). The centre act of ANT is to examine and come up with a theory on how network systems began, the existing connection between them, the responsibility of each actor, and how they can perform specific tasks (Cresswell *et al.*, 2010). ANT technique is effective; nevertheless, it believes that if any of the active players is take away from the network, then the function of the entire network would be affected; albeit networks are consistently changing depending on the complexity and fluidity of social reality's evolvement (Elbanna, 2009).

Various studies identified various actors and challenged contributing to the limited research in several higher learning institutions. The literature identified challenges like limited access and skill to ICTs and collaborations at local and international levels. Female academics were hindered by time due to difficulty in balancing their academic and family lives. Limited government financing on projects channelled towards ensuring connectivity among learning institutions was also pointed as a factor contributing to limited research output in Africa (Wright and Parchoma, 2011; Yaver *et al.*, 2016; Paledi and Alexander, 2017; Kashefi *et al.*, 2019). Accordingly, intervention measures and solutions are critical in mitigating factors inhibiting the development and realization of quality research output in African higher learning institutions. The main objective of the solution is to establish a strong NRENs in Africa to ensure quality learning and research output in higher learning institutions (Oludeyi *et al.*, 2015). Additionally, the below sections identify the actors involved at higher education institutions used to assist in improving the quality of education and research output by availing the required ICT technologies and targets to enhance connectivity among higher learning institutions to attract diverse academic talents and propel the growth of universities as research centres.

2.11.1. The ANT and Higher Education

The Actor-Network Theory plays a pivotal role in higher education in various ways. Previous research (Carroll, 2011) has shown the importance of ANT in higher education in a study that explored the potential usefulness of ANT as pertains to the implications of curriculum change in institutions, especially on the matter regarding reasons for the relative improvement in learning outcomes. The study employed participant observation as one of the data collection techniques within the Language Centre in a private university in Japan. The researcher also used field notes and other data sources from online and offline discussions during the study. Under the CALL program, students were given opportunities to repeat classes they had failed the first time while allocating students their classes to prevent administrative, classroom management, and educational problems associated with slotting the learners into existing classes (Carroll, 2011). The author asserted the application of the ANT approach to examine areas of contention through the identification of actants. Human actants entailed teachers, students, and management staff, while physical infrastructure like classrooms were non-human actants. Carroll (2011) established the role of the ANT approach in curriculum change by starting categories from more similar position to identify the most significant categories and roles. ANT has been proposed to possibly be of importance in deciphering what happens in an education's curriculum and the reason for a low outcome in educational quality and other related outcomes such as research output (Carroll, 2018). As regards education, ANT technique views its curriculum with a social spectacle, one that is affected by physical artefacts that forms the educational system (Carroll, 2018).

Furthermore, ANT provides a more understandable way of social processes within the educational curriculum that is complex (Carroll, 2018). The possibility of utilizing ANT in examining and understanding higher education and its connectivity with technology can be traced back to its origin. Its source is from the science and technology field of study and was initially brought up by Bruno Latour, John Law, together with Michael Callon between the later 1970s-1980s (Michael, 2017). It was concerned about the social construction of knowledge and the interaction between scientist and their environments, more so, how the interactions births acceptable and functional ideas. Furthermore, in studying higher education, ANT handles human and non-human factors equally and accepts that they possess a similar influence on the actors within the network (Michael, 2017). ANT births the concept of the physical and social environment around an educational curriculum as a network, the nodes are the participants (this ranges from human, non-human, and other entities) that can impact each other. The network is, however, not simple, instead of messy, and complex (Mpazanje, Sewchurran, and Brown 2013). Furthermore, ANT proffers ideas that lightens the dynamics involved in educational transformations, together with the links amongst several actors (human, non-human), and their performance (Mpazanje, Sewchurran, and Brown 2013). The utilization of ANT is increasing owing to its ability in simplifying and explaining the complex relationship between humans and non-human objects (Cresswell *et al.,* 2010)., and would be a useful tool in understanding how different actors would affect the quality of higher education and research output in any part of the world; specially developed countries.

2.11.2. ANT and NREN Services for Education and Research

NREN is a special form of a service provider for research and education institutions in a country (Aniedu, 2017). NREN stands out for the high range and high speed of the network that it offers for educational activities and research works (Foley, 2016). There are various NREN associated with different countries. Some existing NRENs and their associated countries are listed in Table 2. 1.

Table 2. 1: Different NRENs by Countries in Africa (Foley, 2016).

Short Name	Country
Eb@le	DRC NREN
EthERNet	Ethiopian NREN
iRENALA	Malagasy NREN
KENET	Kenyan NREN
MAREN	Malawian NREN
MoRENet	Mozambican NREN
RENU	Ugandan NREN
RwEdNet	Rwanda NREN
SomaliREN	Somali NREN
SudREN	Sudanese NREN
TENET/SANReN	South African NREN
TERNET	Tanzanian NREN
TUREN	Tunisian NREN
MARWAN	Moroccan NREN
ENREN	Egyptian NREN
ARN	Algerian NREN
NgREN	Nigerian NREN
SnRER	Senegalese NREN
RITER	Côte d'Ivoire NREN
GhREN	Ghanaian NREN

In practice, it helps in building, developing, maintaining, supporting, managing, and operating physical telecommunication platforms or networks that benefit research and education systems (Aniedu, 2017). This platform links education and research together, and to other NRENs globally, including the Internet (Kotecha, 2009). Also, the ANT approach is theoretically useful in appreciating the beauty in the complexity of a system and the active players, together with the technology involved. This would be of assistance in studying the manner of social effect generation owing to the relationship between various actors in the network system (Cresswell *et al.*, 2010).

As regards education and research, NRENs consist of all the constituent that takes care of the academic and research network (Kotecha, 2009). A synergy between NREN system of a region or country, together with ANT technique would help to improve the educational system and research quality of such if the connection is well harnessed.

Furthermore, of uttermost importance is the ability of ANT system to offer an outlook by which the function of technology in transforming social processes (Cresswell *et al.,* 2010), while lauding the importance of utilizing technology in several settings such like health sector and education. Besides, ANT could be of assistance in offering a theoretical framework to data sampling and analysis when considering the synergy between any country's NREN and its impact on the quality of education (including higher education) and research outputs (Cresswell *et al.*, 2010). Increasing the availability of NREN services will enhance coordination of various undertaking towards learning and research (Kashefi *et al.*, 2018) hence, the availability and access to NREN services will aid the interaction of various actants in higher learning institutions, hence benefiting education and research. On the other hand, Mlitwa (2007) applied ANT in analysing the implications of ICT technologies and services in learning and teaching in higher education. The study affirmed the semiotic emphasis placed on human and technical agents by ANT and enabling specificity concerning technology. ANT presents a network as a sum of numerous interactions of the existing actants due to the significance of various actors like teachers, students, and ICT technologies and services in the network.

2.11.3. ANT and Electronic Devices for Education and Research

In the education system, the utilization of electronic devices has conflicting views. Some instructors/teachers strongly support the use of these devices, while some believe it brings confusion to the classroom (Santos, 2017). On disallowing the use of electronic devices in the academic environment, arguments are that it has the possibility of hindering active learning during class time. Policies, therefore, vary by region in educational institutes on whether to permit the use of electronic devices like eBooks, tablets, mobile phones, and laptops during teaching hours (Santos, 2017). Although most universities are striving to survive the pressures that globalization brings, and some have been trying to get into the flow, permitting the use of electronic devices in teaching and research (Mlitwa, 2007). ANT assists in connecting human and non-human factors in achieving a common goal. Electronic devices could, therefore, be an active player in education systems, while it can also be part of the network of research activity. The effective utilization of electronic devices for research and education would, therefore, assist in improving the educational and research quality of such areas. Wright and Parchoma (2011) asserted that studies concerning mobile learning are concentrated and compulsory at school or undergraduate level hence posing significant issues on its applicability in academic inquiry, postgraduate studies, and professional practices. The research recognized the growing application of mobile devices by students to access online courses. Mobile learning is occurring in practice, absent institutional control (Wright and Parchoma, 2011). The authors acknowledged the growing ubiquity and sophistication of mobile devices and their application in education as a "new paradigm."

Paledi and Alexander (2017) explored the readiness of m-learning in universities using ANT by drawing from a South African University. The authors used a qualitative approach and applied random selection in identifying participants. Semi-structured interviews and open-ended questionnaires were also used in the study. The application of ANT in understanding the readiness of the university to m-learning identified key actors for the utilization of m-learning. Besides, Oludeyi, Adekalu and Shittu (2015) established that the application of the electronic device in learning encourages better lecturer performance and enhance the quality of education. Laptops can further aid researchers (Kashefi *et al.*, 2018) to access the necessary information for their journals through various platforms like google and google scholar. NRENs will increase the productivity and quality of education and research in Africa universities and colleges through the availability of electronic devices to support learning and research (Oludeyi, Adekalu and Shittu, 2015). With devices like laptops, researchers can concentrate on research (Delaney, 2018).

2.11.4. ANT and Institutional Network for Education and Research

Networks are platforms for social connections, a niche for togetherness and a linking bridge. Humans can communicate properly using a network, while non-humans form the critical links between the human actors. A network gives room for organizations that utilize available resources in meeting a specific goal; while solving problems along the path to such goal actualization

(Valencia & Cázares, 2016). Most of the times, the network of an institution works together with the information and communications technology (ICT) infrastructure in the premises of the institutions. The ICT in easing the conveying of information is increasing (Cresswell *et al.,* 2010), especially in education (higher education) and their research work. There is a need for a theoretical and up-to-date evaluation of new technologies in optimizing their effectiveness when deployed for various functions (Cresswell *et al.,* 2010) in educational and research fields. The deployment of technology in enhancing the performance of various field is of the rationale that the use of technology would enhance quality (Cresswell *et al.,* 2010). Creating research platforms for universities has been affirmed to improve access to institutional networks hence reinforcing the quality of education through the introduction of new teaching aspects (Kashefi *et al*., 2018).

Thapa (2011) investigated how ICT actors and networks are affecting the interest of the community in academia using the institutional wireless network project in Nepal as a case study. The author asserted the significance of understanding various actors and their interactions. The study used an interpretive approach to understanding the research problem and proceeded to review the literature and built a conceptual framework. The author also employed interview in Nangi schools and Tkot villages as well as the internet in gathering information. Data comparison was further applied in analysing the information with reliability and validity of the data being assessed by colleagues and other researchers. Thapa (2011) identified various heterogeneous ICT actors in the study. The study established that before the implementation of the institutional network project, several challenges like infrastructure, limited finances, human skill, and political instability hindered the initiation of the project. Thapa (2011) affirmed that the availability of heterogeneous actants, that is, human and non-human actors are crucial in the actor-network theory. This propels the aligned interests of various actors in the network, such as people, organizations, and standards. The research established the enrolment process as another ICT actor that is significant in defining and coordinating the roles of different actors via physical actions and negotiations. The observations and findings of the study led Thapa (2011) to conclude the importance of ICT actors in terms of actions and roles in forming and extending the institutional network projects.

Yaver *et al.* (2016) investigated the NRENs to establish future trends concerning institutional network and their implications in education and research at institutions of higher educations. The study identified three stages: pre-foresight, foresight, and post-foresight. The research established government financing as one of the crucial actors in realizing future trends of NRENs. The research added that the number of connected institutions is vital by asserting that universities are the largest connected institutions to research. The authors affirmed that economies like Colombia and Brazil made precedent concerning the connectivity of institutions in Latin America. Accordingly, the study identified various actors that are influential in mounting research. This reinforces the significance of ANT in terms of identifying actants. Various actants like government financing, the intuitional network and connection between the institutions establish the importance of ANT in identifying the actors for higher education institutions.

2.11.5. ANT and High-performance Computing for Research

High-performance computing deals with the act of gathering computing resources in a manner that offers a higher level of performance compared to the conventional performance gotten from a desktop or personal computer. The main reason for the desired increase in computing performance is to fasten processes and solve huge problems in the field of business, education, science, and engineering research (Houzeaux *et al.,* 2018). The combination of ANT and high computing would fasten the rate at which research is being carried out and subsequently improve the quality of research works. The focus of ANT is basically on non-human actors and their effects on human processes (Cresswell *et al.,* 2010). The synergy between different actors, therefore, gives each the possibility to perform; as different activities are carried out by various actors at different location and time (Cresswell *et al.,* 2010). One of the critical responsibilities of researchers utilizing ANT is to be sure of the functionalities of hidden and obvious actors. Although the networks are apparent when things are going well, however, there should be a form of consistent check on the components of a network at scheduled intervals (Cresswell *et al.,* 2010). The capitalization of high-performance computing (HPC) will support education and research (Delaney, 2018) by availing clear pathways to resolve common aspects, empowering researchers to concentrate on research and increase collaborations to various levels within the learning and research environment. The availability of the HPC platforms to support the research activities is also central in solving the current challenges affecting African universities in terms of improving the education and research environment and foster productive interactions between various actants in higher learning institutions. (Andreoli *et al.,* 2017).

2.11.6. ANT and Remote Computing Facilities for Research

Remote computing refers to making a computer, processing, and storage facilities available via the use of communication systems (Van and Tanenbaum, 2016). The synergy between the human and non-human actors involved in the remote computing facility within a higher education system would support high-quality research output, which would also have a resonating effect on education quality. Data sampling and analysis involves gathering of information, offering theoretically related tools and interpretations to analysed data, shortage of computing infrastructure in the premises of the institutions and limited funding to research requires such infrastructure identified as challenges impeding researcher to do research. Accordingly, those various actants that are affecting researcher hence establishing the significance of the actors in remote computing facilities for research. (Cresswell *et al.,* 2010). A remote computing environment with its all actors involved in the system would, therefore, foster data acquisition for research studies and support the researcher to use the computing infrastructure remotely available to do more research which requires such capacity.

2.12. ANT and its Implications for ICT Research

Today, Information and Communication Technology (ICT) has been attributed as a significant cause of change in society. This perception has created many controversies in society due to different beliefs held by individuals. As a result, there is friction between those who support the deterministic view and the social constructivism perception of ANT regarding technology. The social constructivism view has often undermined the existence of technology; thus, it is criticized for being socially deterministic. ANT is helpful to scientists in examining the concepts that are ICT related, and this further enhances a better understanding of the relationship between society and technology. In general, ANT has provided an account of both the social and the technical view appropriately. Additionally, ANT avoids compromising any facts from either the social or technical view in favour of one or the other, thus providing a positive perception of both in the society (Paledi and Alexander, 2017).

ANT provides a theoretical background, which serves as a transitional bridge that acts as another option in analysing the relevance of technology in society. The theory does not criticize the social constructivism view but supports it fully. Also, ANT supports the role played by technology, and thus, there is a possibility of providing a solution in the field of ICT regarding research. The theory regarding ICT research aims to uphold the integrity of the technology and reduce the myriad of problems associated with it (Paledi and Alexander, 2017). Additionally, ANT provides a room for the examination of various materials that are related to ICT networks (Bueger and Stockbruegger, 2017). This form of scrutiny facilitates democracy because it provides the right of representation to many things. "Nothing is complicated with ANT in place" (ibid). The commitment brought about by the presence of mixed materials regarding network relationships provides a more effective and efficient analytical tool. This is beneficial to ICT research because it enhances the investigation of a variety of human and non-human actors.

The ICT phenomenon is affected by different actors that are connected in various ways, and this explains why a holistic approach to the study is necessary and of vital importance. ANT treats the different actors equally regardless of their size. Additionally, it provides a broad scope of the examination and this account for the various actors and their relationship with one another. This enhances the smooth movement of analytics of entities, for example, from global to local and vice versa (Thapa, 2011). Thus, ANT applies to ICT studies where the level of analysis varies widely depending on different aspects. The connection between innovative technology and society has been deliberated in the history of the human science field and as of late in the ICT field. Two fundamental points of view have controlled the perspective of the association between society and innovation: technology determinism and social constructivism (Russo, 2018). Notwithstanding, the conversation regarding methodologies is not new in ICT. From the subsequent discussion present below, ANT has hypothetically been used to resolve the tension between innovation determinism and social constructivism and incorporate various methodologies that can help with social constructivism.

2.12.1. Technology Determinism Perspective

Technology determinism is a perception by humans that concur with the concept that claims technology is the significant component determining the nature of the society. This model argues that technology directs society along a specified path, which is programmed in a certain way. In line with this approach, technology introduces certain social and political features in society, and this contributes towards a cohesive social relationship among the society members. The technology determinism perspective uses the society as the central point of reference in all its arguments regarding social and political concepts (Chen, 2018).

There is a slight difference in this model when analysing the perception of the two subsets of determinism, namely soft and hard determinism. Hard determinism views technology as an essential tool that does not rely on other elements in influencing the values of society. This approach views society as a medium of social relations between different actors. Russo (2018) argues that new technologies are designed to effectively change the society positively by introducing new ideas that emanate from an undescribed place, making it seem like magic (Russo, 2018). On the other hand, soft determinism views technology as a force that only influences the relationships in the society to a certain extent, meaning that technology is limited due to various factors, but these dependencies are on a case by case basis. For instance, Chen (2018) wrote a detailed article entitled "Imagination machines, Dartmouth-based Turing tests, and a potted history of responses" that jogging the memory of the readers to ponder whether machines would be remembered in many decades later and whether or not they are necessary for improving the social standards of the society. His argument was that technology plays a vital role in enhancing the social relations of society, but this does not mean that machines will make history. However, he affirmed that his views are open to either positive or negative criticism (Chen, 2018). Besides, he claimed that machines would take part in enhancing social relationships in society even if they will be only partly improved, and this should be critically analysed in any future studies. Chen perceived technology as an intermediary in the society that will be found to have been limited in its contribution to any significant difference when history is written down in decades to come. Chen also wrote another article where he argues that history could not be determined using technological input in society (Chen, 2018). He then claims that soft determinism is relevant in determining political, economic, social, and cultural factors in society. Many scientists have often preferred the soft technological determinism to the hard determinism view (Dafoe, 2015). These researchers argue that soft determinism is not fully independent and that it relies on other societal forces. However, these researchers seem to put much effort into showing the significance of societal forces regarding technological advancements. Noteworthy is that these scientists are keen to strike a balance in their analysis, and they are careful not to lose the intended technological focus in their studies. Soft determinism is mainly concerned with political, economic, social, and cultural factors that shape its societal force. Also, the soft deterministic approach views the technology as a driving force in facilitating power in the society, thus proving its efficiency in setting the path of the course of actions in the society (Chen, 2018).

These and other arguments have motivated some scholars to put more efforts into seeking for a fairground, by including the social factor as one of the significant forces that influences technology in the society. For example, White and White argues that it is unfair when researchers only concentrate on one side of an issue that has significance in society, such as technology (White and White, 2016). Researchers who deal with studies related to the macro entity are inclined towards technological determinism, while those who are more concerned with the micro-unit focus mainly on how societal powers to influence technology. White and White argues that the only way to strike a balance in future studies and to avoid biasedness is to adopt a more advanced procedure that analyses how technology shapes the society (ibid).

Dotson (2015) has also argued on the grounds of technological advancement based on its perception locally and internationally. Dotson disagrees with the comprehensive view of technology and argues that technology should be discussed locally because this would deem the debate more logical. However, this calls for a precise specification of the social forces that could enhance technological development.

On a similar note, Jones (2018) claim that there is an interconnection between social, technological, political, economic, and cultural concepts within the society. Jones argues that no single element can bring the desired change in society individually, meaning that interrelationships are the ultimate solution (Jones, 2018).

Based on a study conducted by Bridge *et al.* (2018) entitled ‘technological momentum, a boundary that separates technological determinism and social constructivism in the society is provided. Bridge *et al.* argued that technological systems in their earlier stages of development tend to be more open to socio-cultural influences as compared to the older mature systems since they are more independent of influences and deterministic. They further contended that technological momentum is a valuable interpretative concept as compared to either technology determinism or social constructivism because it is time-dependent, yet sensitive to the ‘messy’ complexities of society and culture(ibid) (Bridge *et al.,* 2018). Unlike other views, technological momentum is time-dependent, and equally appreciates the existence of both technological and societal powers.

2.12.2. Social Constructivism Perspective

In the modern world, various elements of our social lives influence the use of technology and the perception of these activities as either beneficial or destructive. According to Yousefikhah (2017) and Mauthner and Kazimierczak (2018), the difference between Social Construction of Technology (SCOT) of today and the traditional perceptions of technology vary as the society become more transparent on how they want to use certain technologies while avoiding other areas that are considered destructive. While this presents a limited implementation of the immense potential of technological innovations, it alludes to the role played by human beings and society in the implementation of technological reforms. The different types of approaches discussed in this section involve SCOT, ANT, Systems Approach, and the Social Shaping of Technology.

2.12.2.1. The Social Construction of Technology (SCOT)

SCOT is grounded on the Social Constructivist Model (SCM) that was initially developed to mitigate the myriad of problems from the technology determinism perspective (Russo, 2018). The significant role of this approach is in explaining the necessity for a social element in working together with the technological factors to bring forth socio-technical relationships in society. Many controversies that have arisen from this model have been explored in many literature studies. The tendency to perceive the social element as the sole driving force has been attributed to technological advancement. These studies have suggested that the social constructivism view has strictly been the source of technology.

SCOT plays the role of explaining how different designs of technology came into existence after examining different social factors such as organizations, among others. Three principles are associated with this approach, namely, “relevant social groups”, “interpretive flexibility”, and “closure and stabilization” (Yousefikhah, 2017). The principle of “relevant social groups” addresses how different elements (government, individuals) in society share a common goal in understanding the meaning of various objects in society. The second principle of “interpretive flexibility” shows how different groups in society perceive the flexibility aspect of technology in their way. The “closure and stabilization” principle shows how various technological interpretations become more potent than others and how they eventually develop. This principle signifies the end of controversy relating to interpretations, and it marks the conclusion of an issue about technology.

Even though SCOT is against the view of technology determinism, it shares a common idea with the others whereby it concurs with conception, invention, development, and design of technology (Russo, 2018). SCOT does not, in any way, intend to examine how technology came into existence and why people still use it (Russo, 2018). Some researchers have argued that SCOT has undermined the existence of technology since it only supports social factors alone that can influence technology development (Schmidt and Cohen, 2013). As a result, these scientists have criticized this approach, condemning it for being overly concerned with its social determinism. This approach has one assumption that says, “the moment a researcher has done his work effectively in trying to explain the root of social factors, automatically he will have given a clear insight and significant elaboration of technological development,” (Green, 2019). Sage *et al.* argue that this assumption contributes to biasness because it limits actors from different entities to people (Sage, Vitry and Dainty, 2019). What is noteworthy is that SCOT is also criticised for putting more emphasis on the local concept of technology and less emphasis on its global context. The approach also neglects to focus on the broader context of social factors that influence technology (Levy, 2019).

Researchers have also disagreed with the principle of “closure and stabilization” for various reasons. This principle undermines the marketability of technology because it implies that whenever technology is introduced in the society, this signifies the end of its social shaping. The approach also undermines the use of technology after it has been introduced and by whom (Thoutenhoofd, 2018). For instance, this model is not concerned with the historical elements of technology, such as hardware and software. A model needs to address the origin of such elements and address their developments, but SCOT does not consider such facts. These are some of the hindrances to stabilization of technologies caused by failure to account for social factors influencing technology (Russo, 2018).

Despite considerable criticisms of the SCOT approach, some remedies can make it more reliable; however, this can only happen when appropriate suggestions are incorporated. Cotton has offered some assistance to SCOT by giving practical suggestions (Cotton, 2014). These were aimed at helping the SCOT approach to relate with ANT model since the latter has a more holistic view than the former. Cotton argued that SCOT should adopt the strategy of ANT, such as addressing all the key players equally. For instance, ANT entails a socio-technical concept, and it also describes the boundary between the actors of different entities. Unlike SCOT, ANT provides a platform for negotiations that supports researchers' belief in an argument even though it can be deemed as misleading. ANT has given researchers a choice; they can either support the social, the technical, or both. This is important because it allows for comprehensive research that does not undermine the views of one party or actor. Another suggestion by Lewis and Westlund is to blend SCOT's old concept with the "technological frame," was developed by Lewis and Westlund (2015). This suggestion is to provide SCOT approach with a technological advancement that allows for the existence of actors of a mixed nature through continuous interactions among different actors (Lewis and Westlund, 2015). This suggestion is related to the system concept introduced by Bridge *et al.* (2018) and the translation concept that is explained throughout the ANT approach (Tatnall, 2014). Cotton (2014) is in support of the ANT's characteristics, such as the separation of the two main elements, namely, social, and technical. ANT argues that all the network relationships are both social and technical and that despite the differences they work together with a common goal (Cotton, 2014). Cotton further supported the idea of ANT that claims that society is not determined by technology and vice-versa. However, the two elements bring about the concept of socio-technical, which is widely discussed in the ANT approach. Additionally, Cotton agrees with the balanced view of the ANT approach that entails both human and non-human actors.

2.12.2.2. The Social Shaping of Technology

The Social Shaping of Technology (SST) is an approach that is based on the seminal work of Mauthner and Kazimierczak (2018) that focuses on the social determinist perspective. The social determinist perspective entails a description of how social factors regarding technological development shape society. Social relations in the society determine how technology continues to develop. The authors criticized Mauthner and Kazimierczak's work for failing to recognize the real impact of social relations on technology. The authors made suggestions to this approach that would connect to the ANT approach. They argued that it is wrong for anyone to assume that society and technology do not connect (Mauthner and Kazimierczak, 2018). This argument, in line with the views contained in the ANT approach, affirmed that the two authors wanted an extension to be included in the SST approach. In the second edition of the book, the authors included an extension of arguments by Langlitz and Strum (2017) that entailed the concept of interrelationships between society and technology.

2.12.2.3. The Political Approach

Green found a gap in the social constructivism view, and this gave him a compelling urge to fill it, thus the conception and adoption of the political approach (Green, 2019). This approach argues that within the society, there exist technical artefacts that bring about the concept of political force regarding technological development. This approach has two main perspectives that differentiate it from the other models. One of the perspectives is that technology emanates from hidden thoughts in a human's brain and the other one is that technology is an idea that emanates from distinctive political relationships in society.

The political approach to technology is classified among other models that incorporate the social constructivism view. This is because this approach entails a political context, which is classified as being under social occurrences in society (Russo, 2018). According to this approach, political determinism plays a role in enhancing the relationship between technology and political relationships. If a technology has a specific political view, this perspective will continue in the minds of people, and this will result in a similar conception of the idea that will be identifiable in social life. There has been a criticism of the political approach by some researchers who claim that it has undermined the importance of social factors in influencing the political relationships that impact technology. Political relationships face the challenge of being vulnerable to societal forces that subject them to misinterpretation (McQuade, 2016). A scientist may have good intentions in coming up with technology, but this may be compromised by modern interpretations, which change the cause of the desired technological development. The inclusion of social factors in the determination of political relationships that occur during the provision of technology may hinder the implementation of the effective political contents that are related to technology. According to McQuade (2016), there is an interconnection between political and technological factors.

2.12.2.4. The Systems Approach

According to Bridge *et al.* (2018), the contextual perspectives of technology and society leave a gap that needs to be filled in studies regarding technology. This approach bridges the gap by incorporating perceptions that allow an interactive relationship. Bridge *et al. (2018)* point out that the people who have built technological systems or networks have undermined the aspect that includes the existence of different academic ideas regarding technology (Bridge *et al.*, 2018). He gave an example of a scientist called Thomas Edison, who succeeded in technological advancement. Thomas Edison combined different scientific concepts that ended up making sense regarding technology since there was an interactive relationship among them (Bridge *et al.*, 2018).

Bridge *et al. (2018)* argued that the system builders must recognize the relationship that occurs between different elements such as technical and social and combine them to form an all-in-one web. This is the primary goal of the systems approach because it respects the existence of different professional knowledge. This approach suggests that technological systems must come together by interconnecting with one another to have a common goal of forming an all-in-one web (ibid).

In the ANT approach, there is a concept of the network, which is like that of the seamless web in the systems approach. Also, the concept of a network builder contained in the ANT approach is related to that of system builder in the systems approach. Bridge further supports the arguments of two other researchers who have contributed to ANT's approach views such as the concept of the network (Alasuutari, 2015; Tatnall, 2014; Bridge *et al.*, 2018). Bridge *et al.* has conducted intensive research regarding technological systems and has made his contribution to American society, such that his model is worth adopting (Bridge *et al.*, 2018).

2.12.3. Analytical Inclusion

The discussion in this section gives an insight on how the ANT has incorporated inclusivity in the analysis of its different actors.

2.12.3.1. Including Non-Humans

ANT has a different stance on the perception of society by arguing that society is constructed not only socially but also in other different mechanisms (Latour, 2017). The theory argues that society is made up of a formation of a variety of networks joined. These networks comprise both human and non-humans, and their amalgamation is what is referred to as 'social'. This suggests that the 'social' can't exist without the incorporation of the two aspects since in an ordinary world; the interaction of human beings is made holistic by the inclusion of the non-human counterparts. This integration of the human and non-human aspects brings forth the socio-technical element in society (Latour, 2017).

Contrary to what one would expect, the theory (for criticism see: Isaksson, 2018) leaves doubts in that; it ascertains that the co-existence of human and non-human actors is made secure by the latter rather than the former. The prime task of the latter is to pull together the forces that make a society (Latour, 2017). The theory describes the non-human objects as the core joining elements that enhance the durability of all social relations in the society. For instance, a community of orang-utans in a jungle may only be social if these species rebuild their social interactions amongst themselves (Langlitz and Strum, 2017). The reason behind this argument is that these non-human actors are limited to a few resources necessary for time-space distinction, and hence, nothing lives on this earth forever. However, human society varies from the non-human society because of the privilege of having integration of the social and technical relationship. According to Chin-Ee Ong (2014), human beings are talented at interacting with a variety of scientists who enhance the more advanced network of associated mixed units in society.

Sánchez (2016) implies that such advanced network entities are made up of several components, namely, humans, non-human agents, machinery, among many others (Jackson, 2015). Considering this, ANT gives researchers room for carefully selecting any other actors in the society that might be appropriated for inclusion among the different observed occurrences. This allows scientists to incorporate variables of choice in the study and manipulate them to provide the readers with relevant results and findings. ANT allows researchers to use texts, machinery, non-human agents, and people either distinctively or in amalgamation, but the latter is the most preferred method (Jackson, 2015).

2.12.3.2. Including Actors with a Different Scale and Level of Analysis

ANT has a different perception of traditional sociological contradictions about relationships of different occurrences in society. For instance, ANT views macro and micro-entities by striking a balance between the two concepts. The theory views the socio-technical society misleading by lacking a flexible measure as it claims that the observer is not liable for such an occurrence (Latour, 2017). ANT does not find any significant difference in the way both global and local entities are structured, and this applies to other units such as the macro and micro among many others of the same kind. Latour argues that society must respect such variations in the measures, in the same manner, that it would apply to other displacements of variables (ibid). Considering this, it would be logical to affirm that ANT provides researchers with a wide variety of experimental procedures. ANT does not force anything on its actors but scrutinizes them instead to identify the behaviours of the different entities involved.

ANT does not impose the meaning or perception of heterogeneous entities such as the micro and microstructures. This theory leaves room for discussion on what relates to macro and micro or what one would refer to as the outside or inside the world. The theory leaves the obligation for the decision to the different actors associated with the units with which they are involved. In most cases, a boundary is expected to be set up by the actors and is defined based on different aspects such as laws and organizational restrictions, among others. However, the determination of the boundary depends on a case by case scenario (Jackson, 2015). Once there is an agreement by the agents on the set boundary, the relationship of the networks involved can be outlined.

Both human and non-human actors distinguish themselves based on the interactions and relationships that exist amongst them in society (Alasuutari, 2015). Following a description of what falls under the local or inside category, the actors create a mood and space for debate (Jackson, 2015; Tatnall, 2014). The space for debate allows serious discussion between the different actors, and it is associated with two significant features. One of the features is that it is secluded and that it is only accessible to those who are within its boundaries. The other feature is that this is a place that allows the exchange of healthy ideas that may control the outside world without their consent. Hence, it is possible to manipulate the outside world for the selfish gains of the inside world (Jackson, 2015). The space for debate provides an opportunity for independence whereby the human and non-human actors of a macro network create a micro-network. This strategy of negotiation between the different entities, such as the inside and the outside world, allows actors to implement secure networks. One of the examples of more reliable networks involves the socio-technical objects found in society. Tatnall (2014) argue that faults can occur with events that are caused by the existence of the space for agreement or negotiation in society. Besides, the debate space allows the creation of a substantial amount of socio-technical amalgamation because of increased network relationships (Tatnall, 2014).

ANT allows the protection of the existence of local entities/actors due to the endless negotiations that take place on the middle wall that separates the inside and the outside. For instance, according to Latour (2017), the local is comprised of the science room, researchers, machinery, and the incidents occurring by nature. Latour further explained the global as the parties outside the lab, such as organizations facilitating the research, among others. The outside negotiations and the under debate are the cause of the network relationships and perceptions between the global and local interests that constitute the formation of a distinct boundary (Latour, 2017).

2.13. SWOT Analysis

Four main components associated with SWOT analysis include the Strength, Weakness, Opportunity, and Threat, which are, used to inform the decision roles in an institution. These components could aid an institution to develop efficient strategies that can improve the position of a firm. Based on a systematic review of these components, it was noted that System approach has heavily been relied upon to influence the actions of entities, which interact with its surrounding environments. This interaction ultimately results in the reconstruction of two environments, namely the external and internal environment. From strategic management practices, the examination of these environments forms a basis upon which swot components can be understood (Gürel and Tat, 2017). On the contrary, Thompson, Strickland, and Gamble (2015) perceived SWOT analysis as a modest but influential approach for measuring the firm's resources, inefficiencies, its market prospects, and pressure exerted to achieve the goals in future.

The strength of the organisation is associated with the value that is added, putting more emphasis on an entity as compared to others. Additionally, strength refers to the extent to which an entity is considered to be valuable The organization's strengths and weaknesses are determined by five criteria, which include the relative situation in the market, similar financial structure, comparative technical and production capabilities, the relative potential in development and research, relative effective management and human capabilities (Gürel and Tat, 2017). Strength is considered a condition that allows the firm to improve its performance and stay abreast with its competitors. Within this context, strength could be depicted as a reserve or an improvement that allows an organization to meet its demands with minimal obstructions (Thompson, Strickland, and Gamble, 2015). It is a unique competency that offers an organization a relative advantage over other organizations in the market. According to Ogot (2014), the strength of a firm is significant to financial resources when leadership in the market, image, and relationship with buyers, among others are performing well, and strength has a high probability. This implies that organizational strengths represent the firm's capabilities that permit it to achieve its objectives holistically. Therefore, it is essential for firms to realize their potential and know the aspects, which can optimize its benefits over its competitors. The organization is solely responsible in responding to the challenges facing it, and it can only accomplish this by exploiting its strengths, standing a better chance to improve its performance (Gürel and Tat, 2017).

Organizational Weakness, on the other hand, is associated with unfavourable features that should be avoided by the organization. To some extent, weakness can be described as what an organization lacks or regards as being below average. Thompson, Strickland, and Gamble (2015) hold the view “a weakness is a drawback or insufficiency in skills, resource that extremely obstructs an organization’s operative performance”. Ogot also provided clear examples of weaknesses such as poor amenities, monetary assets, organizational abilities, marketing expertise, and brand appearance, which are significant sources of weaknesses (Ogot, 2014).

Environmental Opportunity refers to a condition that is favourable to an organization, and it should be a situation of high interest. Whenever an organization utilizes an opportunity well, it stands a better chance of having more zeal and determination towards meeting its objectives. Therefore, an opportunity gives an organization a chance to excel and stay ahead of others in the competition. For organizational management, an opportunity is defined as a unique and advantageous situation that is presented to the organization by its environment. An opportunity helps the company in improving its performance more than ever before and this, in turn, leads to enlarged profits, the provision of better services and goods, and excellent customer care, among others. When an organization is challenged in the marketplace due to a high level of competition, this makes it have the impetus to look for opportunities that would help it to retain its position or even beat its competitors. In general, opportunities are conditions that exist in an organization’s external environment that encourage it to exploit its strengths, restrict its weaknesses and reduce the threats from the environment (Von Kodolitsch *et al.*, 2015).

Environmental Threat, on the other hand, puts the progress of an organization or an on-going activity at risk. It refers to situations that subject activity to an unpleasant occurrence either now or in the future. An environmental threat is associated with undesirable features that should be avoided at all cost. For structural management, a threat may be described as anything that hinders the organization from meeting its financial goals, among other objectives. Threats are conditions that are observed in an environment when changes occur or are predicted to occur in future, thus restricting the organization from meeting its goals or staying ahead of the competition in the market. When an organization is prevented from competing favourably with the others in the market, this jeopardizes its profitability and stability, thus subjecting its failure (Gürel and Tat, 2017). Threats also contribute to obstruction to the smooth progress and success of the organization, thus causing it to incur substantial losses from which it may take a long time to recover, or it may never recover. External opportunities and external threats may be described as economic, social, cultural, and political trends, among many others that in one way or another contribute to either the success of the company or its failure. It is difficult for any organization to control both opportunities and threats. The difficulty that an organization must control some of these activities brings about the concept of external strengths and weaknesses.

On the other hand, an organization may effectively control some of the activities, and this brings about the concept of internal strengths and weaknesses. The internal strengths and weaknesses occur in different departments of a business such as in the management, accounting, and production, among others. In strategic management, one of the critical things is the identification and evaluation of internal and external strengths and weaknesses of an organization. It is essential for an organization to strive for maximizing the internal strengths and at the same time, minimize the internal weaknesses (David, Poole, Alan, and Mackworth, 2017). "Understanding one's organization entails an evaluation of strengths, weaknesses, opportunities and threats. Also, it is necessary to conclude how an organization can adopt effective methods to exploit its strengths, as well as maximizing on the opportunities in the environment" (Thompson, Strickland, and Gamble, 2015).

SWOT-analysis helps in understanding how new strategies can be adopted to enhance improvement in an organization (Gürel and Tat, 2017). Both internal and external factors influence the system's performance and prospects. To overcome problems affecting the organization, the management must increase strengths, reduce weaknesses, take advantage of the available opportunities, and tackle the emerging and existing threats (Gürel and Tat, 2017).

An organization focused on maintaining its success should always adopt strategies that can result in improved profits and overall better performance (Brinkschröder, 2014). This is only possible if there are appropriate identification of factors influencing the growth of an organization and the implementation of better strategies to improve its performance (Kudriavtceva, 2019). These two factors are categorized into two broad categories, namely, internal and external factors. SWOT-analysis helps in the examination and evaluation of these factors (Delaney and D'Agostino, 2015). Therefore, SWOT analysis is an instrument that is used by organizations in the cause of assessing its progress by considering their internal and external factors (Kudriavtceva, 2019). The definition is simplified and shown in a matrix depicted in Figure 2.9.

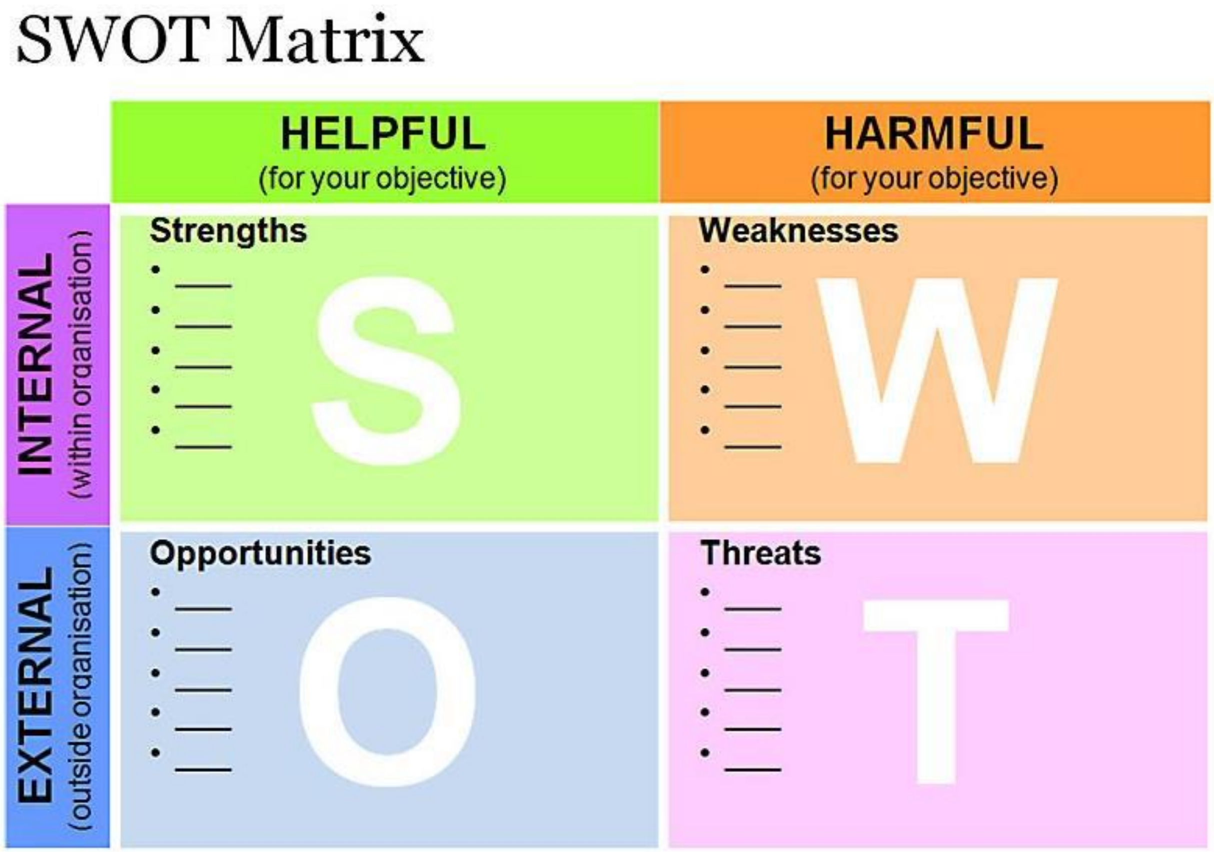


Figure 2. 9: SWOT Analysis Matrix Diagram (Humphrey, 2005)

The strengths and weaknesses are factors that can be controlled by an organization; thus, it is possible to influence these internal factors. On the other hand, it is impossible to control the external factors (opportunities and threats), which are executed by the organization's environment. However, Ishijima *et al.* (2015) argue that external factors can be controlled up to a certain level depending on the factors, which vary in one organization to another. As shown in the SWOT analysis matrix in Figure 2. 9, it is apparent that every organization that is focused on achieving success should concentrate on the strengths and opportunities. Regardless, it is prudent for an organization to minimize its threats and weaknesses because failure increases the chances of a firm's performance being affected adversely (Kudriavtceva, 2019).

2.13.1. SWOT Analysis: As a Process

SWOT analysis is an economic analytical tool that enables researchers to evaluate both the internal and external environment of an organization by identifying key factors that determine either success or failure in the implementation of strategies. As such, the recommendations are forwarded to the management for incorporation into the decision-making process to improve efficiency and the overall productivity of an organization (Delaney and D'Agostino, 2015).

According to Delaney and D'Agostino (2015), the phases of carrying out a SWOT analysis follow the four phases identified below:

- Step 1: Collection of all relevant data about the organisation, which affect the operational success of the organization includes factors such as financial capability, technological adaptation, and customer demographics.
- Step 2: The information collected above is divided into various categories depending on affiliation to the four elements of SWOT analysis. These four are Strengths, Weaknesses, Threats, and Opportunities.
- Step 3: This involves the creation of a visual representation of the various options available to the management during the decision-making process.
- Step 4: Involves direct interpretation of the results in a manner that allows operation strategies to be implemented as a way of improving business activities. In this stage, the comparison between the different alternative recommendations are evaluated, and the best are acted upon.

To ensure that all the required NREN services are readily available at EthERNet or university premises, this research focuses on identifying the required NREN services that end users would like to have in Ethiopian public higher education to improve the quality of education and research output. SWOT analysis strategy is used to categorize services into a short-term and long-term roadmap. According to Stadnyk *et al.* (2018), SWOT analysis invites owners and management to assess the organization's internal and external environment to gain a clear view of a company's resources and capabilities for growth, as well as to avoid any threats from external sources (Delaney and D'Agostino, 2015).

Boon, Eckardt, Lepak and Boselie (2018) explains that managers use tools for strategic thinking, decision making and implementation. Boon, Eckardt, Lepak and Boselie adds that these tools act as an approach, concepts, ideas, and techniques that will influence strategic activities. SWOT is one of the tools that can be used by management so that it can positively react to changes that occur within the internal and external environment of a firm. Gürel and Tat (2017) describe SWOT analysis as a model for the development of marketing plans. It is claimed to be simple and easy, but that is always going to be an underestimate. The information that exists from the environmental analysis should be separated into strength, weakness as the internal factors and opportunities and threats as the external factors of a firm. In the end, analysis from the SWOT will determine the objectives to be sought and the obstacles that must be overcome. With this knowledge, the weaknesses that exist should be transformed into strengths, and the threats should be converted into opportunities. Finally, the strengths and opportunities, which are the decisive factors, should be optimized toward the realization of the positive potential of a firm. Thompson, Strickland, and Gamble (2015) agreed that SWOT is a powerful tool to assess a business or proposition. By using SWOT analysis, a business will run from a position of its strengths that they have identified.

2.14. Service Portfolio and Technology Road-mapping

2.14.1. Service Portfolio Management

According to Schumpeter (2017), service is the outcome of different actions that cannot be expressly determined. However, they must have occurred, between the business suppliers and consumers, given the nature of the services being paid for by the customers. The exchange produces a change of state in the portion of the real world of interest for the customer. Cardoso *et al.* (2015) consider that the complexities of the service industry as more complicated with the advancements made in the technology industry. The service-oriented computing (SOC) shifts from supporting design-oriented methodologies to include technology in the delivery of services

(Verlaine, Jureta and Faulkner, 2015; Yoo and Pan, 2014). In a different study, Kaval and van den Belt (2017) argues that the ecosystem of the service industry involves the whole process of creating a service, commercialization and use of the service such that the appraisal techniques need unique decision criteria to make sound judgements. A good example involves the use of socio-economic features associated with the service.

With these changes, it is necessary for the dimensions of risk. It returns in business organizations to be restructured in a way that allows portfolio managers to diversify their investment portfolio into different groups rather than a single group, where the risk exposure is elevated (Ruppert and Matteson, 2015). According to Doorasamy (2017), this decision is based on the need to adhere to maximizing the objectives of portfolio management, maximizing profit, mitigating against probable risks, and strategically implementing identified approaches. The different types of portfolio models include scoring models, decision support systems and behavioural approaches (Doorasamy, 2017; Gemici and Alpkan, 2015). According to Comerio *et al.* (2015), different Service Portfolio Management (SPM) perspectives are considered with different degrees of complexity depending on the assets and services used in the Service Oriented Architecture (SOA) to provide answers applicable in the delivery of services from the supplier to the consumer (Kapitsaki and De Almeida, 2016).

According to Suhardi, Doss and Yustianto (2015), one of the renowned developers of various methodologies for evaluating lifecycles, IBM, released another program for testing service life cycles called "Service-Oriented Modelling and Architecture" (SOMA). This system uses three principles that are used to gauge the performance of an SOA network; the nature of components in the systems, how items flow from one point to the next, and the ease of identifying and realizing the benefits of a service. To effectively identify all the three elements, the IBM services are arranged topologically from the least granular to modularity. In a study conducted by Charter and Tischner (2017), the researchers noted that sometimes a business would reuse certain services within a process to help a new business or introduce solutions to problematic issues affecting the current business environment. Reusing services has become a regular phenomenon in various industries due to the benefits accrued through agile operations, financial implications, and the environment of dealing with risks known and identified earlier while using the service the first time. According to Ibraheem, Abdallah and Mohd (2014), the best approach to reusing the service provision criteria is through the introduction of two phases within the process: an application engineering and family engineering. Ultimately, the SPM methodology developed will automatically offer advice on the best services that should be offered consistently and the type of investments that will offer the best returns on money invested (Martens and Carvalho, 2016).

Apart from the use of the service portfolios and technology road mapping, possible alternatives can include the strategic roadmap, product roadmap, IT roadmap (technology roadmap) among others. However, most of these options do not apply to institutions of higher learning and possess a different set of variables (Hussain, Tapinos and Knight, 2017). For example, the strategic roadmap (also called a strategic plan) provides a layout of an institution's operations concerning its strategic goals. In contrast, the IT roadmap serves a wide range of stakeholders within a large enterprise where technology is considered to be complicated. Therefore, the use of both the service portfolio and technology road mapping is considered appropriate for meeting the required NREN services in an institution of higher learning (Hussain, Tapinos and Knight, 2017). Perception of service portfolios are categorized in three categories; the theoretical view that hypothesises the service needs, the logical view, which involves the hierarchical arrangement of the various elements that constitute the service and the physical view, which denotes the external components that make up the service (Justin, 2018). The below section explains the workflow for the development of the service portfolio.

2.14.1.1. Portfolio Development Workflow

Justin (2018) provided the following steps, which can enable the creation of an efficient ICT service portfolio:

- Structuring the Portfolio: The project team identifies the needs and the initial processes that will be used to arrange the elements in a manner that depicts an efficient portfolio.
- Designing the Services: The Service definition, reference portfolio and Enterprise Technical Capabilities (ETC) map is leveraged to design a complete initial draft of IT Services end-to-end across the enterprise. Industry leader CISCO recommends the use of documentation in asset management systems to create service chains depending on the design adopted by the transformation team.
- Designing Remaining Portfolio Elements: This occurs at the latter stages of development whereby the arrangement is made according to the features of each element and the responsibilities at different levels of management.
- Identifying Service Chains: The project team provided with the tools for documentation will possibly participate in the process to acquire the first-hand experience and identify approaches for improving the performance of each portfolio.
- Finalizing the Portfolio: A final full review of the whole portfolio is initiated to gauge performance consistency, the effectiveness of support facilities, and to provide possible recommendations on how to restructure the IT model and the whole business strategic position within the industry.

The effect of timeline ranges has been knowingly removed from the above steps as it encapsulates inconsistency that will make the variables differ, which make it harder to determine the level of complexity being dealt with or how they should be applied when using the ITaaS Framework. It is widely accepted that service designs are the most challenging phase in the process of creating a portfolio as they can utilize nearly two-thirds of the whole project’s life. The ability to create an efficient enterprise made up of a range of portfolios requires the engagement of stakeholders to note the nature of effects and a timeline that will make the whole process appealing to consumers. The implementation of these steps is expected to occur in a structured manner; however, it is acceptable for the transformation team to adopt different approaches during the implementation.

The most popular approaches are waterfall and agile. Both approaches are mature and usable, though they have their strength and weakness. There are many considerations to make a choice between the two approaches or for using a hybrid approach. For this thesis, the waterfall approach is chosen as designing of strategic service groups, and service categories become apparent after the first batch of services are provided but would characterise pure presumption if begun parallel to the service design effort.

Figure 2. 10 shows the waterfall approach, which requires that a single-phase be completed before the team can proceed to the next phase, thus avoiding complications that could minimize the project quality. The example used in the illustration shows the designation of services within Strategic Service Groups.

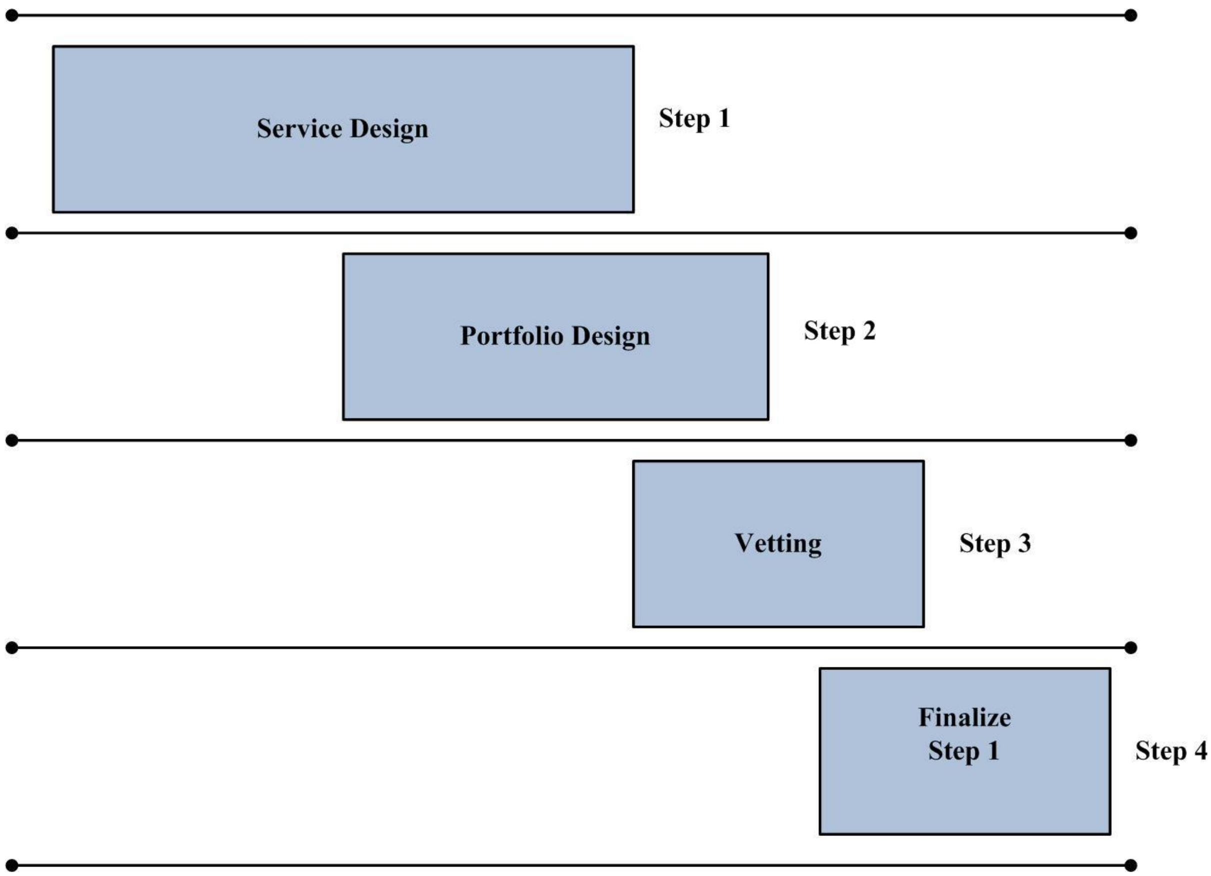


Figure 2. 10: Service Portfolio Development (Justin, 2018)

2.14.2. Technology Road-mapping (TRM)

Rahman (2016) and Brotchie, Hall, Newton, and Nijkamp (2017) state that advancements in the technological sector have improved the ability of enterprises to compete in the global market. This is because this is an approach for improving short-term performance levels and generating sustainability of business operations for a long time after the adoption of such innovations. Given the ever-changing nature of the technology industry, many organizations view the uncertain nature of the industry with cynicism such that crucial risk mitigation strategies are planned for in advance to negate the possibility of technologies becoming obsolete after a few years.

According to Liu, Kim and Wang (2018), Technological Road-mapping (TRM) accounts for the processes within the management's criteria for making decisions that enable creativity among personnel as a way of improving the morale and interests of students and researchers to initiate projects that will lead to changes in the society. While there is another variant definition of TRM, the underlying factor is the use of specific guidelines to improve the innovative spirit among employees. Invariably, the process of road-mapping should show the staff how the short- and long-term goals of an organization are incorporated to attain the vision of the institution (Toro-Jarrín, Ponce-Jaramillo and Güemes-Castorena, 2016). Another definition used by many experts alludes to the strategic use of communication tools in a way that helps the management determine the relevance of the decisions made within the current economic and social environment (Vishnevskiy, Karasev and Meissner, 2016). This approach shows that science as a subject in higher education institutions should be inculcated into students' curriculum in a manner that displays how it can change the input of resources and the planning of activities (Datta, 2018).

2.14.2.1. The Process of Technology Road-mapping

The creation of a Technology Roadmap (TRM) begins with the initiation of the generic frameworks that are used to design the architecture of the roadmap. Some of the earliest forms of technology roadmaps were developed by Garcia and Bray in the year 1997, consisting of different stages to envision a holistic roadmap. The first element involves the preliminary activities that ensure system requirements are available and that the management direction confirms the area that the roadmap will cover. The second phase involves the actual creation of the TRM by identifying the different actors and how they will focus on the execution of commands to attain the expected results. At this stage, it is also essential to show which type of technology will be used, whether there are alternatives that have been discarded, and to have recommendations of better-quality roadmaps that can be adopted in the future to improve performance efficiency. The last stage involves a review of the TRM and the collection of feedback to show which areas should be amended.

According to Cho, Yoon and Kim (2016), the creation of the TRM can be accomplished through a different set of phases that involve the initial phase of assessing the needs of an organization and how the technological roadmap will resolve these issues. The actual development of the roadmap follows this through the engagement of personnel and workshops that provide the detailed procedures and information of the network. The last stage in this methodology involves the integration of the roadmap into the organization structure to improve efficiency, and then scheduled reviews are carried out after a definite period.

As indicated on the Figure 2. 11, the flexibility and personalization of TRMs are possible after the transformation team has identified the timeframes and layers that are specific to the client requirements and a sample design has been simulated to show its potential (Allanwood and Beare, 2014). In any TRM, the layers on the uppermost sections are used to denote the current trends and preferences of the organization towards a technology roadmap. They can use the market or industry characteristics to show the competitive advantage or constraints that affect the business. The intermediate layer represents the physical facilities that an organization uses as response mechanisms to the trends identified in the top layer. In various cases, activities within this intermediate layer will involve the reshaping of products and services or the creation of new services depending on the market knowledge. The bottom layer accounts for the raw materials and human personnel required to carry out the recommendations within the intermediate layer. It includes the technical skills of the staff, financial resources, and collaborations with third parties to maximize on the opportunities noted.

	Past	Year 1	Year 3	Year 10	Vision
External Market/Uncertainties					
Internal Business Strategy					
Product/Service/Strategy					
Technology					
Resources					

Figure 2. 11: Technology Road-mapping Framework (Phaal and Muller, 2009)

As depicted in Figure 2. 12, a function-based sectoral roadmap will encompass various activities at different levels of the organizations, shown in the following list (Haddad and Uriona, 2017):

- Planning – the activities are occurring during the planning stage are aimed at defining the context of the issue, how many elements will be involved and the project lifetime.
- System functioning – the transformation team, come up with analytical tools to measure the current features of the existing network to note all the structural components that were used to create the network. After that, further research can be done on literary texts as much as ten in number to ensure that the assessment of the current system is carried out thoroughly.
- Workshops – these are workshops involving experts and stakeholders who try to discuss the report from the literature review carried out in the phase above. A total number of 60 experts within the education industry and the affected industry are divided into various groups, which will try to account for the validity of processes up to this point, determine the way forward henceforth and the influential industry trends that could aid or block the whole process. An example of a workshop is shown in Figure 2. 12.

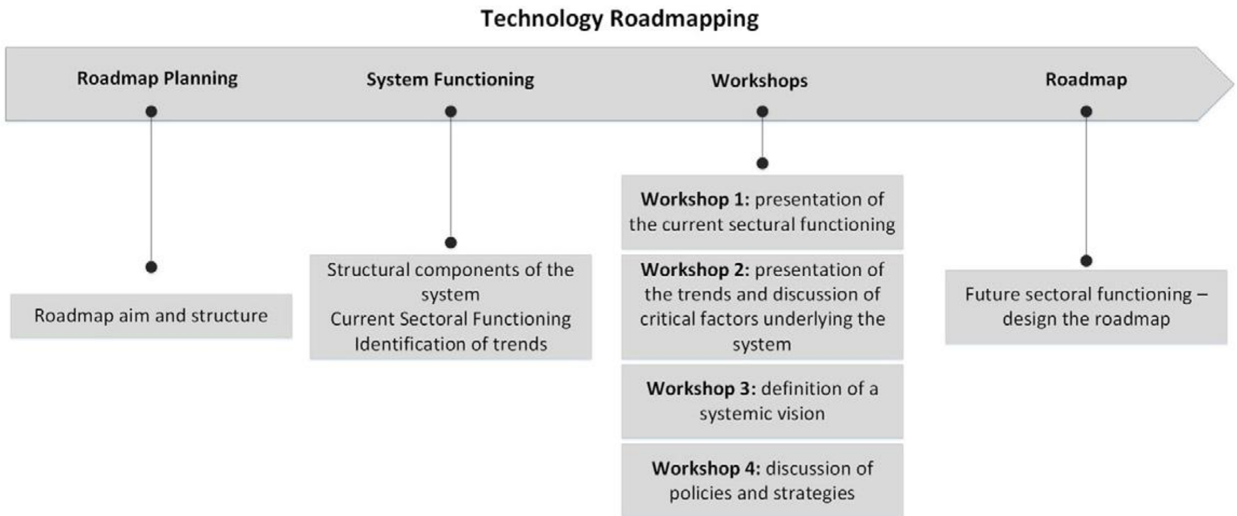


Figure 2. 12: Outline of the Road-mapping Process (Haddad and Uriona, 2017)

2.14.3. Design Science Research

Design is accepted mostly by engineering fields as an effective and treasured research method owing to its rising and efficient solution technique (Peffers *et al.*, 2008), it is a form of applied research techniques (Hevner, 2007). Recently, various researchers have thrived in applying design science (DS) as a model in research related to information systems (IS) (Peffers *et al.*, 2008), while integrating it as a vital element of research (Peffers *et al.*, 2008). Nonetheless, the rate of its utilization in IS-related research in a decade-and-a-half is low (Peffers *et al.*, 2008). For the full acceptance of DS in research, a mutual framework is needed for ease of evaluating the outcome of research where it is utilized (Gacenga *et al.*, 2012). Several researchers within and beyond the IS field have tried to offer some direction to describe research related to design science (Peffers *et al.*, 2008). DS is different from research testing, structuring of theories and the research models (Peffers *et al.*, 2008). Peffers *et al.*, (2008) recommended a DS method for IS research by offering a generally recognized framework and mental model for executing research that is based on the principles of DS (Gacenga *et al.*, 2012).

DS has been identified to be of assistance in comprehending, elucidating, and augmenting the performance of a prevailing system via the creation of ground-breaking and exceptional artefacts, together with frameworks using a well-defined approach, sometimes it could be via thorough analysis and evaluation of designed artefacts' performance (Hevner, 2007; Pournader *et al.,* 2015). Before the interest in DS by researchers in the field of IS around the early 1990s, the fundamental difference amongst DS and other models like "theory building, testing and interpretive research". The fundamental difference was that while research concept via social; and natural sciences tries to know the reality, DS tries to produce things that assist human in achieving their goals (Piirainen *et al.*, 2011). DS was introduced into IS research around the early 1990s (Peffers *et al.*, 2008). Later, it was proposed that the incorporation of system advancement into research procedures by offering a multidimensional methodology approach. The dimensions include the building of theory, development of systems, investigation, and remarks from what is observed (Nunamaker *et al.,* 1991).

Furthermore, research that is based design science model has the possibility of adding to the applicability of IS-related research by aiding its potential of addressing a various problem that IS researchers face (Islam and Grönlund, 2011). Pournader *et al.,* (2015) utilized a 3-step DS method in developing a useful artefact for HR-framework that comprised of thoroughness, significance, and design sequences (Pournader *et al.,* 2015). In the execution, a qualitative and investigative study of two engineering organizations that are into construction was carried out. Purposely to confirm the face cogency of the proposed framework (Pournader *et al.,* 2015). At the final phase of the design sequence, the possibility of applying the projected framework was tested via a quantitative test that was accomplished with the aid of a survey of experts in the studied organization (Pournader *et al.,* 2015). Research related with IS has been reported to be more impactful in practical applications once DS research method is used (Peffers *et al.*, 2008), with different fields reporting the advantages of utilizing this research model (Peffers *et al.*, 2008). It would, therefore, be of immense benefit if used in IS educational research. Different views exist on how to go about research that uses the concept of DS. However, one of the generally accepted steps includes programming to define the objectives of the project, collection and analysis of data, evaluation of the objectives with the result obtained, improvement using the observed result to develop an improved future result, development of prototypes and proper documentation (Piirainen *et al.,* 2011).

While several forms of IT-related portfolio for service rendering and technology models that aids roadmap development have been issued, nonetheless, the applicability of such models for NREN and the suitable portfolio and roadmap for specific IT service group is unclear (Nissen *et al.*, 2015). Furthermore, prevailing research on IT portfolio for service execution and development of roadmaps need models that can explain the preparation, scheming, construction, application, and utilization of a service portfolio, together with roadmapping (Nissen *et al.*, 2015). Research related to design science births informative knowledge in IT artefacts form and is broadly applied to the field of research related to information systems and computer science (Sonnenberg and Brocke, 2012). Roadmapping and Service portfolio are good examples of IT artefacts; similarly, a well-created and applicable design science would produce a functional roadmap and portfolio for the research (Hevner *et al.*, 2019).

2.15. Barriers Affecting the use and Integration of ICT in Teaching and Research

Many pieces of research have been conducted to identify the common barriers to the integration and use of ICTs for learning and research projects. The intensity of these barriers has varied from one nation to another. Chris (2015) classified the obstacles that hinder the incorporation of ICT in the education sector; the barriers were divided into exterior and interior obstacles. Common barriers that are encountered outside the organisation include the costly hardware and software facilities, inadequate time allocation, and the lack of ICT experts in the country. Some of the obstacles within an institution involve the negative perception of new technologies by the staff, as they perceive traditional approaches to be equally successful.

Another barrier identified by researchers includes a management disregard of appropriate locations to install ICT infrastructures (Roztocki and Weistroffer, 2015). New inventions are bandwidth-intensive and need a high-quality of service in the network to function correctly; for example, a video conferencing application for teaching and telemedicine requires a large bandwidth. As such, the cost of investing in standard campus networks can offer challenges that are common in many educational institutions in developing nations. The associated cost of setting up a backbone that can support research and education activities is still very high. Thus, the availability of resources from various sources such as the government and donor funding could form a critical part in achieving the realization of the NREN services. Makoni (2016) believed that commercial providers significantly contributed to an increase in the barriers affecting the integration of ICT. In Uganda and Zambia, for example, commercial providers came up with cheaper, customer-friendly packages, which made it quite difficult for the national NRENs to compete against it. The ability of ICT to support educational activities and research in these nations is wholly dependent on the type of leadership practised. In research done by Kunda (2014), inadequate allocation of time, absence of incentives, poor quality of ICT services and lack of adequate personnel with ICT skills, are some of the main barriers faced when integrating ICT in education and research.

Foley (2016) argued that network-based collaborative research and education could not be achieved without the presence of a robust and accessible infrastructure, which can only be provided by the NRENs. However, the absence of reliable network infrastructure in most developing nations is considered an obstacle to the achievement of high-quality education and enhanced research output. An additional barrier to developing African nations is that it should develop a technological capacity to effectively engage with other researchers and research communities within and outside their current setting.

2.16. Challenges of National Research and Education Networks (NRENs)

The Research and Education Network (REN) supports education and research activities in higher education so that these activities can be more efficient and effective. NREN can provide advanced services required by end users in higher education to support collaboration and facilitate access to resources. In Ethiopia, there are still numerous institutions that are yet to incorporate the NRENs into their systems.

These inherent problems for African NRENs arise from the lack of adequate research experts. They can contribute through impactful projects and lack the resources and facilities to carry out the projects. Some of the critical factors that contribute to this unwanted phenomenon include a shortage of skilled human resources, disabling policy and regulatory environments, slow sector reform, poor access to broadband infrastructure, the seeking of individual advantage by member

NRENs, weak financial bases, generally poor campus networks and limited PCs for users (Nyirenda-Jere and Biru, 2015). The challenges that have confronted landlocked nations while setting up the NREN was highlighted through a report presented by the AAU entitled “Riding the National Research and Education Networking Train in Africa.” The report indicated that the use of a lower density national fibre is expected to increase connectivity cost because of relying on the costly cross-border routes (Makoni, 2016).

Additionally, the national fibre is expected to restrict the extent it can support educational activities as well as research output. Makoni also provided a list of challenges influencing the degrees of success of most networks in LDCs. Some of these challenges include routing traffic, the absence of an effective management and governance framework, ineffective use of advanced resources, in the ability to mobilise resources, capacity building for skill development, among others. For instance, the establishment of regional networks has been affected by increased delays and accumulating costs because of adopting the use of intra-regional traffic, which several transverse routers in other nations such as London or Amsterdam.

In research conducted to evaluate the challenges faced by Zambia Research Education Networks (ZAMREN), the following insights were derived. Affiliates in their use of services or data-intensive applications that enhance the quality of education and research faced the following challenges: intermittent power outage, financial constraint, fibre cuts, lack or low level of ICT technical knows-how, high Internet tariffs, unhelpful bureaucracy, lack of management support on ICT matters and poor services (Wanyambe *et al.,* 2016). The Study into European Research and Education Networking as Targeted by eEurope (SERENATE) released a report detailing the needs assessment of communities in LDCs and compared the results with the current environment in Europe. This report concludes that the main reason for reduced performance levels in Africa is the unavailability of quality communications networks and Internet connections on many campuses. The report states that the management of universities should look for avenues and platforms that will help improve the institution networks on their campuses. There is no way that this problem will be resolved by ignoring the facts alluding to the current inadequate level of education quality in these universities. Researchers in developing countries face many challenges, such as limited access to scientific journals and weak Internet connections. Many of these challenges can be addressed by focusing on improving access to ICTs (Muriithi, Horner and Pemberton, 2016).

2.17. The Impact of NREN to Improve the Quality of Education and Research

Researchers, scientists and educators need to collaborate and work together with each other and with their contemporaries in other countries who share a common goal so that they can solve their everyday challenges, such as sustainable development, human rights, global warming, conflicts, emerging diseases, and others. By itself, education serves the purpose of enlightenment and the ladder for social mobility from poverty to self-reliance. Thus, the application of technology to improve the whole process of education delivery through efficient communication and information strategies is imperative (Pearlson, Saunders and Galletta, 2016). The consequence is that teachers must contend with changes in course content as well as the manner of teaching (Gay, 2018). Also, information technology has significant influence over the research process as it engages with the gathering of information and the application of analytical tools required for data analysis (Bell, Bryman, and Harley, 2018).

The NRENs need to be connected and collaborate via their regional NRENs and then be connected to the global Research and Education Network (REN). For developing NRENs to gain resources, technical expertise, and other experiences, they must connect to more advanced NRENs and regional NREN associations. Global experience shows that to establish an NREN in countries where it does not already exist, the regional RNEN must play a supporting role to help launch customized NRENs to conjoin with other federations (WSIS, 2014). Additionally, the regional NREN is expected to provide a unique approach that can be used to resolve most aspects associated with the connectivity at the national level and service requirements. Many case studies show how the NREN can improve the worth and quantity of the research output from the local universities of one country. For instance, after the CamREN (Cambodian Research and Education Network) connected to the Trans-Eurasia Information Network (TEIN3) in April 2012, 35,000 researchers in the Institute of Technology of Cambodia (ITC) in Phnom Penh used the global research and education network via the Trans-Eurasia Information Network (TEIN3). Thus, enabling the association of the CamREN with the high capacity regional network of TEIN3, which in turn, enhanced the right of researchers to use the global resources. Besides, it encouraged higher education and scientific institutions to enhance the campus network set up to collaborate and link with each other and with their counterparts globally. After the connection, the quality of education and the quality and number of study outputs from Cambodia's universities and scientific institutions improved considerably. Via this advanced setup, these institutions can use applications, which are network resource-intensive, including, but not limited to; health programmes, food security, climate research and meteorology (TEIN3, 2013).

There are many challenges faced by tertiary institutions regarding the quality of education they can offer. But NRENs can play a significant role in addressing those challenges. Another case study illustrates the number of challenges that tertiary institutions in the Caribbean face regarding the quality of education. This study says that Caribbean universities can collaborate and share their professors via video conferencing in the delivery of lectures so that they can improve the quality of teaching and learning. The case study points out that most of these tertiary institutions have a relatively small population and offer a minimal range of study areas. Hence, they cannot afford to have the required infrastructure and resources to deliver the full range of programs for their students. However, a few universities do have packages in the field of science and technology, although they have suffered through lack of resources, including skilled and qualified lecturers in mathematics, engineering, and other science fields. As a result, young, skilled, and talented citizens of the Caribbean are leaving their countries to get quality education and decent job opportunities elsewhere, resulting in a brain drain, which restricts the development of the Caribbean. For instance, around 80 per cent of tertiary graduates in Jamaica have left the country seeking better job opportunities and improved quality of life. In November 2013, the University of the West Indies had a video conference broadcast to other universities in neighbouring countries while the tutors were in Jamaica using the C@ribNET. This case study showed the first-ever online platform for uniquely sharing information in the field of telemedicine. According to the CEO, Mr Sylvester, this operation would be a first of many as the university was very keen to take advantage of the advancement in the technology industry, to help in the tutoring of students who are in low-quality institutions. The list below shows the expected benefits that can be accrued through investment in NREN infrastructure, as well as other non-essential supporting programs:

- Reliable and affordable bandwidth.
- Creation of a fully operational national research and education network dedicated to providing the required service for researcher and educator.
- Efficient international links to the public Internet.
- Reliable networks strengthened by contemporary security policies.
- Single sign-on access to research and educational resources locally and remotely.

The National and International Communities of Practice have facilitated other benefits that are not directly linked to the primary function of NREN, as shown below:

- Advice on the development of collaboration and funding opportunities.
- Creation of cloud services to support the needs of end-users.
- Development of advanced ICT for e-Science and e-Infrastructures.
- Leadership training.
- Organization of national end-user conferences and workshops.
- Provision of on-line collaboration tools for research and education.
- Provide a platform for software development.
- Setting up of e-Learning platform, which enables to provide distance learning programmes.
- Training and support of networked services and best practices.

From the above points, it is apparent that students and scientists should expect organizational changes that offer access to materials previously inaccessible and the opportunity to work with peers in developed nations. For example:

- Collaboration between scientists and scientific analytical tools available in local or international institutions.
- Instant access to the network provided the students have a suitable gadget with which to logon to the network.
- National content can be put at the disposal of potential international users, with an immediate impact of promoting these contents.

An NREN creates a platform for users to access the Internet and foster the spirit of sharing and teamwork through:

- Access to education and research services provided by international partners and active research communities.
- An Internet search for educational support and preparation of research papers.
- Remote delivery of courses/conferences.
- Remote execution of experiments.
- Remote participation in conferences.
- Virtual meetings using videoconferencing/Web-conferencing.

Having accessible softcopy of information enables lecturers to update and review their subject contents, which are then immediately available to the learning audience (Mohammadi, Abrizah and Nazari, 2017). Furthermore, the number of educational activities being done by ICT changes the nature of education, which is spreading into web-based systems (Salomon, 2016). There is an expectation from society for easy access, quality information, more flexible approaches, and more significant online opportunities in education, which in turn affects teaching and learning. Consequently, worldwide demand for higher education is influencing teaching, learning and research and supporting those activities in ICT assist in improving the delivery and quality of education, research, and administration of higher education institutions. Figure 2. 13 and below section explains the ICT applications and usage for higher education institutions.

1. ICT in teaching and learning

Many universities have adopted a multidisciplinary repository of information that shields the whole organization from the challenges of shortages as they look for options from the national research and education networks such as EthERNet to suggest quick solutions depending on the nature of programmes. For instance, depending on the previous ICT infrastructures available in any university, the institution could suggest collaboration with virtual library databases or sound out ‘investment pitches’ to research organizations looking to work with universities in local regions. The out-dated model of teaching that involved teachers, chalks and chalkboards are obsolete since the introduction of smarter modes of teaching that yield better results. For instance, Power-Point presentations, the use of visual or video clips and simulation classes offer students the best platform for understanding complex subjects without exhausting the teacher. Given the technical capabilities of video conferencing, students can be geographically far from the teacher but carry on with classes and engagement in a similarly productive manner. University administrative departments have also taken the opportunity of offering courses to the global market through online classes. The role of ICT in teaching redefines the context of student-centred learning approaches as teachers' priorities the needs of the students (Cheah, and Lim, 2016). Aside from the teacher-student relationship, other elements that support the learning environment includes Tele-Education, Virtual Learning Campus (VLC), virtual libraries and digital learning.

2. ICT in research

In the past few years, the Ethiopian academic society has contributed little or no research projects in the education sector, as many researchers have to contend with the lack of necessary resources or the available facilities are out-dated compared to the technology in other countries. The decision to invest in ICT equipment should lead to an increase in the quality of research projects produced by the brightest minds in the country. These researchers will easily make collaborations with counterparts in the global community as well as access the massive amounts of information available on the Internet. The impact on costs will be to save money that can be invested in other departments, and the impact on research will be to reduce the time it will take to complete research because of the help of technological gadgets. Calculations such as data analysis can be run on statistical software to generate trends that are interpreted by the researchers. Aside from the pool of resources available through ICT, it also provides the avenue for Ethiopian researchers to share their work with the world and receive the acclamation for good work done (Cheah and Lim, 2016). Figure 2. 13 presents the proposed ICT Integration and Usage in Higher Education, which different actors can relate.

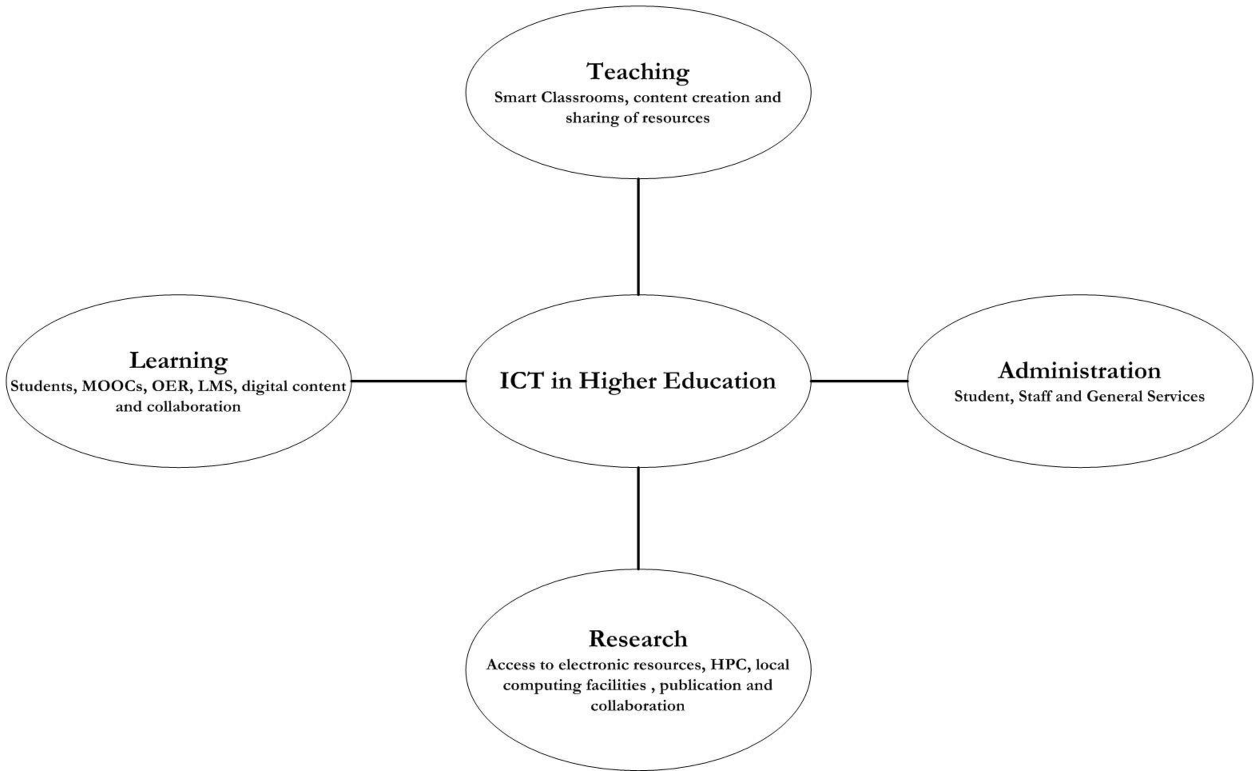


Figure 2. 13: Proposed ICT Integration and Usage in Higher Education

2.18. Future of ICT and Higher Education

According to the UNESCO Position Paper on Education Post-2015, there are specific visions and goals concerned with achieving quality education through non-discrimination and access to technological components to rectify the global imbalance in the education sector (Baskaran, 2017). The role of ICT in this millennium has progressed with the continued development of facilities that will restructure how information is provided to students, how knowledge is created rather than simply being transferred from tutor to student and the development of technical skills required by those who want to become competent personnel in a wide range of domains. Sokku and Anwar (2019) concurred with these findings when they suggested that ICT can transform learning from a teacher-centred to a student-centred learning process. Sharma *et al.* (2018) further suggested that ICT has transformed teaching approach from the use of content-based curriculum to a competency-based approach, which involves the development of students' skills and knowledge. The use of ICT in supporting educational activities in higher institutions of learning is consistent with a wide range of ICT-based educational studies, which emphasize on how educational technologies can offer enhanced learning (Drew and Mann, 2018). This is despite that most learners, including those in Africa, are less convinced and in most cases, favour the traditional approach to learning.

Based on a position paper by UNESCO, it was apparent that many people lack the opportunity to access high-quality knowledge since they reside in economies influenced by inadequate investment (UNESCO, 2010). The level of e-literacy, especially in LDCs, is alarmingly low, which continues to affect the development and growth of various industries since they suffer by remaining in the non-tech environment. However, the latest advancement in the use of ICT for education, such as e-learning and research, is expected to support enhanced literacy among the users. Additionally, such strategies will help in the creation of technologically oriented learners who are very competitive worldwide.

2.19. Summary

In this chapter, the research problems were globally contextualized and narrowed down to the current state of African; specifically, Ethiopian's NRENs. Besides, the state of higher learning and research institutions, science, technology and innovation, the use of ICT and NRENs in LDC have been explained explicitly as it affects Ethiopia. More importantly, the literature review provided a comprehensive insight into the concept of NREN, the existing infrastructure at EthERNet, the NREN services that can be provided to end users, the challenges and impact of NRENs in augmenting the quality of education and research in Ethiopia. Also, the details of ANT, its pros and cons, and its applicability for ICT research were highlighted. The concept of Service Portfolio and Technology Roadmapping, together with the use of SWOT analysis as an instrument, to effectively use and analyse the planning of an institution's services were mentioned. Lastly, design science (DS) as a useful technological tool that forms the basis of the research method in conjunction with ANT technique were discussed.

Chapter 3: Theoretical Framework

3.1. Introduction

This chapter incorporates the different aspects of the theoretical framework that were applied in this study to investigate NREN services required by end users, provide the service and to develop a service portfolio and roadmap for EthERNet. Additionally, the research output from the study as well as the actors involved, was used to infer the benefits of the NREN services in improving the variables under scrutiny. To look at the process of creating and using the actor networks, this study employs an in-depth evaluation of all the actors involved in the research process and those within the education facilities. In the latter stages in this chapter, a representation of the proposed theoretical framework is provided to aid consideration of all factors discussed. Owing to the enumerated theoretical framework, and design science, this study aims at coming utilizing the ANT technique in studying the complicated relationship between active players in Ethiopia's NREN and its effect on the quality of education, together with research output.

3.2. The Method used to Develop Theoretical Framework

Generally, in research that is based on design science (DS) principles, the methodology is usually made of theoretical principles that describe what is expected, application principles and procedures for research execution and presentation (Peffers *et al.*, 2008). Besides, DS might include social inventions, technical, informational or social resources, or any other object that would be used as part of a solution for a research problem (Peffers *et al.*, 2008). A methodology consists of ideologies and actions applied to a precise division of knowledge. Practical and strategic methodology like DS's, would assist in researching elevated quality in higher education and research (Peffers *et al.,* 2008). Since DS assist in the creation and evaluation of objects used in IS and IT to resolve problems, evaluate designs, and in expressing research observations. It would, therefore, be of immense benefit in evaluating the impact of NREN on the quality of education, together with research output in Ethiopia (Hevner, 2007). The design framework for this research is like the one utilized by Pournader *et al.* (2015) for human-resource (HR) management. The design science method was approached such that a theoretical framework was initially developed in the form of hypothesis and actions.

Furthermore, the hypotheses were later assessed to evaluate their validity. The possibility of applying the proposed frameworks and hypotheses were confirmed via survey. At the same time, data analysis was performed to affirm the order of priority of the artefacts in the framework and their relationship were established (Pournader *et al.,* 2015). The validation of the theoretical framework was assessed using exploratory analysis.

3.2.1. Applying a Three-Step Design Science Approach

Pournader *et al.,* 2015 presented a thorough review of the application of a DS method that involved a 3-step approach (Pournader *et al.,* 2015). DS concentrates on specific research whose components are human-made artefacts or other human constructs and their synergetic relationship in accomplishing the desired goal; while tackling problems that are related to real-life scenarios (Simon, 2019; Pournader *et al.,* 2015). Reportedly, DS was initially introduced as an efficient approach for solving problems in a structure that obtains novel characteristics of a system while dealing with existing challenges (Niederman and March 2012). In utilizing DS in an organization, its task in supporting the artefacts design and knowledge promotion must be specified (Pournader *et al.,* 2015). Doing so would offer a method that is directed at meeting the needs of the business, as shown by the artefacts (Pournader *et al.*, 2015). The three major cycles that have been identified for the development of artefacts in real-world scenarios include relevance, rigor, and design. They have been described as been needed to clearly be stated to realize valid artefacts (Pournader *et al.*, 2015). Artefacts consist of frameworks, theories, constructs, models, instruments, and methods, and are the main result of a design task (Pournader *et al.,* 2015). For this study, a three-step approach to design science is proposed, and the cycles are customized and illustrated in Figure 3. 1.

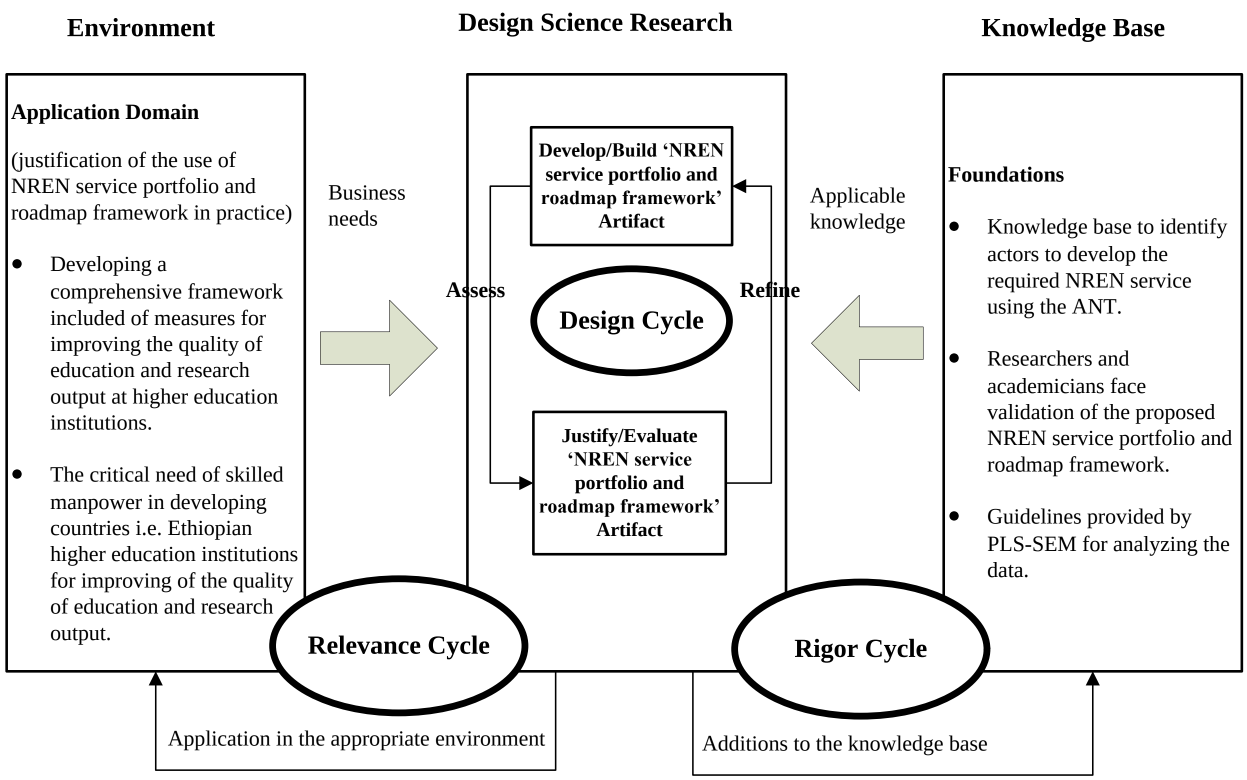


Figure 3. 1: Three-step Design Science Approach for the Theoretical Framework

Figure 3. 1 presents the concept behind the design science approach that was used in this study. It consists of three cycles, namely: relevance cycle, rigor cycle and the design cycle, all in an embodiment of environment, design science research and knowledge base. The relevance cycle pursues the appropriate input requirement that properly fits the studied environment in the framework built on the concept of design science, intending to validate the utilization of artefacts under satisfactory criteria. Besides, it presents the established artefacts to the environment under study. The relevance cycle contains entities, assemblies, and other participants in the system. For the rigor cycle, it covers existing literature and methods that are scientifically proven in the design of artefacts and some other tools that are based on understanding the system. Furthermore, it adds to the precise growth of artefacts that are present in the design cycle.

There exist different guidelines on theses cycles; however, Baloh and Desouza (2009) claim that depending only on the existing knowledge regarding artefact construction is not enough, more so, it is not sufficient for the development of new artefacts. In the same vein, Hevner *et al.* (2019)

present that the sole artefacts, which design science should be bothered with, are the new ones. Instead of this, this research focused both on literature studies and an empirical investigation that is exploratory in the cycle development. This would add to a realistic similarity and uniqueness the theoretical framework that studies the influence of NREN on Ethiopia's higher education and research quality. Furthermore, it permits validating the study constructs and assists in the evaluation; perhaps there are omitted constructs. Therefore, surveys were also carried out, in addition to secondary data from the literature to understand the significance and possible application of the theoretical framework. Thus, the essential artefact, in terms of NREN, was evaluated using the ANT technique to offer a solution to the developed constructs. The design cycle, which is useful in examining the initial state of the artefacts, was employed before testing the artefacts in real-world scenarios. A conclusion is always drawn once the artefacts satisfy the solution requirements (Hevner, 2007.

3.2.2. The Steps Used to Develop the Theoretical Framework

The anticipated service portfolio and roadmap framework in this study is going to be developed as follows. Primarily, the theoretical framework is hypothesised in the form of constructs and measures while discussing the limitations of the literature in addressing to identify the required NREN service in developing countries of higher education institutions in improving the quality of education and research output. Considering the null hypotheses made for assessing NREN services and its impacts in improving quality of education research outputs at higher education institutions, it then evaluates the face validity of the proposed theoretical model by measuring the variable or constructs in the model through exploratory quantitative study at the higher education institutions in Ethiopia grounded on the ANT model, which emphasizes on the association between the actors and networks. Finally, to evaluate the applicability of the proposed service portfolio and roadmap, a survey on one hundred and seventy-two (172) participants drawn from twenty-nine (29) Ethiopian Public Universities is conducted to identify and analyses the NREN services required by end-users and to evaluate the constructs and measures within the hypothesized theoretical research model. The Partial Least Squares (PLS) method was used to identify and evaluate the latent variables and indicators of the framework to establish their interdependencies.

A proper understanding of the points above resulted in the development of the research hypothesis in the below section.

3.3. Hypothesis Development

The objective of this research is to investigate the impact of NREN services to improve the quality of education and research output in Ethiopian higher education institutions to develop a service portfolio and roadmap for EthERNet to assist in improving the quality of education and research output. NREN has been associated with numerous benefits that can lead to improved research outputs as well as improved educational quality. NREN services are critical in facilitating communication within a network infrastructure and providing networked services for lecturers and researchers (Kashefi *et al.*, 2018). However, most the Ethiopian higher education institutions have been unable to get the required service from the EthERNet because of lacking robust and standard campus networks infrastructure at the institution's premises (Bankole and Assefa, 2017). The institutions of Ethiopian higher learning need to develop the standard campus network that can assist them in using the services offered by the EthERNet to improve the learning quality, research outputs and, in general, to serve the community better.

Consequently, literature support and the associations of the constructs are provided in Table 3. 1. A details explanations and definition of the constructs are also given in Section 3.4.2. Therefore, this study seeks to evaluate the following null hypotheses concerning NREN services and its impacts on improving the quality of education research outputs at higher education institutions. The hypotheses are stated as follows:

- **H1:** NREN services have positive impacts on the educational quality at most institutions of higher learning
- **H2:** Institutional networks have positively affected the educational quality at most institutions of higher learning.
- **H3:** The EthERNet has positively impacted on the educational quality at most institutions of higher learning.
- **H4:** Electronic devices have positively impacted on the quality of education at most institutions of higher learning.
- **H5:** There is a positive correlation between research output and quality of education at most institutions of higher learning.
- **H6:** Institutional network has positively affected the research output at most institutions of higher learning.
- **H7:** NREN services have positively impacted on the research outputs at most institutions of higher learning.
- **H8:** Electronic devices have positively impacted on the research output at most institutions of higher learning.
- **H9:** High-performance computing has a positive influence on the research output at most institutions of higher learning.
- **H10:** Remote computing facilities have a positive influence on the research outputs at most institutions of higher learning.

To assess whether NREN services has influenced both educational quality and research outputs in institutions of higher learning, the study has developed a theoretical framework (see Section 3.4) based on the concept of ANT theory (see Section 2.11) that serves as a guide to carry out the research.

3.4. The Proposed Framework

In ensuring the development of a proper framework in NREN research, the role of Actor-Network Theory (ANT) cannot be overemphasized. The concept of ANT is formed on "generalised symmetry" theory that considers both human and non-human players in its framework. It forms a network of associated interest in a heterogeneous manner (Paledi and Alexander, 2017). Its main goal is to reconstruct the social-related system by concentrating on the networks and their relations. This theory would assist in shedding more light to other factors that affect education's quality and research output in developing countries; especially Ethiopia, despite the recent effort put into some tools that are believed to foster education (Paledi and Alexander, 2017). Owing to the thoroughness of the ANT system that puts all actors in that would ensure that a system works well into consideration; thus, this theoretical research framework has developed and hypothesized based on the ANT theory explained in Section 2.11.

3.4.1. Face Validation and Exploratory Case: Using ANT Model

The face validity (Mosier, 1947) of the framework is evaluated through exploratory quantitative study at the higher education institutions in Ethiopia grounded on the ANT model, which emphasizes on the association between the actors and networks. The Ethiopian Education and Research Network (EthERNet), currently provides fast and reliable networking services to the thirty-six public universities and institutes of technology across different regions of the country. Besides, it also provides value-added private cloud service for its member institutions. The high-speed connections meant that researcher and educators could communicate with their global counterparts irrespective of the geographical location. This helps Ethiopian higher education institutions to address and overcome the critical shortages of resources (Bankole and Assefa, 2017). Owing to the scope of the study, Ethiopian higher education institutions that have been reported to benefit from EthERNet facility in the country was selected, therefore becoming the subjects of the exploratory study. Purposive sampling was used in generating samples from 29 higher education institutions that generated 172 participants at Ethiopian Public Universities. This was to identify and analyses the NREN services required by end-users and to evaluate the constructs and measures in the study.

Furthermore, the data generated were analysed using the Structural Equation Model (SEM)- Partial Least Squares (PLS) method. The latent variables and indicators of the framework are identified, and their interdependencies were established. The study used the major concepts of ANT to investigate the impact of NREN services following the requirements of the end-users at the higher education institutions in Ethiopia. The identification of both internal and external actors that work towards the success of NREN services actors and their interaction with each other resulted from the data provided by researchers, educators, and ICT directors, through the questionnaires they answered. Accordingly, ANT technique was used further to improve the validity of the proposed framework's constructs and measures.

3.4.2. Explanation and Definition of the Construct: Rigor and relevance cycles

Existing studies have explored different constructs related to NREN service requirements at the university level of education. For instance, Bukvic and Savic (2019) quantified NREN services that can improve internet services to the local communities limited to 38 European NREN. Bukvic and Savic focused on the quality and availability of data on European NRENs activity using several factors such as the backbone capacity, available budget, development of the NREN physical infrastructure and the servers available in a network. This suggests that most NRENs are primarily human networks and their accompanying organizational structures for producing and sharing knowledge and for promoting a continuous research agenda. This is opposed to the services considered by Kumar *et al.* (2015) that were used to examine users' preferences for NREN services such as network services, security services, identity services, collaboration services, multimedia services, storage and hosting services, professional and ISP services, among others.

Kashefi *et al.* (2018) depicted the NREN as a critical tool that supports several strategies applied in learning and research as it attempts to coordinate and deploy several services. This includes networking, connectivity, cross-institutional support for learning and research (such as NREN services for educational and research, electronic devices for education and research, the institutional network for education and research, and high-performance computing). Also, general services (such as training) and collaboration services (such as remote computing facilities), can be mentioned. A notable NREN that can provide the services mentioned above is the eduroam, which offers internet access to its users at the institutional level.

Subsequently, according to the literature support presented in Table 3. 1, the ANT theory used to identify the NREN actors that are found at Ethiopian public universities for identifying their requirements and challenges affecting the need for NREN service. In line with the rigor and relevance cycles presented in Figure 3. 1, all the NREN actors have been extracted and categorized in several constructs. As per explained in Section 2. 11, most of these constructs are identified and supported by the existing literature. Besides, an additional construct of the theoretical framework has been identified from the face validation phase using the ANT technique.

Table 3. 1: Literature Support for the Theoretical Framework and its Construct

Construct	Description	Supporting evidence
NREN services for educational and research (NSE and NSR)	These are value-added services, which are provided by a dedicated national research and education network to meet the increasing demands of researchers and the learning community. Also, the utilization of NREN in education and research would assist in augmenting their qualities	Section 2.4, 2.7, 2.11.1, 2.11.2, 2.17 and 3.4.2.2. Kashefi *et al.* (2018); Mkandawire, 2013; TEIN3, 2013; Taylor and Abbott, 2016.
Electronic devices for educational and research (EDE and EDR)	This comprises of end-user devices, which support educational and research activities such as laptop, mobile devices, personal computers (PC), iPad, among others. The synergy between electronic devices, education and research would assist in improving their qualities, together with their outputs.	Section 2.11.3, 2.17 and 3.4.2.3; Sedivy and Chromy (2015); Oludeyi, Adekalu and Shittu (2015); Kashefi *et al.* (2018)
Institutional network for education and research (INE and INR)	Institutions of higher education in Africa need access to various resources online and peer with their counterpart in the globe to do collaborative research, which in most cases requires reliable	Section 2.4, 2.11.4, 2.17 and 3.4.2.6; Kashefi *et al.* (2018); Andreoli *et al.* (2017); TEIN3, 2013; Nyirenda-Jere and Biru, 2015; Bankole and Assefa, 2017; Yaver *et al.*, 2016.

	and standard institutional/campus network.	
High-performance computing (HPC)	This is meant to provide access to high-performance computing resources to support researchers by providing pathways to solve significant problems in science, engineering, and business fields.	Section 2.7, 2.11.5, 2.17 and 3.4.2.4; Delaney (2018); Cheah and Lim, 2016; Charter and Tischner, 2017; Dwivedi *et al.*, 2015; Apon *et al.*, 2015.
Remote computing facilities (RCF)	This consist of virtual-based computing facilities, which intended to provide remote access to researchers to assist their research work.	Section 2.11.6, 2.17 and 3.4.2.5; Trucano (2014); Kashefi *et al.* (2018); Tusubira *et al.* (2011).
EthERNet	EthERNet should be a fully operational NREN and acknowledges the need to meet the requirements of the users and the various challenges they are likely to encounter in higher education institutions.	Section 2.11.2, 2.5, 2.6 and 2.17; Bankole and Assefa (2017).

Overall, after the constructs for this study were identified and discussed, the theoretical framework was validated, discussed, and presented in the below subsequent sections.

3.4.2.1. Education and Research Actor Involvement in Higher Education

A Research and Education Network (REN) aims to support education and research activities at higher education institutions, thereby facilitating increased efficiency and effectiveness. An NREN can provide advanced services required by end users at institutions of higher education to support collaboration and enable access to resources.

An advanced NREN provides many services, which differentiate it from the commercial Internet Service Provider (ISP), such as middleware services. To demonstrate the benefits when using the NREN services, the research and education institution should count the supplementary services that are part and parcel of the NREN, such as Authentication and Authorization Infrastructures (AAIs). The collaboration between different research and educational institutions is based on the expectation that all parties will maintain the integrity and truthful representation of their personnel on the network as illustrated in the ANT model that gives more emphasis to the sociological aspects (Shim and Shin, 2016). Additionally, the main ICT actors at higher education institutions are identified in the literature, as shown in Figure 2. 13. This is expected to assist in avoiding any misunderstandings that arise from unknown interactions between different networks and the leading service provider (Yousefikhah, 2017). To guarantee this is implemented, it is prudent to introduce authorization process measures that require all users to present their original digital identification during registration into the network. The assigned authorization password can only be used by the designated user to access the library database and other resources on the digital network. In a modern environment where education facilities have become more technical and easily accessible from anywhere in the world, an authorization system shared by the institutions will give users access without cumbersome, repetitive authorization checks. The possibility of collaborating with home service providers and AAIs will allow for more efficiency and access to a global pool of resources from academics anywhere in the world (Chen, 2018). When the top administrative leaders have agreed on a singular process for security protocols, the local users can collaborate with global counterparts provided all the digital resources are made available on the NREN network.

While many people will not be fully aware of the full software capabilities and specifications of the NREN, numerous services are influential in the education process. Some of the conventional systems that are part and parcel of the federated SSO include the Shiboleth (developed by Internet2), and eduGAIN33 (developed by GÉANT). These systems allow students conducting research to access additional materials that would require remote access or physical presence in a faraway university. Additionally, a student travelling to another country can access the same materials in the network provided they have access to a local university registered under the NREN. This software is called the eduroam, which differs from SSO that allows students to use the same credentials on a different online service. The interchanging of username and passwords to access different websites without repeating the process of registration is very helpful when users want to avoid the nuisance of having different credentials for each academic database. These would be possible by implementing ANT theory that presents that the success of any technological implementation is dependent on both human and non-human factors and the synergetic relationship between them (Pournader *et al.*, 2015). Below are the actors who impact the roles of education and research in the higher education sector and used to develop the theoretical framework.

3.4.2.2. NREN Service for Education and Research

It is high time that the management of educational institutions realized that the improvement of education quality and the improvement of research studies depend on the acquisition of the best human resource personnel within the ICT departments. People with the requisite skills can capably transfer such skills to the students, thus producing highly skilled graduates that can work anywhere in the world.

In a time when Ethiopian and Nigerian Universities have initiated numerous collaboration programs among themselves as well as with other higher education institution across the world, ICT provides the avenue for efficient communication and sharing of research materials. The myriad of opportunities available through ICT, as shown by online classes could introduce a new era of efficient practices and the improvement of quality in education and research spheres (Mammo and Ngulube, 2019). The advancement of information technology has enhanced students' ability to access educational materials and empowered them to communicate with their professors and colleagues irrespective of their geographical location. In consideration of these advancements, it would not be ideal for local universities to fail in vigorously adopting ICT within their systems (Apuke and Iyendo, 2018).

Maintaining a competitive edge over rivals in the same industry through the implementation of the NREN and ICT, thereby enabling the increase of research quality as well as enhancing the development of the science-related curriculum is another benefit. The National Research and Education Network allows this to become a reality through creating a robust network of research and education facilities that can be shared and accessed by users in their respective institutions. However, the realization of the full potential benefits requires that the research, tutoring and NREN strategies are synchronized so that the capacity of all parties in tandem will optimize the smooth operation of the whole network (Mkandawire, 2013).

From the advancements made in the best universities in the world, it is essential to note the role played by the creation of research and education networks that improve the productivity of the users through the provision of access to high-speed networks and worldwide databases. Barakabitze *et al.* (2019) claim that for Africa, access to such networks through research and education networks is even more important for various reasons: one is that there are insufficient human and ICT resources in Africa, and when they are available, the cost of acquisition is beyond the financial constraints of most universities.

The solution presented by NREN networks brings an opportunity to share the initial costs between all the member institutions, looking to join the networks. Notwithstanding the apparent benefit of quick sharing of academic materials, the users can use other services such videoconferencing with professors in faraway universities and help avoid the financial and security concerns of constant travelling from one institution to another. A cursory look at the admission numbers of various African universities shows an ever-increasing number of students enrolling into undergraduate programs. In contrast, the management of the said universities has lagged in investing in ICT facilities to aid the learning process. The institutions are thus incapable of providing quality training and sufficient academic materials. Using the NREN networks, this challenge can be resolved through the implementation of e-learning platforms and shared curriculums that reduce the burdens placed on limited resources.

With the help of a secure network that is characterized by low latency, high availability and reliability, one can provide efficient distance education programs using online platforms that can aid in the skill development of the students (Esmat Adrian, Mischa & Maria, 2017). This is possible mainly via NRENs as they have a dedicated backbone that can provide fast connections to databases that maintain academic information.

Based on the findings presented by GÉANT Association (2014), it was noted that many European NRENs are active in Open Education (OE) activities and have made a significant contribution to the deployment and availability of OE digital technology and content. Beyond providing and supporting the technology that delivers OER/MOOCs to users, NRENs are engaging with educators as well as participating in the production of open educational content especially in ICT fields, for the benefit of teachers and, in general, the next generation of the knowledge economy.

One of the primary missions of higher education is research, which is strategically important to facilitate, in turn, the quality of education, the other pillar of higher learning. Han and Yin (2016) argue that research helps higher education institutions to motivate and empower its researchers and promote the training of future researchers. Robertson (2016) concurred with these findings when they indicated that African Universities have yet to acquire the capacity for doing sustainable research. The modern world is currently being transformed through research and the growth, and economic vitality of nations depends on their dedication to knowledge generation and the accumulation and utilization of research (Prettner, 2018). The Association of African Universities (AAU) has exclusively cited the negligence or inability in providing the required attention to research as one of the main failures of the African continent (AAU, 2011).

NRENs and the implementation of ICT have assisted collaboration in education, and among research institutions, which provides a platform for the quick exchange of data and conducive environment for cooperative research projects between different institutions and researchers. This collaboration would be impossible without a connection that allows the exchange and discussion of ideas. The results of such connections will be the production of studies that are perfected through the contribution of various researchers, thus improving the overall quality of education within all the participating institutions.

Thus, Research and Education Networks (RENs) are mostly platforms that will guarantee quick sharing of information for both students and research scientists, contributing to better graduates and high-quality studies that can be implemented to help change the society. Through the deployment of NRENs and ICT facilities in higher education institutions, the current crop of students and future generations will acquire skills such as teamwork and the IT knowhow relevant in the modern environment of education and research. The anticipation of future risks and mitigation strategies relies on the current ICT departments that are responsible for personnel verification and agreements with other tertiary institutions in the local and global education industry. Adopting the positives from regional and global institutions while at the same time learning from the mistakes committed by these institutions during the collaboration process will guarantee that only the best intellectual properties are shared. The REN platform presents the dream of a perfect combination of synergy and growth that local universities desire in their attempt to meet the rising demand for higher education services, considering their scarce physical and human resources (Ogunmakin, 2018).

In 2011, the Massive Open Online Courses (MOOC) was introduced as a more efficient platform for students and learners to interact with while undertaking online courses without negatively affecting the individual attention provided to each student. NRENs can assist the teaching and learning processes by providing a platform to share and create traditional and online (such as MOOCs) course development. NRENs are also in an excellent position to facilitate how Open Education Resources (OER) can be findable and accessible; through enabling students with a positive learning environment, minimizing instances of systematic discrimination, helping teachers in the delivery of class materials, producing better-qualified graduates, and reducing the overall financial costs of tuition and providing learning materials, thus making higher education more accessible (GÉANT Association, 2014). Related ICT facilities, in combination with the NREN, create an environment for further advancements in e-Science and other industries that are impacted by improvements in technology (Bornman, 2018).

The Ghanaian Academic and Research Network (GARNET), provides the required services for researchers and educators at Ghanaian research and education institutions. These services are guided by the need to enable cooperation among users in the same region with the possibility of engaging international peer researchers that have similar interests (Dakubu, 2010).

An initiative from the Lagos Higher Education Connectivity Project (LHECP), which connects some of the higher education and research institutions in Nigeria, has helped foster joint studies in subject areas, such as network development and the ability to organize training or capacity building for exercises centred on the idea of sharing information. The institution has undertaken the mandate for providing the required platforms such as fast Internet connections and facilities for showing the output of benefits of the collaborative efforts (Uwadia, 2011).

NORDUnet, the service provider for networking in countries within the Nordic region has the mandate for providing reliable and efficient network connectivity within the member countries and with the global network. It also assists these countries in sharing different NREN services such as AAI, storage, hosting, video conferencing, etc. The NRENs share eScience infrastructure services, grid computing, storage, and others, which are used for researchers to collaborate and work together to improve their research output (Kashefi *et al.*, 2018).

Various studies also confirm the contributions of NRENs in initiating the creation of a positive learning environment in the education facilities that have implemented the technology into their systems. For instance, one of the healthcare-related institutions in Dakar approved an agreement with ULB Brussels allowing experts to provide professional input to improve the quality of learning materials provided to medical students. The programs use Distance learning platforms and telemedicine practices with surgical students, to provide on-hand experience for students. For example, when medical experts are conducting surgery, this can be followed and learned from through video-conferencing tools (Osuzuwa, 2011). Invariably, the main objective of the NREN is to enable the creation of an environment where information can be shared by simply clicking on a link on the network, thus improving the research projects and the wholesome learning experience of all students. This requires the three main elements of the systems to work efficiently together: teaching strategies, NREN strategies, and the management approach to the whole phenomenon (Mkandawire, 2013).

The current information revolution and the increasing impact of ICT have restructured the practice, education, and exploration in various higher education institutions (Altbach, Reisberg and Rumbley, 2019). Several studies provide evidence about the usage of ICT and its adoption in universities. There are several technologies, which include but are not limited to wireless networks, web portals, unified communication, and digital libraries as a virtual collection of reference materials, etc. These have brought changes in higher education establishments from the early

2000s. According to Harvey (2017), research scientists are increasingly applying the advanced investigation skills through web-based research, and there is an over-reliance on online academic materials as the primary source of information rather than physically perusing through thousands of pages in the out-dated library designs. ICT supports education and research by providing collaboration platforms. Researchers and Educators can collaborate locally or long distance using the collaboration platform to conduct research and educational activities in both temporary and long-term situations. Collaboration through ICT usually involves students with peers in other schools or the same school and teachers working together with their counterparts in the same vicinity or other institutions (Adams Becker, Cummins, Davis and Yuhnke, 2016).

Foley (2016) has provided many NREN cases that show their support for the improvement of teaching and learning activities at higher education institutions. One specific example that has been commonly used in the high definition video conferencing (telepresence). For example, Georgetown University from the USA is remotely connected to Qatar, New York University of Abu Dhabi and Shanghai via the Internet, and this link provides lecture and experience sharing. The other case is from India, using the National Knowledge Network (NKN) of India: Indian Institutes of Technology expand their reach with the ‘Country-wide Classroom’ so that students can have improved access to educational materials required for suitable undergraduate programs. Also, NRENs can provide services, like quick unrestricted access to the database without delays, irrespective of the number of users using the systems concurrently, a supporting platform such as Massive Open Online Courses (MOOCs), pre-authenticated and authorized access to e-journals, video-based streaming lectures, telemedicine applications for remote diagnostics. These are some of the services that can be provided by NRENs to assist in the training and learning process.

Enquiries relating to trends in ICT applications in higher education show that several technologies can improve the interaction between students and their peers, or students and the lecturers while in college or university. The following six developments in educational technology were chosen using the Horizon Project (NMC Horizon Report, 2017). The choice of criteria was based on indicators that show the inclusion of technical facilities to improve the learning environment within the institutions.

1. **Adaptive Learning Technologies –** This is a technique that combines the need to create a customized learning environment for students and analytical tools that monitor a student's progress through the data trail in the network (O'Connell, 2016). This technology has been personalized to satisfy student needs regarding the course of which they are partaking, the nature of the mentor's instructions and the determination of the weak areas in which the student needs to improve (Pugliese, 2016). To show the adaptive learning promise that is held for the future of higher education, Henderson, Selwyn and Aston (2017) argue that technology can be used to analyze data in real-time as the students and lecturers are engaging in discussion or studying information materials in the database. The adaptive learning technologies program developers have aimed to introduce a technology that would allow for empowered learning through reducing the mistakes unseen by humans and identifying the risk factors associated with students performing poorly in the class tests. The strategy introduces an 'iron triangle' strategy that solves the problems associated with costs, quality, and ease of access. In a study conducted in 2010, the program emerged among the best ten strategic solutions that help in advancing the aspects of a customized learning curriculum (Susan, 2016).

   In the face of minimal research studies investigating the impact of adaptive learning using empirical data, the institutions that adopted the technology have shown progressively improved results in the performance of students. In a program at Arizona State University in conjunction with CogBooks, the next-gen adaptive curriculum was introduced to a restricted set of courses. In these subjects (Biology and History), students showed average test scores rise from 76% to 94%. In contrast, the interest of students in classroom engagement rose, thus reducing the overall dropout numbers from the institution (CogBooks, 2018).

   According to Connie (2016), Colorado University was another institution that adopted the adaptive learning technology into their long-distance learning program. An increase in the number of users who regularly used the Intellipath rose to a higher number within a few weeks, denoting the popularity of the system among faculty members. In similar research studies, the performance of students was shown to improve when they had control over the nature of the work; they accomplish weekly provided guidance is offered. This element of fun introduced through the technology improved student-lecturer engagement, a pivotal requirement for academic excellence. The software Intellipath introduces the possibility of computer-generated analytics that guide the teachers on the strengths and weaknesses of all the students in the class.

In the above examples, the subjects used for testing involved specifically STEM subjects, an area with which many students have problems. However, the University of Georgia decided on a different path to test the efficiency of the innovation when applied in English Composition classes. The curriculum was strategized categorically from the introductory topics to more complicated ones to ensure that the students comprehended the class materials, an approach similar to the technique that was used by the best teachers (Lindsey, 2016).

The use of adaptive learning technologies is expected to continue to generate positive ripple effects within the education system. This is in line with the study report released by Clicks and Mortarboards by Nesta, which identifies the increasing role played by ICT in the education sector, through increased collaboration among different institutions. A good example is the case of the formation of groups of students to work as teams, with the critical requirement that each member is chosen from a geographically distant institution, to foster sharing of information and improvement of student's skills in computer and web browsing. Integration of Artificial Intelligence technology is crucial since it enables unbiased assignation of tasks to the members, only depending on the decision criteria that have already been programmed. These criteria can be based on the cognitive abilities of students to ensure that the best in each area are assigned the tasks related to their most excellent skills.

2. **Mobile Learning –** There is no denying the increasing role of mobile phones in the day-to-day social activities of human beings in the current economic environment where nearly two-thirds of the world population have access to a cellular device. The processing power of cell phones continues to increase with each latest device that is introduced into the market by the leading manufacturers in the industry. This has a direct influence in the education sector as students can quickly process data and access databases using their

phones. The convenience informs the essence of mobile phones they offer the user (Witten, Frank, Hall, and Pal, 2016).

To take advantage of the increased use of mobile technology, instructors are looking for avenues through which students can access course content and interact with tutors with minimal need for physical interaction. The nature of instant texting and the possibility of calling for any clarifications allow educators to respond quickly to students' needs in a personalized manner compared to classroom responses. Despite these advancements, there are guidelines and authorization processes for which teachers have to seek support before they are legally allowed to use mobile phones while in class or as a learning supporting tool (Baiyun, Ryan, Luke and Sue, 2015).

As per the statistics from the worldwide usage of mobile phones, it is evident that people increasingly use mobile phones as their primary browsing gadget (51.3%), which is higher than the number of users who prefer desktop browsing (48.7%). These statistics have been sourced from web analytics as presented by StatCounter for the year ended in 2016. In response to these data, companies such as Google have decided to increase their focus on mobile-related strategies in their development of applications to ensure that the mobile consumer market is captured in their marketing strategies. A good example is the nature of results yielded through mobile Google search, which include more recent results than desktop-based search. According to a study conducted by Hannover Research in conjunction with McGraw-Hill Education, data results showed that nearly 80% of students currently own a modern cell phone, with the number expected to increase as the demand for mobile phones is expected to reach a peak of $37 billion by the year 2020. Countries that have shown the highest demand for mobile phones in the past ten years include China, Japan, USA, and South Korea (Adkins, 2015).

The founding principles for mobile learning initiatives are that they should generally lead to improved access to higher educational facilities irrespective of the user's physical location. According to Maina (2016), one of Kenya's most famous private university's administration partnered with IT students to create an App called Daystar Mobile. This application allows students to undergo a full 4-year undergraduate program without attending classes by exclusively using the app to access course materials and examination papers. The course content is personalized according to the strengths of the students such that it can be filled with videos or text materials, or a mixture of both, provided that the students know that they can access the tutors through the interactive user interface for any support.

Additionally, this mobile technology has influenced the working culture of many employees who have the ambition to further their studies. In a study initiated to look at the correlation between these two variables in South Korea, the researchers concluded that most of their online students were working part-time jobs and that they used the school's mobile LMS more frequently than the full-time students. The benefits offered to work students such as simple click to access a class tutor or class materials at their convenience in their free time offered a better approach to scheduling work responsibilities and schoolwork (Serdyukov, 2017).

According to Latchem (2017), mobile apps such as Hotseat provide additional platforms for increased interaction between students and lecturers. In this app developed at Purdue University, students can post comments and questions as the teacher is engaging the class on a specific topic. During the class, other students can read comments by fellow students and reply with their comments, or only like other posts. The real-time feedback provides the necessary backdrop to gauge a tutor's performance and the comprehension of students during class, as well as providing the teacher with material to gauge what the students failed to grasp during class. The effect on students who are unlikely to engage in class due to lack of confidence is also a positive one since they can anonymously post their questions on the app.

Depending on mobile phone specifications, tutors have the freedom to customize course content in a way that is interesting to the students. A good case study is a project initiated by Alyssa Amen at the University of Nebraska-Lincolns College in the year 2015. The faculty member prepared video tutorials of food science that showed the students the nature of food laboratories, faculty members engaged in beneficial discussions, and field research using the GoPro Camera and an iPad. In a similar study conducted at the Middlesex University, Wilkinson, and Barter (2016), mobile-related programs were introduced as course content for first years undertaking the anatomy unit. The students could use their iPads to access class materials such as 3D animated skeletons of different animals, after that, partaking in a quiz or game simulations that tested the students' grasp of course material. The first-year students reported that the anatomy class was the most interesting compared to other units. The fact that the students in this class performed better than counterparts who were not using the technology goes to show the potential benefits of mobile learning technologies. Another example is the Jibu mobile app used extensively in East African countries, which provides nursing students with the opportunity to continue with training while practising, avoiding the risk of losing their professional license.

According to JISC (2017), there are numerous materials on the web that can guide users on the implementation of various frameworks. Additionally, there are numerous case studies, which explain how other institutions have integrated mobile-based technology into most initiatives for university students as a way of improving the quality of learning. For instance, the elements of the SAMR model (Substitution, Augmentation, Modification and Redefinition) helps tutors to understand the best practices for integrating technology into learning. Ruben Puentedura created the SAMR model as a way of enabling real-time interaction between teachers and students. The University of Central Florida created a checklist that mobile app developers can use to test the efficiency and applicability of an app in the modern market. The metrics under these guide lists include issues such as privacy policies, user guide, and the possibility of both desktop and mobile versions. A simple sample test study can be done to gather user sentiments towards the mobile app by asking questions related to accessibility, Family Education Rights and Privacy Act (FERPA) compliance and opportunities for learner feedback.

3. **The Internet of Things (IoT) -** Samuel (2016) defines the Internet of Things as a plethora of tools that have optimal processing speeds to share information from one network to another. The difference with information transfer from other technologies is that IoT permits remote monitoring, tracking, and forewarning about any suspected unauthorized use. According to Cadwell and O'Brien (2016), the use of this technology is not limited to educational institutions as other municipal governments have shown interest in connecting their networks using this system, to restructure the process of sharing data from one department to another. Given the ever-changing nature of the technology industry as well

as the increasing complexity of most gadgets in the market today, it is essential that educational institutions need to study the implication of the overall security of users and prevent any potential breaches by uncouth hackers. In this regard, it is expected that there will be an increase in focus on engineering students to expound on the security measures of internet designs to avoid the pitfalls of legal and ethical considerations. Engineering students have the best environment for doing research projects on IoT devices, as institutions invest significantly in the subject area. The most common IoT gadgets include Apple Watches and FitBits, which have resonated with a significant percentage of the consumer market. In a study by Gartner in 2015, the author predicted that nearly every gadget in the year 2020 would be interconnected while the IDC (International Data Corporation) also expects that the total demand for tech gadgets will surpass the $1 trillion mark (Rhea, 2017).

According to Olavsrud (2016), the implication of technology on social services is exemplified by the formation of smart cities that use registered users; they have gadgets to analyze real-time data as a way of determining the deficiencies present in the current system that need to be scheduled for improvement. One of the leading cities in implementing this technology in Copenhagen, here smart LED streetlights that can detect road users during the day and night, and then illuminate the road for users only when they are detected; this system helps to save on financial costs and reduces unnecessary use of public resources. According to the Computer Business Review (CBR), another good example is the Dubai 2021 project, which was initiated as a way of introducing consumer traffic mobile apps and sensor cameras that will make the city's roads usable by computer-controlled cars. To reduce potential accidents, the city government initiated a parallel program for installing over 250,000 smart meters by the end of this year to provide more analytical data for the database that will control the whole moving across the city (Neckermann, 2017).

Concerning higher education institutions (HEIs), internet of things (IoT) is expected to introduce a new approach that presents novel opportunities of improving the learning process as well as the existing infrastructure of the institution (Gul *et al.,* 2017). Two of the crucial positive effect of IoT mainly revolves around, on the other hand, the shift from a typical teaching practice where the teacher is the focus to the student-oriented learning and the various positive changes, which are introduced to the educational infrastructure. These form two perspective of comprehending IoT in education. On the other hand, IoT has been able to connect researchers and several universities in real-time as a way of supporting collaboration (Abbasy and Quesada, 2017; Gul *et al.*, 2017). Additionally, the IoT has enabled researchers to access a significant data volume as they seek appropriate solutions to the existing problems as well as identify potential research areas (Abbasy and Quesada, 2017).

Despite these expected benefits, leaders have to contend with the possibility of a surge in Smartphone use, if nearly every person has their personal device or other devices switched on concurrently. For instance, many people use a phone, smartwatch, laptop, and probably have access to other mobile phones at home. The bandwidth requirements for all these people to connect their devices to the network are a legitimate concern, considering the instances of network inaccessibility or breakdown when there are too many users. This is in addition to the ethical concerns of student data privacy when the personal, financial, and technical data trail is easily accessible to third parties (Kylie, 2016).

Continuing with the expected implications of IoT on the infrastructure of universities, there is the apparent acquisition of skills by students that will permeate the workforce environment. This assertion is backed by a study conducted by Cybersecurity Venture Market that shows that the market demand for students with proficiency on Internet/information security will rise to a global total of six million, an expected shortage of 1.5 million, considering the future projections based on the number of graduates annually simply possessing knowledge on information security guarantees to improve a student's quality of life while on campus as well as their chances of securing employment opportunities upon graduation. According to Saarikko, Westergren and Blomquist (2017), the number of students and faculty members that use the institution's Virginia Tech to access their security alarms and receive email alerts has risen significantly.

According to Saarikko, Westergren and Blomquist (2017), the University of New South Wales is using sensors that automatically design the internal process to optimize energy consumption while not compromising on the connection speeds. These sensors are used to collect data on student movement across university groups, which are positively used by group leaders to schedule activities or for emergency response services. According to Horn (2016), which focuses on higher education-related news, this technology can also be applied to track the health of students, such as potential students going through depressive states, depending on their meal plans or the tendency of oversleeping. Successful implementation of the said technology to improve service delivery is dependent on the proper adherence to ethical standards and legal requirements to avoid the misuse of data collected and the possible breach of student personal privacy.

In another study, scholars at the University of Texas Arlington, working in the department associated with the esteemed LINK Lab, conducted a study to determine the relationship existing between emotional wellbeing and learning. To determine the emotional wellbeing, the researchers used wearable technology that analysed biological factors which were then compared to given corresponding emotional states. In another study at the University of the Pacific, the researchers used sensors attached to students' chairs to determine the relevance of posture and skeletal position on student aptitude during class. In all these studies, the essence or implication of the results collected is to determine the relevance or expected impact of the technologies on student performance through identifying the approaches that make it easy to analyze and cause change (Grush, 2016). In the presence of an expected rise in the popularity of IoT, it is the opportune time for educational institutions to encourage young students to be creative and innovative with modern approaches to improving the learning experience. An event at Texas A and M University was reported such that during the program titled Aggies Event; students were engaged in a competition to judge who has the best IoT innovation idea in collaboration with Texas Instruments and Accenture, who provided mentor assistance. To show the impact of such programs, it is essential to look at the winning ideas from the contest, such as the LED projector for advertisements, laundry facility for shared households. Other universities offer students the choice of majoring on IoT as a way of producing graduates that can provide impactful technologies in industries such as healthcare, retail, and transportation (Yang, Kumara, Bukkapatnam and Tsung, 2019).

4. **Next-Generation LMS (Virtual Learning Environments)** – Learning management systems (LMS), use a mixture of software and web-based analytical tools, so that lecturers can supply students with course materials while at the same time track the student's use of the materials to note who absconds from reading the materials. This is the most common type of technology used currently by administrations to assess the online and long-distance learning students. The type of centralized management capability offered by the system gives lecturers complete control over the online students' schedule and performance assessment. Some of the services offered to students on this platform include the possibility of reading notes, viewing video materials, doing online exams, and accessing grades on the same platform, without the need to be physically present on university premises. There are also chat areas for communicating with peers or for the few cases when students require further clarification from the tutor. Opponents of this approach argue that it is merely a restructuring of the current system of learning without significant improvements in the process of learning from the perspective of students (Ismail and Salih, 2017).

   According to Finkelstein and Winer (2015), the definition of Next-generation LMS (NGDLE) is a system of integrated tools and frameworks for classroom learning that satisfy the need to improve formative learning by students while maintaining the standard requirements for any learning environment. As such, this is not a single application, instead of an interconnected network of different systems that collaboratively support the learning experience through diversified applications. Some of the known brands in today's market include Canvas, Sakai, and Edmodo (Phil, 2015). Despite the apparent takeover of this sector by these big companies, numerous small-time players have introduced online modes for specific courses that are not affiliated to a single business entity. These open-source applications include the OpenEdX and the Helix LMS, which are common among business entities looking for short-term competency training facilities. The NGDLE is driven by the desire of tutors to move from the out-dated specific curriculum to the use of more personalized and open-ended content materials that are presented to students in a unique manner irrespective of the app being used.

   Two areas that have experienced changes due to the above technology include the adaptive learning and dynamic social exchange platforms, for students who use advanced models, to resolve persistent challenges in the older models. According to Matijašević-Obradović, Banović and Joksic (2019), the 2017 Higher Education Expert Panel report asserts that many of the organizations remanufacturing LMS technologies are unwilling to abandon control of the decision on where and how to use the technologies. Instead, they prefer to define the implementation of the designs on projects that serve the organizational vision of the management of the company. As such, students are forced to use multiple apps outside of the LMS to maximize the learning experience when using software such as Word Press, iTunes U and Google App. On the other hand, the application of Open Education Resource and gaming technologies in the learning process has been shown to have a significant positive impact on student performance and the overall reduction of financial costs, without being necessarily integrated into the LMS network. As such, it is prudent that the current inventions are adaptive to possible changes in the technologies predicted through research materials (Adams *et al.* 2017).

To analyze the best platforms that will result in maximum performance improvement for students, the Bill and Melinda Gates Foundation initiated a research study titled EDUCAUSE in the year 2014 that would provide a holistic report on the needs and strengths of the current LMS landscape. At the end of the study, the researchers produced three different reports based on interactions with society leaders and students on aspects such as interoperability, privacy, accessibility, and the importance of a universal design recognized across the globe. This approach was termed as the 'Lego' an ellipsis for creating accommodative and responsive environments to the needs of the students (Brown, Dehoney and Millichap, 2015).

The resounding message that is universal among all research studies on Next-gen LMS systems is the need to focus on restructuring the learning environment to make it accessible to students rather than making it easy for tutors to do their administrative works. The out-dated designs that assumed that all students require a similar level of attention are being eradicated to include systems that respond to the requests of the tutors and the students while using the applications. Despite the challenges faced in making this dream a reality, various organizations are collaborating with educational institutions to provide the most efficient learning tool in the next few years.

While the Competency-Based Education (CBS) continues to garner more popularity in the modern learning institutions, there is still a need to ensure that the necessary foundations of learning, skill acquisition and examinations, are not forgotten. A good example is a project initiated by Grand Canyon University, known as the LoudCloud. This learning technique or tool applies the concept of shared resource databases and analytical tools that provide the interface for personalized student experience while using course materials. The Western Governors University technology of learning portals are designed explicitly for singular subjects and related activities, such as facilitating discussions and disseminating course materials within the portal, rather than providing a model LMS system. Another similar CBE platform is called the Acrobatiq, a product from Carnegie Mellon University in collaboration with National Louis University, which provides tutors with the freedom of customizing course materials using in-built analytical tools that recognize adaptive learning frameworks (Ronald, 2016).

The relevance of adaptive learning technologies in the creation of future LMS technologies is aided by the availability of past data that is analysed based on user trends and feedback. One adoptive learning technology that has shown promise concerning LMS technology is the Smart Sparrow. This is a technology that employs the use of visual content as the primary course material to determine how students perceive certain concepts to determine the misconceptions and common challenges students face. From this information, the next generation LMS technology can provide the best platform that integrates the whole learning experience from class grades to the social life of students.

The next phase of this technology will be to evaluate the possibility of self-directed course learning using the same nature of technology applied in the open-source applications. It is important to note that ‘self-directed’ does not mean coming up with a new course for personal purposes, instead of the possibility of customizing one’s learning experience into a package of various digital tools that are chosen by the student from a select number of options. For instance, the EdCast technological tool applies this concept by providing the user with selected course materials available on the LMS database with links to additional facilities depending on the specifications of the user.

5. **Artificial Intelligence –** This refers to the technological attempts of replicating human decision-making capabilities into computer intelligence that do not require human interaction for the functioning (Hammond, 2017). The way computers analyze data is based on the arrangement of zeros and ones (computer language) that does not consider other variables that affect human decision making. To rectify this, the concept of an AI will be able to imitate humans as much as possible through learning the way the human brain correlates information sets based on specific information provided, the existing relationships between the sets, and the role of human perception in the final decision-making phase. While AI does not necessarily do away with current machine languages, it will help without the limitation of restricted programming. One of the areas that have been difficult to integrate into AIs is finalizing the tests on AI interactions with humans to replicate human to human interaction. Explaining this requires the users to understand that the human brain has neural networks that automatically pick up on characteristics such as voice pitch and tone as part and parcel of the words being uttered by the person. If this is replicated with AIs, then it would be easy to replicate machine interaction with humans to emulate human conversations (David, Poole, Alan and Mackworth, 2017). From this snapshot of what AI technology entails, it is apparent that the education industry can reap significant benefits if new technologies could easily interact with the students similarly as a tutor.

   As with any technological advancement, AI serves the purpose of improving the social lives of human beings as well as improving the production and efficiency of processes that adopt the technology (Thomas, 2015). Using this argument, AI could be used to improve the provision of online course materials based on the data collected from students engaging with the machine and their performance after finishing the course (Constance, 2016). An essential by-product of increased technological integration is the amount of data collected from students that join higher education institutions annually that can be mined to infer trends and actionable information. Software such as the IBM SPSS and Jenzebar is the best statistical software that allows for such analytical purposes to determine trends such as dropout figures, future projections, and performance. The CBE programs that use technologies such as 3D printing will require more advanced levels of AI.

In the released reports from the EDUCAUSE project, Bill Gates mentioned that the future of learning is reliant on the advancement of AI tutors who will be able to accomplish administrative tasks faster and more accurately than human tutors. The number of hours spent by tutors reading students' work to assign grades can be accomplished much more quickly using AI technology. The possibility of combining AI and human beings is also a perfect prospect during online classes where the tutor has the role of only explaining the parts not understood by students, either by replaying the course material or answering directly to the questions asked (Casey, 2016). This proposed collaboration is most suitable for complex introductory courses that require the constant presence of a tutor to answer questions on areas that are not clear to the students. In a study conducted at the National School of Engineers in Tunisia, scholars concluded that AI learning tools could be designed to discern different facial expressions from students in a physical classroom setting or a virtual setting (Khalfallah and Slama, 2015).

The downside to the use of AI is associated with the ethical concerns that could yield learner discrimination as an unintended consequence due to the cultural differences and the range of mannerisms of different speakers (Julia, 2016). Despite these drawbacks, research studies into the potential implementation of AI in the education industry continue with selected universities acting as incubators. A good example is a technology that analyses still images and then predicts the expected scenarios that will happen soon that has been created in a project involving collaborative efforts between MIT and Artificial Intelligence Laboratory (Ted, 2018). Another case study of a research project involving AI is the ground-breaking study at the University of Zurich, which involves the creation of human-like robots. The essence of AI is providing technology that imitates human to human interaction without losing any of the characteristics that define humanity. The continued research projects in Brussels exemplify this; these researchers are on the verge of making robots imitate human ability to comprehend different meanings of one word in different languages or merely the ability to organize one's thoughts.

6. **Natural User Interfaces –** With every new day, technological companies introduce new gadgets that have in-built user interfaces that can be controlled through different actions by the user. Most common actions include voice-controlled interfaces, touch, or body

movement for healthcare-related gadgets. Smartphones were the trailblazers for gadgets that require specific human interaction, such as command language (Florence, 2013). Modern forms of NUIs have integrated systems that interpret human movement with specific actions, such that one person can use different facial expressions to command a different set of instructions. The advancements that have been made in the use of hand gestures is years ahead of relatively new technologies such as tactile sensations. This new technology expounds on the possibility of machines conveying information to the user through interfaces like those by which they receive the instructions. This is relevant in the learning process where feedback is frequent during engagement in class discussions (Taraska, 2015).

This research study attempts to analyse the application of technological tools in the education sector, and it is essential to analyze the prevalence of NUI in the healthcare industry. For instance, at Rice University, students of neuro-technology are creating a user interface that will make it easy for patients suffering from stroke to relearn body movements. The idea behind this technology is a wearable orthotic device that transfers electric waves to the brain or the exoskeleton on the body parts to which the brain signals movement. In a similar study at Stanford University, students created a technology called Wolverine, which has the capability to transform any rigid object into a virtual disposition that can be transferred to the human brain (Choi *et al.*, 2016).

NUI technology is best suited for patients with physical impairments such as visual disabilities. By using this example, a team of researchers are working in conjunction with the Arts department at the University of Michigan to create a browser display that applies the braille language to create pictorial presentations of content materials such as pictures and graphs (Angela Fichera, 2017). Another research team at Deakin University is involved in a project for developing a Haptic Enabled Art Realization (HEAR), which translates visual data into the braille language for visually impaired students. This is different from the electronic vibration device designed by a team of researchers at Disney Research, which uses the touch sensation as the interface between human beings and the gadget. Any slight change in the smoothness of any surface is relayed to the user. Application of this technology in the education sector is possible for students who can touch the interface of their devices to read and manipulate items through the user interface (Jake, 2016).

The bright and promising future trends in the application of NUIs is shown by the futuristic study at the University of Tampere, where a team of researchers are designing Digital Scents projects that can detect different smells through olfactory perceptions.

3.4.2.3. Electronic Devices for Education and Research

The presence of digital gadgets such as laptops and smartphones has become a common feature in the modern classroom environment, replacing textbooks as the most valuable learning object in higher education (Kay and Lauricella, 2015). For purposes of comparison and adhering to the use of terminologies in the subject issue, the term ubiquitous computing is used extensively in the study to denote a specific requirement for faculty members and students to use specific configuration settings that provide access to Wi-Fi (Fried, 2008). While this measure is to prevent unauthorized personnel from accessing the university internet network, it also serves the purpose of monitoring students' usage of computer within the campus premises and during class time. While it is inappropriate to expect the traditional approaches of teaching to work harmoniously with a class of students using laptops, some approaches can be adopted to improve the overall learning experience. In such a case, a prudent tutor will know that increased engagement will yield better results regarding comprehension and student performance (Blake, Bowles-Terry, Pearson and Szentkiralyi, 2017).

Many research findings show that the prominence of laptops within the classroom setting is gaining popularity as the current crop of millennials are knowledgeable in necessary computer skills required for learning. For instance, the use of the Internet to access reading materials as secondary sources of information or the use of simulation software to formulate ideas is common practice for young students (Kay and Lauricella, 2015). The result is that some tutors have decided to introduce subject-based software that focuses on the completion of one single task before proceeding to the next tasks. The plethora of databases accessible through laptops is also an opportunity for students to avoid having to carry heavy books to the classroom. Additionally, students have the freedom of analysing visual content or online past studies that relate to the subject they are undertaking (Kay and Lauricella, 2015). According to Engels (2016), a study conducted on Grade 7 students showed that they improved their academic performance after they could use computers in conjunction with other class materials during the whole period of the project. The world is experiencing one of the most revolutionizing times, given the substantial change that technological developments are facilitating in different sectors. There is no reason why the education industry should be so determined in remaining in the dark ages when there are newer and more efficient means to facilitate student learning using mobile phones. New York mayor has taken the mantle for this initiative by lifting a ban on using phones on school premises that have been in effect for the past ten years (Kay and Lauricella, 2015). This is the first step in providing an equal environment for students to access learning opportunities, in common with more progressive education sectors in other countries.

Cell phones provide the technologies that students in the 21st century is best accustomed to in their daily lives; thus, they are the best learning medium to help the students to retain the information presented to them. For instance, a study conducted by the Student Pulse Survey revealed that students prefer using interactive texts on digital screens rather than static textbooks in class. Nearly sixty per cent of participants in the study agreed that educators should re-evaluate course materials to include embedded digital texts and possibly video instruction manuals (Kay and Lauricella, 2015). Since many schools face the challenge of limited financial resources required for libraries, the platform provided by allowing laptops within school premises will provide students access to infinite databases of information on the Internet. The key to the effective integration of gadgets in the classrooms rests on the pedagogy of the tutor and the readiness of the institutions to allow digitals tools within HE classrooms (Kay and Lauricella, 2015; Mayes and de Freitas, 2017).

The process of acquisition and implementation of ICT facilities is a complex process guided by four elements across the whole industry. Migration from one system to wireless networks does not happen overnight as the management has to define the underlying motivations and elements that necessitate a change in technological applications (Mwenya and Brown, 2017). The four common motivations include; the need to improve academic performance, to reduce discrimination of students in accessing educational materials, to improve the skills of students to make them more valuable in the market, and to effect positive change in the teaching profession by adopting progressive strategies.

The application of information technology has spread in the past few years with computers and smart mobile devices becoming indispensable to our daily lives. Personal computers are vital for higher education communities as portrayed by the fact that an overwhelming 50% of students in Kenyan universities have personal laptops or access to school computers (Brault *et al.*, 2017). The other students are forced to look for computer services in places such as cyber cafés. In societies where many students face financial difficulties, it is critically desirable that the university management explore the possibility of building computer labs (Kashorda and Waema, 2014). All in all, electronic devices such as laptops and tablets influence the learning environment in higher education institutions by enabling quality research and improved student engagement.

3.4.2.4. High-Performance Computing

The advancements made in hardware computing technology has led to the creation of better, quicker computers that have high-speed processing powers that can solve robust mathematical equations in micro-seconds and carry out other processes such as simulations and data analysis (Cheah, and Lim, 2016). The essence of selecting high-performance computing technology in this study is based on the concept of integrating different algorithms and application software that can work harmoniously as parallel processes to accomplish a given task. The difference between HPCs and standard computer desktops is that the latter contain single processing chips. At the same time, the HPCs have numerous CPU processors in-built within the system to execute any number of programs concurrently, depending on the user requirements. While the use of HPCs is uncommon for private consumers, governments and big data companies have used HPCs to ensure minimal breakdown in processes that could cost millions in losses. The industries that have yielded positive benefits from the use of HPCs include the financial sector, healthcare, and transportation networks (Charter and Tischner, 2017).

Perusing through past reports on HPCs, it is apparent that financial investment into improving ICT facilities with HPCs is a sound financial decision as it positively influences production or research efforts in educational institutions. In the United States, the President's ICT Advisory Committee approved the increase of federal funding into research projects within the information technology sector (Dwivedi *et al.*, 2015). In a study conducted by the National Academy of Sciences in the year 2008, the leading team of researchers projected the relevance of Internet security on national security. The ability to provide a secure environment for the citizens within the country's borders, so that other activities such as learning and trade can continue without possible mishaps, can be aided using HPCs.

Every university conducts frequent appraisals of their research projects to appreciate positive results and to identify failing research studies. According to Ezell and Atkinson (2016), these measuring strategies are out-dated and do not account for all variables that are relevant in today's demanding market. Traditionally, the higher the number of research studies, the higher the score the university was awarded, without consideration of any other factors such as efficiency and productivity. After many universities adopted the HPCs, the performance measurements of research projects showed improved success rates and efficient re-allocation of resources to other departments (Apon *et al.*, 2015). The fact that local computers cannot be used to solve complex calculations that require HPCs means that every university must have at least one HPC resource within campus premises.

HPC can support scientific research in several fields. Most studies on the use of HPC has emphasized the need for increased investment and how it can influence research (Apon *et al.*, 2015). This suggests that HPC is expected to provide a wide range of economic benefits, which includes driving research and supporting the discovery of new insights regarding the present problems existing in the real world. However, these have focused on the research output and wholly ignored the extent of the operation, the level of efficiency and productivity generated from the research output.

3.4.2.5. Remote Computing Facilities (RCF)

One significant challenge confronted by educational policymakers and researchers is associated with the use of remote computing facilities (RCF). According to Trucano (2014), RCF is composed of technology-empowered solutions tailored to resolve an aspect under challenging conditions. When such solutions cannot be replicated in the scale, it is often perceived that ICT is ineffective.

A review of existing literature studies related to RCF indicates that there is a more substantial need for seamless access to e-resources remotely by the researcher (Rao and Bhat, 2018). This is especially common among researchers who are located offsite the research labs and seek to access data and facilities remotely using the RCF. Rao and Bhat also indicated that authentication is a significant problem that affects access to RCF. In this research, the use of RCF is a view from two scenarios. First, when the facilities are not always available within the institution's premises. Second, when the researchers or the lecturers are away from their respective universities, and they need to access resources remotely, without a break in the information.

According to Tusubira *et al.*, research output in Africa is lower compared to other nation. One of the reasons for this is the lack of laboratories and other ICT related facilities that can support research. This challenge is primarily for science-based disciplines. This is mainly because cutting-edge research facilities, along with the skill to maintain and sustain them, cannot be achieved in the short term for African higher learning institutions. Those limitations can be overcome by providing access to remote computing facilities and laboratories for researchers, especially considering that modern research equipment is mostly computer driven. This should be combined with specific training in modelling and simulation; an area, which will reinforce advanced research (Tusubira *et al.*, 2011).

3.4.2.6. Institutional Network

These days, the institutional or campus network has become an essential asset for attracting and retaining the best students and faculty members, boosting learning and research, reaching off-campus students, providing lifelong learning, and creating a more collaborative learning environment. In addition to student expectations, however, a campus network must also meet the technical requirements of the university administration, staff, faculty, and IT department.

A 2016 review from Michigan State University, examining 15 years' worth of inquiries, reported that giving each school learner a PC had a statistically substantial progressive effect on student test scores in all subjects (Herold, 2017). As a result, most of these students were "digital natives" by the time they entered college or university. According to a 2016 study from the Educause Centre for Analysis and Research (ECAR), 78 per cent of students agree that the use of technology contributes to the practical completion of courses (ECAR, 2016).

According to an Internet World Stats study, nearly 57 per cent of the population will have an Internet connection in 2019 (Internet World Stats, 2019). According to Vala (2014), of the sales force chief digital evangelist study, when asked about the importance of Wi-Fi, 60 per cent reported that they could not go more than one day without Wi-Fi. As a result, students expect Wi-Fi to be on campus, to use Wi-Fi for everything, from their laptops, tablets, and smartphones, to their gaming systems, televisions, and streaming video services. Moreover, they want to be able to connect everywhere on campus, from their classrooms and dorm rooms, to the cafeteria, common areas, and even in sports stadiums.

University administrators, including chancellors and vice-chancellors, want to leverage technology to create an environment that attracts more students, enhances the success rates of existing students, enables more advanced research, and improves the rankings and reputation of their school. Naturally, the administration will also have budget concerns, but most will understand the importance of building a secure and robust network, with excellent coverage for the entire campus. Many professors in engineering and science faculties have labs full of sensors and actuators. Typically, they prefer dedicated networks with specific requirements. And, in many cases, they do not want to ask the IT department for approval for every device that is added to their network. Proper integration of ICT with the educational system increases the quality of education, which eventually increases economic productivity. To prepare the student for the digital world and to serve them with a high-quality education, cost-effectively, many institutions are incorporating ICT into their education, administration, and research programs. However, many developing countries have a problem with hardware, software, and access to reliable network connectivity (Kaiwartya *et al.*, 2016).

Wi-Fi services provide Internet connections for students and teachers to access a wide variety of information with a simple click of the search button. If implemented, this technology will enable future personnel and students to work efficiently and improve instant communication between departments. The benefits of Wi-Fi are associated with the benefits of quick Internet connections such as the possibility of doing videoconferencing, attending online or virtual classroom platforms and the incorporation of social media tools in the curriculum. The commonality of modern gadgets in accessing Wi-Fi networks across smartphones also ensures that nobody is exempted from enjoying the services due to the lack of a personal computer. Wireless technologies provide a more convenient option compared to wired networks that limit the area of access and require an Ethernet cable to access Internet portals.

3.4.2.7. Overall construct

The summary of the constructs that were utilized in developing the theoretical framework is presented in Table 3. 1. The main aim of the constructs and measures was to recognise and analyse the required NREN services by end-users in the evaluation of the developed constructs in the theoretical framework. The end-goal was later to understand the requirements for improvement and to use for the development of the NREN service portfolios, setting up a clear roadmap for EthERNet's influence on higher education and research output in Ethiopia.

NREN can provide many services for higher education to increase the quality, equity and significance of higher education and research output, specifically for developing countries, which have a shortage of resources and skilled human resources. A dynamic higher education ecosystem is essential to provide opportunities for learning and advancement in the higher education society. As explained in the above section, ICT is impacting the technology trends in higher education; hence, NREN services are useful and positively influence the quality of education. NRENs offer new opportunities for the higher education sector to produce, disseminate and apply knowledge in a collaborative way. These opportunities can only be grasped if researchers and lecturers have the required attitudes, skills, and knowledge to apply in the field of ICT in a meaningful way. Solutions and services that can be provided by the NREN for member institutions such as video- or web-conferencing, collaboration tools, open access, Open Education Resources (OER), digital library resources, Massively Open Online Courses (MOOCs), institutional emails and social media all of these offer essential prospects to develop the value of education and research output if correctly applied. Technical support personnel also need to be in place to provide the necessary back-up and support to make good use of pervasive ICT tools.

This study has already substantiated the opportunities available for RENs to be applied to improving the overall quality of higher education and research projects in Ethiopia. The first effect is produced by the availability of fast speed Internet connection that makes teaching easier, learning more resourceful and completing research projects possible in a shorter time. African countries such as Ethiopia are indeed lagging in the IT sector; nevertheless, connections to the resources and database of universities in other countries provide sufficient academic data to carry out informed research projects. The essence of RENs is the possibility of collaborating with faraway institutions to create an online community of people with similar objectives. In the subsequent sections, this study aims to investigate the relationship between the different actors, technology, quality of higher education and the research efforts of scholars in Ethiopia, through the technique of ANT. This technique is relevant since it enables the categorical analysis of different aspects of the network while investigating the possible reasons that can either lead to successful implementation or failure.

Various scholars have explored the association between research output and the quality of education from a university perspective. Cadez, Dimovski and Zaman Groff (2017) discovered that the quality of research was positively related to the quality of education when they surveyed multi-disciplinary areas in a research-oriented university. From an African perspective, most university institutions have relied on the development of robust communication network infrastructure and networked services to support research output and the quality of education (Kashefi *et al.,* 2018). Some of the factors considered by Kashefi *et al.* (2018) have an impact on the association between the research output and the quality of education. These include the presence of online conference and academic articles, provision of research services and access to high-performance computing facilities. These factors are conceptualized in the study to examine the association between education and research in institutions of higher learning, and the identification of actor-networks.

Sedivy and Chromy (2015) examined the various electronic devices that are most likely to be used in educational activities among students and lecturers and discovered there was an apparent discrepancy in the preference between the different groups. For instance, students preferred the use of mobile devices as a means of communicating while lecturers opted for iPads. However, teachers' preference was influenced by the absence of suitable software that was developed explicitly for iPads. Oludeyi, Adekalu and Shittu (2015) discovered that the use of electronic devices during the learning session could positively impact on the performance of lecturers as well as improve the quality of education offered. Regarding the use of electronic devices for research, no study has comprehensively examined how the devices have impacted on research output apart from Kashefi *et al.* (2018). They discovered that laptops are familiar to researchers as compared to other electronic devices. According to Delaney (2018), high-performance computing is critical in supporting both education and research to provide clear pathways for resolving common aspects. Even though there is a stronger tendency to have efficiency networks, most institutions of higher learning have treated data in isolation. Delaney further added that HPC had empowered researchers to concentrate on their research work, come up with innovations, and enhance their collaboration among researchers.

From the perspective of the institution, remote computing facilities are expected to provide educational activities by offering specialized teachings. Trucano (2014) indicated that among others, has provided useful guides, which can assist during the implementation of educational technologies. On the other hand, RCF provides remote access to critical data, and the findings can easily be shared with other researchers. This suggests that the remote computing facilities can provide remote access to data, results, as well as procedures used for examining the data.

According to Kashefi *et al.* (2018), institutions of higher learning in African countries are in dire need of institutional network that is linked with an external network. In most cases, this type of network can never be provided by the global community. Kashefi *et al.* (2017) added that institutions have only been able to access institutional networks through improved bandwidth, adoption of other nations' NREN and increased partnership. Institutional networks have improved the quality of education by introducing new aspects of how teaching can be achieved; however, lecturers are left with the responsibility of choosing the type of technology. Andreoli *et al.* (2017) created a platform, which provided a model upon which three institutions of higher learning were able to support their research activities and improve the quality of education. These variables are used by the study to understand the impact of reliable networks on the quality of education and research output. The theoretical framework based on the identified variables is presented in the subsequent sections.

Generally, this theoretical framework will facilitate an investigation into the interactions between higher education research and education activities, the development of actor-networks, and the elements that impact the functioning of these shared relationships, in the perspective of improving the quality of education and research output at Ethiopian higher education institutions (Paledi and Alexander, 2017). These associations are hypothesized in Figure 3. 2. There are two main components. The first one focuses on the factors, influencing the quality of education of actor-networks. Based on the details of existing studies on higher education that have already been discussed in this chapter, the four factors, NREN Service for Education (NSE), Electronic Devices for Education (EDE), Institutional Network for Education (INE) and EthERNet are the most likely ones to influence the Quality of Education (QE) in Ethiopian higher education institutions. The second main component focuses on the factors influencing the research output and its actor-networks. This chapter has already discussed the details based on the existing studies in higher education, showing that the five factors, i.e., NREN Service for Research (NSR), Electronic Devices for Research (EDR), Institutional Network for Research (INR), Remote Computing Facilities (RCF) and High-Performance Computing (HPC) are most likely to influence Research Output (RO) in higher education institutions. Additionally, the provision of reliable networks and enough bandwidth has a positive impact on the improvement of institutional ICT infrastructure and service and provides researchers and educators with a reliable and stable campus network. By viewing the end-user requirement perceptions of higher education communities along with the identified challenges, it is then possible to provide all the required NREN services to improve the quality of education and research output.

The Theoretical Framework used to develop the NREN services portfolio and roadmap is presented in Figure 3. 2. Also, the responses from lecturers, researchers, ICT directors at Public Universities in Ethiopia were empirically tested to justify the applicability of the proposed theoretical framework in real situations. The data gathering method and the outcomes of this evaluation are discussed in Chapter 4, 5 and 6.

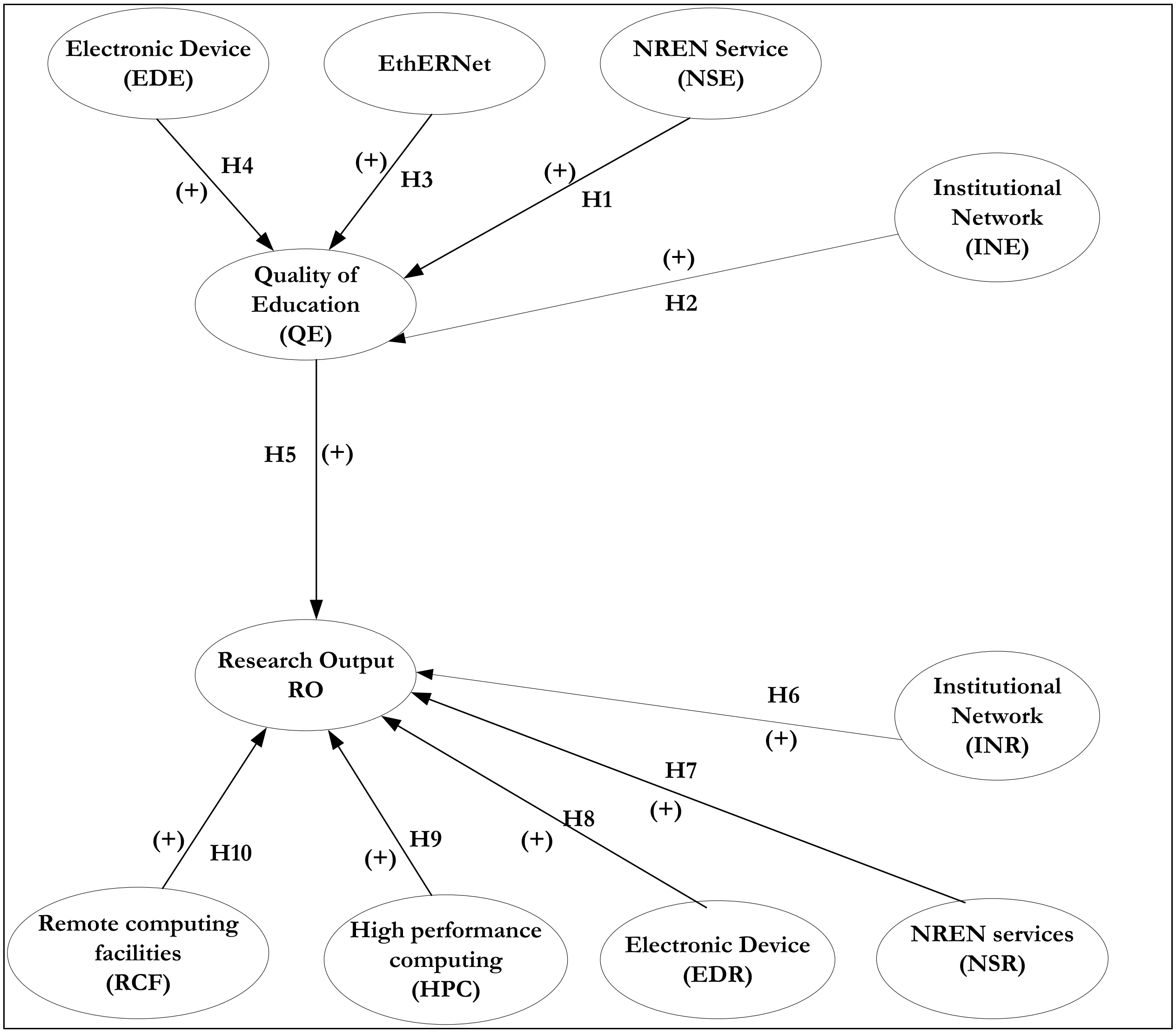


Figure 3. 2: The proposed Theoretical Framework

3.4.2.8. Empirical Testing of the Theoretical Framework using the Design Cycle

As the core objective of the study, to do the impact of the national research and education network on the quality of education and research output, the case of Ethiopian EthERNet has been taken. Based on the design cycle of the adopted 3 phase design science approach, to justify the proposed theoretical framework and to determine the potential relationships between the constructs in the framework, it is required to be applied within a relevant contextual environment.

Since the major aim of the research is developing a theoretical framework, which will be used as a base to identify and analyze end-user requirements at Ethiopian higher education institutions and to use for the development of the NREN service portfolios and roadmap that effectually assist in improving the quality of education and research output via the aid of EthERNet, an exploratory study was conducted at Ethiopian public universities, and EthERNet and PLS analysis were therefore applied to test the practicality and applicability of the theoretical framework. This could also help to understand better the extent to which the proposed theoretical framework could be applicable in real-world scenarios as it will be presented in Chapter 5 with the hypothesised theoretical framework.

3.5. Summary

To conclude, this chapter incorporated the proposed theoretical framework and the different aspects needed to understand the relevance of research output and the quality of education. Moreover, the chapter discussed the details of the actors involved, the constructs and the factors influencing the actor's involvement in higher education and research institutions. Also, the concept of design science was elaborated, and the cycles involved well discussed. A thorough look into the synergy between design science, constructs, ANT method, and theoretical framework is sufficient to form a solid ground for the study.

Chapter 4: Research Design and Methodology

This chapter reflects briefly on the conventional approaches and on the methodology applied in this study for answering the research questions posed in Chapter 1. The presentation of the study design and methodology includes a brief introduction, purpose, approach, discussion of the research design, population sample, research instruments used, data collection procedure and an outline of the data analysis, consistency and rationality of data, and finally the ethical considerations.

4.1. Introduction

This research uses a quantitative research design to investigate the Impact of EthERNet on the performance of education and research in Ethiopian higher education. It identifies the NREN services required by end users and addresses challenges faced by Ethiopian higher education institutions with regards to their network. Furthermore, it examines the capability of EthERNet to develop a better quality of education and research output by establishing a service portfolio and adopting a recommended roadmap to enhance the efficacy of the establishment.

Research can be quantitative or qualitative. Ong and Puteh (2017) define quantitative research as a type of research that employs numerical data only as of the input into the data analysis tools, to determine the existence of a relationship between the different variables. Quantitative data can only be collected through specific data collection approaches such as surveys or sourcing data from existing past research studies. Quantitative research examines the relationships that occur between two or more variables. Quantitative research designs support a descriptive framework for different variables in the study for explorative purposes. This study employs a positivist approach to the analysis and the process of data collection. Schoonenboom and Johnson (2017) indicate that quantitative designs often involve more breadth but less depth. Quantitative or positivist studies attempt to capture a population's characteristics by making interpretations and inferences from looking at the characteristics of a sample. Generalizations about findings are then made and presented based on the inclusion criteria of the sample and the legitimacy of the design (Kennedy-Martin, Curtis, Faries, Robinson and Johnston, 2015).

This study employs the use of a limited positivist deductive approach where generalization and interpretation of the results were limited to the descriptive framework. The restriction of the sample size was attributed to the use of limited responses from the respondents. The final aim of the study is to develop with an NREN service portfolio and a roadmap for EthERNet. According to Sutton and Austin(2015), before initiating any research, it is essential to identify the methodology to be employed and, in this case, explain how using specific data collection strategies will yield relevant data that can be acted upon after completion of the research. The researcher adopts a positivist epistemological standpoint that aims to recognize end-user requirements and challenges in their network and in using EthERNet in higher education institutions. This is consistent with a quantitative research model. This research was approached by firstly observing an overall presentation of the strategy, the research procedures, data gathering, data analysis tools and research ethics. The right study strategy was then identified based on the research questions chosen.

Figure 4. 1 below shows the overall research methodology and includes the components, which are used for this research.

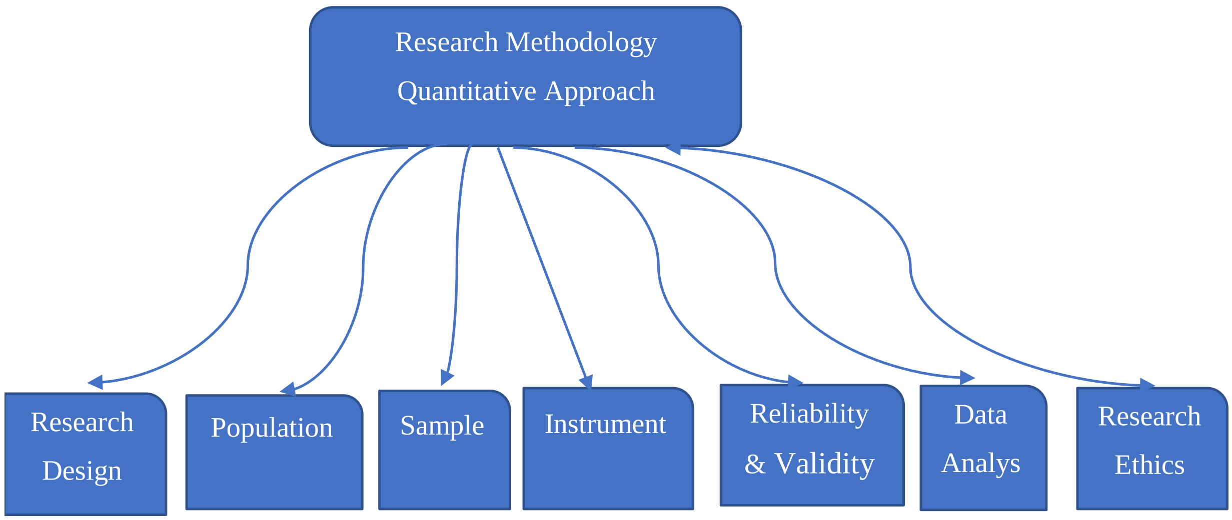


Figure 4. 1: Summary of Research Methodology

4.2. Research Purpose

Quinlan, Babin, Carr and Griffin (2019) distinguished research purposes to the overall objectives. The authors further define the scope of exploratory research studies to encapsulate the investigation of specific problems without necessarily being driven to yield actionable solutions to the problems. In such a case, the research problem is not yet fully defined, and only a partial section of the problem is analysed. Quinlan, Babin, Carr and Griffin (2019), provided three primary ways that researchers use to gather information during the fact-finding process; an extensive review of previous cases, interviewing subject matter experts or conducting focus groups discussion with peers interested in the research problem. According to Schoonenboom and Johnson (2017), surveys provide the best approach to studies relating to technological concepts since it allows the researchers to collect quantitative data; data collected is relatable to the respondents and to the possibility that the researcher has prior knowledge of the subject under scrutiny.

In this study, the researcher used an online survey questionnaire to identify essential NREN services that meet end-user needs in Ethiopian public higher education institutions. A literature or document review search was also done. Most questions used in the questionnaire were structured and closed; only a few were open-ended.

4.3. Research Approach

A deductive research approach relates to quantitative research designs, and an inductive research approach relates to qualitative research designs (Creswell and Creswell, 2017). Since the nature and purpose of this research are to explore, describe and comprehend the situation with regards to the challenges faced by those who use NRENs effectively, a quantitative research design was used with a focus on getting descriptive rather than deductive results. This was achieved through document and data review, frequency table and bar charts. Even though quantitative research approach is economical, however, this was not the main motivation for choosing this path. The potential of quantitative research style to assist in sourcing for existing data, and in performing appropriate numerical analysis that would support the hypothesis of the research was the major drivers for choosing this research style. Therefore, a quantitative approach seemed more suited than the mixed one (qualitative/quantitative)

4.4. Research Strategy

Among the research strategies identified, surveys were deemed of uttermost importance. The surveys conducted allowed the gathering of data from a large sample population, while maintaining the possibility of augmenting data using different sources, including primary ones (Quinlan, Babin, Carr and Griffin, 2019). The use of the survey questionnaire allowed the researcher to collect data from the respondents by using questions that reflected values or weights (Hendricks, 2017). The survey was initially subjected to content validity and test-retest reliability to examine the consistency of the data collected. Hence, the strategy applied in this study primarily surveyed.

4.5. Research Design

This research employed a non-experimental research design, given the features of the design in determining the variables that should be given priority treatment. (Greenfield and Greener, 2016).

For the proposed quantitative approach, a structured questionnaire was be used to collect data regarding the existing situation in Ethiopian higher education, to investigate the impact of NREN services on the quality of education and research output concerning the challenges faced when using the EthERNet. This data was being used to develop an NREN service portfolio and roadmap framework used as a guideline for the service that could be provided by EthERNet.

By using a descriptive research strategy, the research can describe the link between; the services required by the end-user, enhancing collaboration and the possible challenges it may experience. For the quantitative approach, a structured questionnaire was used to gather data from the respondents regarding the requirements of the end-user, NREN services and resources required, and the challenges faced in using the network infrastructure and EthERNet. The questionnaire was administered using LimeSurvey online tool, and hence, most questions in the questionnaire were deliberately made close-ended to reduce item non-response. According to Quinlan, Babin, Carr and Griffin (2019), literature research is used for the evaluation and assessment of current methodologies, and investigations and descriptions of case studies. This suggests that a literature search can be used for evaluating ad-hoc problems and other specific knowledge. The outcomes from the literature search in this research helped the researcher to study the existing infrastructure and services provided.

4.5.1. Questionnaire Design

The questionnaire used in this survey was specially prepared to enable the collection of relevant data that can help understand the impact the NREN services in higher education institutions in Ethiopia. The questionnaires were derived from the proposed theoretical framework and the literature provided in this study. Knowing that the projected theoretical framework was made of 11 latent variables, a survey that consists of the variables was distributed amongst the network and actors of 29 public universities in Ethiopia’s, and a total of 110 responses were received. This was further analysed and evaluated. Some of the key characteristics that had to be adhered to during preparation of the questionnaire included; reliable measurement stipulations and a representation of a few open-ended questions in addition to the predominantly closed-ended questions to ensure respondents had the opportunity to provide any additional insights about the subject under investigation. Respondents were provided with support if they had questions about some aspects within the questionnaire. The survey was divided into four main parts: For university staff members involved in the teaching and learning process and those who required NREN Services for their work, for university staff members involved in research and those who required NREN Services for their work, for ICT directors managing the campus network and for EthERNet staff. Respondents were able to fill in all sections if they so wished. Most of the questions asked for responses using the Likert-scale and rating ranging from strongly disagree (1) to strongly agree (5). This is was deemed appropriate since it provides a uniform method of gathering data (Eutsler and Lang, 2015).

Additionally, the use of likert-scale method allows the analysis of data, reporting of findings. In the study conducted by Rogers, they developed a five Perceived Characteristics of Innovation (PCI) scale that could evaluate consumer goods. However, only two items could only be used per perceived feature, with no reliability coefficients (Rogers, 2015). Additionally, the use of likert-scale method allows the analysis of data, reporting of findings. In the study conducted by Rogers, they developed a five Perceived Characteristics of Innovation (PCI) scale that could evaluate consumer goods. However, only two items could only be used per perceived feature, with no reliability coefficients.

4.5.1.1. Variables of the Study

As explained in Section 4.5.1, data gathering techniques focused on four main areas. At the same time, the research model for this study consisted of 11 latent variables or constructs (refer Section 3.3 and Table 3. 1). The data collected through the questionnaires involved 59 different items that would help analyze the existing relationship between the variables (refer Table 4.2 - 4.12).

All constructs (59 items) used in the questionnaire were developed after careful deliberation between the researcher and the advisor, and by referring various related reference materials, which provides rich information on the best approach to use. For instance, the decision to categorize two latent variables as formative meant that they are considered to cause the latent variables of the study. In comparison, the remaining nine latent variables are reflective meaning that the indicators reflect the latent variables. The motivations on how the latent variables were categorised into formative and reflective are explained in Section 4.9.2.

All the variables or constructs in the proposed theoretical framework are included in the survey. Table 4. 1 provides the items in the questionnaires and the constructs used in the research model.

Table 4. 1: Constructs in the Research Model and Associated Questionnaires

Construct	Items in the questionnaires.
NREN services for educational and research (NSE and NSR)	Part A - Q. 7 And Part B - Q. 20
Electronic devices for educational and research (EDE and EDR)	Part A - Q. 9 And Part B - Q. 21
Institutional network for education and research (INE and INR)	Part A - Q. 10 & Q.11 And Part B - Q. 22 & Q.23
High-performance computing (HPC)	Part B - Q. 19
Remote computing facilities (RCF)	Part B - Q. 19
EthERNet	Part D - Q. 3 & Q. 7

4.5.1.2. Quality of Education and Research output Construct

Several constructs were created, which support the study in developing measurement scales that can quantify the Quality of Education and Research Output. Each of these constructs comprises of several scale items for which the research participants were requested to provide their responses. The scale items were limited to the research participants’ understanding of NREN services needed by the end-user, the challenges, and the impact of EthERNet. Tables 4.2- 4.6 indicates the latent variables representing the Quality of Education (QE) while Tables 4.7 - 4.12 indicates the actions and latent variables, which represent the research output.

Table 4. 2: Institutional Network for Education Construct: Scale items

	Institutional Network for Education (INE); 5 items (reflective).
INE1)	I can easily access online materials without any network problems
INE2)	I can quickly put materials online without any network problems
INE3)	My students can easily access online materials online without any network problems
INE4)	I can easily access online software without any network problems
INE5)	My students can easily access online software without any network problems

Table 4. 3: NREN/Networked Services for Education Construct: Scale items

	NREN Services for Education (NSE); 13 items (reflective).
NSE1)	Unified Communication /Videoconferencing Services
NSE2)	Collaboration platforms including file sharing, event/calendar management and wiki.
NSE3)	Tools for Lecture Recording
NSE4)	Online Educational resources
NSE5)	Online Educational platform/LMS like Moodle
NSE6)	MOOCs for distance learning Massively Open Online Courseware
NSE7)	Digital Libraries and Repositories resources
NSE8)	Using local IDP to use other institute resources
NSE9)	Institutional Email service
NSE10)	Facebook
NSE11)	Twitter
NSE12)	LinkedIn
NSE13)	Research Gate

Table 4. 4: EthERNet for Education Construct: Scale items

	EthERNet for Education (EthNet); 2 items (reflective).
EthNet1)	I can create distance learning programmes in Ethiopia using EthERNet.
EthNet 2)	I can create international distance learning programmes using EthERNet.

Table 4. 5: Electronic Device for Education Construct: Scale items

	Electronic Device for Education (EDE); 3 items (reflective).
EDE1)	Fixed PC can assist students in having access to educational resources online
EDE2)	A laptop can assist students in having access to educational resources online
EDE3)	A mobile device can assist students in having access to educational resources online

Table 4. 6: Quality of Education Construct: Scale items

	Quality of Education (QE); 5 items (reflective).
QE1)	It will have a substantial impact on the teaching learning process and outcomes
QE2)	It will have a substantial impact on student's learning outcomes
QE3)	It will have a substantial impact on the students who receive their education via distance learning
QE4)	It will assist students in having a better education by interacting with their teachers remotely using unified communication system whenever required.
QE5)	It will encourage lifelong learning

Table 4. 7: Institutional Network for Education Construct: Scale items

	Institutional Network for Research (INR); 8 items (reflective).
INR1)	I can work with other international researchers without the network problem
INR2)	I can easily search journals, articles and online conferences using my network
INR3)	I can easily (be able to) access online journal, articles and conferences using my network
INR4)	I can access data sets easily using my network
INR5)	I can easily publish open access research online with my network
INR6)	I can access software online easily with my network
INR7)	I can publish software online easily using my network
INR8)	I can access remote sensors online easily using my network

Table 4. 8: Access to Remote Computing Facilities Construct: Scale items

	Access to Remote Computing Facilities (RCF); 1 item (reflective).
RCF1)	Facilities to access remote computing would empower me to complete research exercises that are as of now inconceivably

Table 4. 9: HPC Access Construct: Scale items

	Access to High-Performance Computing (HPC); 1 item (reflective).
HPC1)	High-performance computing access would empower me to complete research exercises that are as of now inconceivably

Table 4. 10: NREN Services for Research Construct: Scale items

	NREN Services for Research (NSR); 11 items (reflective).
NSR1)	Unified Communication /Videoconferencing Services
NSR2)	Institutional Email service
NSR3)	Collaboration platforms including file sharing, event/calendars management and wiki
NSR4)	Portal to give secure access to online information, application, sensors to help a research community
NSR5)	Digital Libraries and Repositories resources
NSR6)	Using local IDP to use other institute resources
NSR7)	Access to storage at the Data Centre
NSR8)	Social media/Facebook
NSR9)	Social media/Twitter
NSR10)	LinkedIn
NSR11)	Research Gate

Table 4. 11: Electronic Device for Education Construct: Scale items

	Electronic Device for Research (EDR); 3 items (reflective).
EDR1)	A desktop is helpful for researchers to have access to research resources online
EDR2)	A laptop is helpful for researchers to have access to research resources online
EDR3)	A mobile device is helpful for researchers to have access to research resources online

Table 4. 12: Research Output Construct: Scale items

	Research Output (RO); 7 items (reflective).
RO1)	It will have a substantial impact at national level on research outcomes
RO2)	It will have a substantial impact at international level on research outcomes
RO3)	It will empower the researcher to have a noteworthy national effect on their research outcomes
RO4)	It will empower the researcher to have a noteworthy international effect on their research outcomes
RO5)	It will help the researcher to start new partnerships
RO6)	It will empower the researcher to work with associates all over the world without leaving his nation of origin
RO7)	It will empower the researchers to work with their peers at different institutions all over the world

4.6. Population and Sampling

According to Quinlan, Babin, Carr and Griffin (2019), a research population is defined as the general population that should be studied, but due to financial and reliability concerns, a few units are selected, and this sample is used to represent the whole population. Alternatively, the population may also be defined as the total number of units (individuals, organizations, events, objects, or items) from which samples are selected for measurement (Mullinix, Leeper, Druckman and Freese, 2015). The study chose to utilize Ethiopia's higher education institution and its research output for the construct valuation in the proposed theoretical framework. This is because they are the major user of NREN for their day-to-day activities. Besides, they incorporate the usage of NREN into their system to improve their output. Hence, a good research sample.

In this study, the questionaries' are targeted the staffs at Ethiopian public universities (33 public universities were targeted during the study, who directly report to the ministry of Education) involved in teaching and research and ICT administrations. Accordingly, the targeted population is comprised of senior researchers and academicians, ICT Directors, and the Chief Technology Officer (CTO) of EthERNet. Even though students were not directly involved, but the ANT system that was deployed catered for all the active actors (human and non-human) that took part in the study and the perceptions of the students on the impact of the variables used to develop the theoretical framework has been included from the academic staffs. Hence, the results of the study are valid even without the participation of the students in the survey as the majority of their perceptions are addressed by their lecturers, which knows more about the existing situations inside their campus premises.

The ministry of education sponsored this research. As such, it provided meaningful assistance. Notably, this includes a letter from the state minister of higher education to the universities to provide all required support, as well as an exclusive group email from the Ministry ICT personnel management, addressed personally to all Ethiopian public universities' presidents, academic vice presidents and research vice presidents, as well as ICT directors to follow-up and provide additional assistance where necessary.

Consequently, the first step was to get the list of contact email address of senior researchers and academicians working at Ethiopian public universities. This was achieved by requesting the university presidents and ICT directors via the group emails to get the email address of the staffs within their research and education community. The academic and research vice presidents were also asked to forward a copy of the letter written from the Ministry to their School scientific directors, faculty deans and department heads who would, in turn, circulate it to their academic staffs to get their email address. Based on this, a list of 372 senior academic and research staffs' email and 33 ICT directors email addresses was documented to send the questionnaires' and to periodically remind them with the intention of hopefully ensuring a high level of timely response and delivery rate.

The survey consisted of a questionnaire in four parts. Part A and B were sent to academic staffs of the universities involved in teaching and research. Three hundred seventy-two people were reached by email to fill the survey. Part C of the questionnaire was sent for the 33 ICT directors of the universities, and part D was sent to the EthERNet CTO. The participation of the respondents was based on the email invitation. Out of the thirty-three Ethiopian public universities invited to participate in the survey, 29 (twenty-nine) responded to the survey. The researcher also tried to reign in order by actively discouraging unsolicited feedback that could come from any participant.

The study used purposive sampling to select a knowledgeable individual that can accurately distinguish the latent variables and quantitatively measure the variation of the constructs (Palinkas *et al.,* 2015). This was mainly proposed to obtain an understanding of individuals' views, which can provide relevant data to the study. In this case, the purposive sampling technique is considered as a non-probability sample, which is chosen while taking into consideration to what extent the participants of the study are knowledgeable about the study phenomenon. Additionally, the researcher used his personal judgement such as academic rank when selecting members from the research population. Time allocated for conducting the study is somewhat limited due to the need to maintain the associated cost at a manageable level. This was also intended to select participants that can answer questions in an informative manner, in alignment with the requirements of the study (Quinlan, Babin, Carr & Griffin, 2019). This is opposed to the use of random sampling, which is used primarily to increase the number of selected participants, as well as to enable the generalization of obtained results (Babbie, 2015). This is achieved by reducing the potential bias during the selection of the research respondents, thereby controlling the potential influence of formative and reflective variables. The selected participants were required to provide a filled-out consent form indicating their willingness to participate in the study before they were offered a structured questionnaire. Additionally, the participants were informed of their rights and privileges regarding responding to questions being asked.

4.7. Research Instruments

The study used questionnaires to collect primary data from the targeted respondents. The questionnaire had structured questions consisting of close-ended, multiple responses, scaled-responses, and ranking types of questions with a few open-ended questions. According to Ali and Bhaskar (2016), a Likert type scale was linked to many statements to measure perceptions (see Appendix 3). This is accepted as a universal method of gathering data that can easily be understood as it permits the easy drawing of conclusions, results, and visualization of the participants' responses (Bishop and Herron, 2015). Bishop and Herron further added that Likert-type responses need to be based on an accurate scale, which comprises of multiple-questions related to research phenomenon that provides a score.

In most cases, each Likert-response item is provided with a measurement scale that varies from "Strongly Disagree" to "Strongly Agree" indicating the existence of a dimension that is adopted. This was after they made a comparison between the use of the Likert-scale and obtaining individual Likert-type responses. Therefore, in this study, most of the research questions were constructed based on the standard Likert-scale model.

4.8. Procedure

The structured questionnaires were sent to the targeted respondents electronically via email links, and the survey was made available online using LimeSurvey and could also be downloaded from there. Emails had been sent which contains the objectives and aims. On the email, the links to the online survey and the soft copy of the document also attached. To reach potential participants, the researcher collected a list of senior staffs' email addresses from the universities. If undelivered email message was found the questionnaires were sent to the ICT directors of the respective universities to forward to the respondents since they have a database of email for all the staff. This was not difficult given that most of the respondents worked and lived in the same area in the vicinity of their respective universities

4.9. Data Analysis

Ali and Bhaskar (2016) state that to make sense of raw data, first, it is necessary to summarize it. The data received from the questionnaire respondents were classified and tabulated and were imported into IBM SPSS (v24) software for further analysis. Hence, descriptive statistical methods were used to analyze the NREN services required by the end-user. The graphs from the IBM SPSS (v24) were exported to Microsoft Word and mapped to the table. Pie charts, bar graphs and histograms were generated to present the data and analyze the tabulated results. The findings of the study identified the necessary end-user requirement, and the impacts and challenges that helped in developing the NREN service portfolio and roadmap for EthERNet and these are presented in chapter seven of this thesis. Besides, Structural Equation Modeling (SEM) was used as a statistical tool for analysing the data collected. The decision to choose the SEM technique was based on various reasons discussed in the next section.

4.9.1. Structural Equation Modelling

SEM is an advanced model that is essential in determining the relationships between different concepts in statistical research such as the significance of all the variables involved in the study, and how they help in arguing the main points. This technique has been widely used by researchers to solve multivariate related problems. The technique has been applied by scientists from other fields such as biology, marketing, economics, and medicine (Pugesek *et al.*, 2003). Besides, the SEM technique has been applied by scientists in the determination of significant null and alternative hypotheses that are contained in research datasets about technological advancement (Henseler, 2017). Essentially, the SEM technique is a model that relies on instrumental procedures to reveal different results when a scientist uses several variables in each piece of research (Postek, Vladár and Purushotham, 2014). As stated by Tarka (2018) and Rivera *et al.* (2018), structural equation modelling is characterized by two main procedures that make it stand out from other related techniques in science and technology. The first procedure entails the significant processes that show how regression analysis is conducted in a group of variables, rendering the research free of measurement errors (Henseler, Ringle and Sarstedt, 2015). The second procedure provides a structural model that enhances the conceptualization of the SEM technique holistically and the hypotheses that a researcher intends to analyze throughout the study (Tarka, 2018).

LISREL and PLS are the most used statistical software packages that adopt the SEM approach. They are both SEM-based; however, their estimation approaches and objectives are relatively different. Overall goodness-of-fit measures are one of the main measures used in LISREL, which evaluate how well the hypothesized model fits the experimental data (Jöreskog and Wold, 1982). PLS structural equation modelling (PLS-SEM) is grounded on a least-squares valuation with the main objective being to maximize the description of variance in the dependent constructs of a structural equation model and it is relevant while doing exploratory research (Nitzl, 2016). On the other hand, while using the PLS program, users are guaranteed that the software does not require specific measurement units (Henseler, Ringle and Sarstedt, 2015). Another reason for choosing the PLS program is its suitability when using small sample sizes, and the option of measuring formative latent variables essentially targeted for causal-predictive analysis. (Kock, 2017).

Hence, this study decided to use PLS-SEM to analyze the data for numerous reasons:

1) PLS-SEM is more regression-based approach that reduces the residual variances of the proposed constructs for the framework (Hair, Matthews, Matthews and Sarstedt, 2017).
2) The proposed theoretical framework in Chapter 3 should undergo empirical test based on the data collected from the Ethiopian higher education institutions. Because of its merit of predicting latent constructs, PLS-SEM is, thus, the preferred method to evaluate the framework and its applicability in real-world projects (Hair, Matthews, Matthews and Sarstedt, 2017).
3) Relatively, our study sample size is smaller with skewed variables; hence, PLS-SEM is the preferred method to analyse the data as it demands minimal input on residual distributions, measurement scales and sample size (Urbach and Ahlemann, 2010).

4) To assess the result of the study null hypothesis and the proposed hypothesised theoretical framework, PLS-SEM path modelling is the best approach for estimating causal models in many theoretical models and validation of the hypothesis (Henseler, Hubona and Ray, 2016).

In most cases, there are two types of variables involved, namely hidden variables and observed variables. Hidden variables entail the use of theoretical terms that are used in explaining the different concepts in a study. In contrast, the observed variables refer to the items measured by the researchers during a given study, and they are significant in explaining the results. According to Heale and Twycross (2015), hidden variables can either be dependent or independent, and the objects determine this understudy. Henseler, Ringle and Sarstedt (2015) have given varying definitions regarding the meaning of hidden and observed variables, which are widely accepted by many scientists all over the world. One of their rules is that a circle graphically represents the hidden variables while a square graphically symbolizes the observed variables. The two scientists further define a hidden variable as the one that is theoretically unseen but still relevant in the study. A hidden variable can only be determined from the examination of multiple different variables within the study (Berends, Smits, Reymen and Podoynitsyna, 2016). The literature review on SEM gives varied opinions on the aspects of both the hidden and the observed variables and the distinct relationships between them in a convincing way that leaves no doubts in the reader's mind. The measurement model of the hidden variable depicts a connotation of the two factors involved, namely; the reflective and the formative indicators that are significant in a statistical study (Chang, Franke and Lee, 2016; Park, Lee and Chae, 2017; Hair, Matthews, Matthews and Sarstedt, 2017). The following section gives an insight into the differences between the concepts of reflective and formative indicators holistically.

4.9.2. Reflective versus Formative Indicators

In business and marketing, the practice of measuring through prediction is categorized under the reflective indicators that are typically used in showing the differences in hidden variables contained in each study (Fuchs and Köstner, 2016). Considering this, the interconnection path is expected to join both the hidden and observed indicators, which is the primary function of the reflective indicators (See Figure 4. 2); thus, one would probably expect to see the variations in hidden variables contained in the variations already indicated in the observed variables (Cizek, Andrade and Bennett, 2019).

As earlier noted in Section 4.5.1.1, the study sub-divided the latent variables into two categories, namely formative and reflective latent variables. This is based on the idea that two formative measures caused the latent variables of the study while the remaining latent variables provided reflective measures on the study variables (Willoughby, Kuhn, Blair, Samek and List, 2017; Park, Lee and Chae, 2017). Various approaches exist that can be used to distinguish these two categories of latent variables into reflective and formative such as the use of correlation, using equations, shared or total indicators, among others. However, this study employs the use of statistical representation, such as confirmatory and exploratory factor analytic models to determine the difference between the variables. This is selected to determine the most appropriate constructs, which affect reliable networks.

Additionally, formative indicator theory depicts a movement of the interconnection of hidden variables in the opposite direction, and this explains why the content of indicators describes the meaning of the hidden variable (See Figure 4. 2). This observation gives an inference that one of the essential requirements for reflective indicators is internal consistency, but this does not apply in the case of a study that relies mainly on formative indicators (Thornton, Henneberg and Naudé, 2015).

In this case, the study employs on the data collected in correlation to reliable networks. The constructive indicators were not correlated while the correlation results of the reflective measures were contrary (Park, Lee, and Chae, 2017).

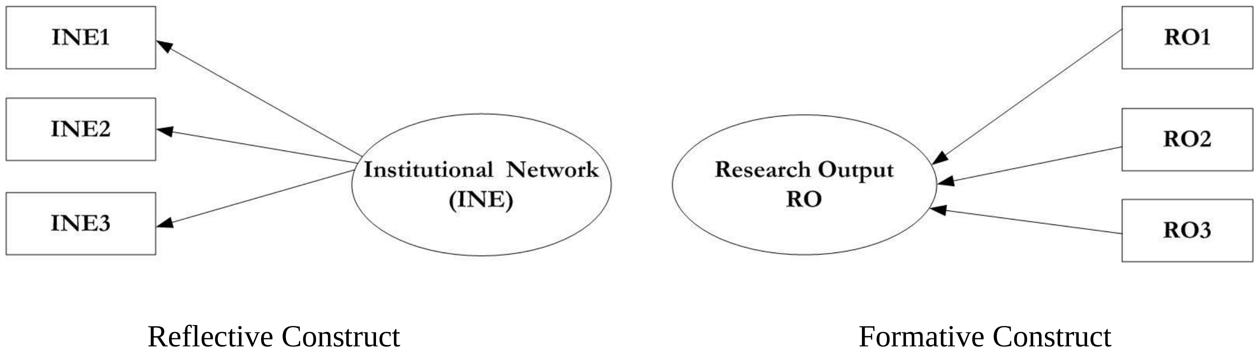


Figure 4. 2: Latent Variable/Casual Structured

According to Guyon (2018), there has been confusion in a lot of studies already conducted by scientists, whereby the scientists have mistakenly adopted the use of reflective indicators in studies that should have applied formative measurement theory. The inaccuracy arising from choosing the wrong indicators in a study disqualifies the research from a reference in future studies. It is inappropriate for any scientist to confuse the imperative such as using formative indicators in place of reflective indicators or any other kind of erroneous adoption of significant concepts in a study (Memon *et al.,* 2017). Cizek, Andrade and Bennett (2019) further added that the issue of misspecification of vital concepts in a study subjects the entire research to negative criticism, and it also interferes with the discussion and conclusions drawn regarding the conceptualisation of the hidden variables within the study. According to Steenkamp and Van (1996), the major statistical procedures used in the estimation of SEM are covariance-based and partial least squares path modelling. The discussion below will give a clear insight into the features of the Partial Least Squares Path Modelling (PLS-PM) method, which is related to this study.

4.9.3. Variance-Based / PLS-SEM

The Covariance-Based (CB) SEM method was designed many years ago as an approach that would apply to several types of research and could be used in conjunction with software such as SEPATH and LISREL. According to Heale and Twycross (2015), this method helps in reducing the difference between the calculated variables and the observed variables such that the extreme figures can be integrated into a goodness-of-fit graphical representation.

The PLS-PM methodology is employed as a means of maximising the calculated deviation of the dependent variables, which is used to calculate the covariance (Guyon, 2018). From the analysis, this is apparent as the estimates create a residual effect on the formative latent variables. The researcher has the option of using other software to calculate the PLS-SEM such as SmartPLS, LVPLS and PLS-Graph; however, The WarpPLS 6.0 was used for this study.

The PLS-SEM method has the benefit of being simple and easy to calculate if all the weight relations are provided following each latent variable estimate. The researcher should assign case values to all the constructs, which are used as regression equations (Hair, Hult, Ringle and Sarstedt, 2016). According to Nitzl (2016) and Heale and Twycross (2015), the PLS-SEM technique has lost its appeal over the years, given the advancements made by the CB-SEM software that can provide similar results.

The following section will quickly explain the reasons for choosing WarpPLS for this study.

4.9.3.1. WarpPLS SEM- Variance Based

The decision to use the WarpPLS was informed by the fact that it uses the SEM generated values in the PLS regression calculations to determine the existing non-linear relationships that define various latent variables. The software also has multiple uses regarding statistical methods that provide the researcher with options on the best method to apply given the nature of data collected. The generation of p values (and other coefficients Stable1, Stable2 and Stable3) is also possible given the ability of the program to configure standard errors in the data collected.

According to (Kock 2017), the program can also be applied when using data that has extreme outliers and non-normal distributions; it also can carry out functions that are not provided in other software programs such as the CB-SEM software.

4.9.4. Missing Values and Outliers During Data Preparation

Before keying the collected data into the software program, the researcher double-checked all the entries, especially the outliers, to note any potential mistakes that could alter the reliability of the study results. For instance, 81 questionnaires to be rejected due to incomplete answers from the respondents. This left the remaining data set free of missing data. According to Kock (2016), the WarpPLS has the capability of using the distribution-free jackknife method to determine the nature of relationships between the variables. The method also does not involve any substantial assumptions. The coefficients Stable2 and Stable3 are used as back up for Stable1 in case the method of exponential smoothing fails to yield concise results (Kock, 2014b). Accordingly, this study also uses Stable3 method.

There was a relationship between the standard errors obtained from the coefficient estimates through Stable3. The study showed a direct link between the actual and the predicted paths of standard errors, which proves that the research was accurate. Typically, Stable3 and Bootstrapping were significant in estimating the standard errors because there were no conflicting figures in the study findings. Besides, Stables 1 proved to be a superior method of estimating the standard errors compared with the Bootstrapping method, which is limited to a small sample size, which increases the chances of inaccuracy. This is important to note because standard error and the P-value are affected whenever the sample size reduces, meaning that a larger sample size translates into more accuracy.

4.10. Reliability and Validity

Ali and Bhaskar (2016) explain content validity as the concept measured in a theoretical framework. They further added that test-retest reliability could be used to determine the degree to which the test scores are reliable. This suggests that the reliability of numerical experiment data can be strengthened by maximising on the data collection process and maintaining consistency of the output. For this study, the questionnaire was developed under the guidance of the supervisor and piloted. The degree of agreement between the supervisor and the expert determined the reliability of the questionnaire. The questions were pre-tested using University staff. After the piloting phase, the problem questions were adjusted for some slight ambiguities and other related issues to enhance the reliability and validity of the instrument. White and White (2016) explain that research is said to be reliable only if its findings can be repeated in another study, and that study makes similar conclusions. Greenfield and Greener (2016) explain reliability as the degree to which a variable can be used repeatedly in a study.

Filtering was used to enhance valid responses for the research. This was achieved through the elimination of incomplete data provided by the research participants. Before data analysis was done, data cleaning and consistency checks in the captured information were done using cross-tabulations and frequency tables. Values that were inconsistent with what was expected for questions were dealt with accordingly that is, either removed or corrected.

4.11. Research Ethics

The respondents were assured about confidentiality and anonymity of the information they provide, before starting the interviews and managing the questionnaires. All the relevant permissions concerning data collection were obtained from the state minister of education and the university presidents. Considering that, public universities have similar laws, rules, and practices, precautions were taken to ensure that these regulations were not violated during research. The relevance of the research was clarified online before commencing the survey and administering the questionnaires. The data collected was purely used for academic purposes. After the research was granted permission to go ahead with the data collection process, an official letter was obtained from the state minister of higher education to all public universities. The purpose of the letter was to show potential respondents the authenticity of the study being carried out and constituted the ethical clearance by the institution. Sources for secondary data were acknowledged.

4.12. Summary

This chapter addressed the research purpose, approach, strategy, design, population and sampling, instrument, procedure, and research ethics used to study the research questions. The research design described the quantitative research approach that is followed to answer the research questions. The quantitative research conducted used both explorative and survey study methods to gather data from the population. The population sample consisted of researchers, educators, and ICT managers responsible for their respective institutions. The study instruments were developed to guide and assist in the processing of the data gathered that included a study reference framework of existing models and a structured questionnaire.

Chapter 5: Research Results and Findings

This chapter presents the results of the analysis of the survey responses for the data collected through quantitative methods. The results of the study are presented by way of tables, charts, and graphs to answer the Research Questions. Among 253 responses received during data collection, 172 responses were complete, and 81 responses were incomplete (68% completed rate). This response rate is, however, consistent with self-administered and online questionnaire response rates (Ali and Bhaskar, 2016). Concerning the completed responses, 157 were received through the online survey platform, while 15 survey forms were received by email. Of the 172 responses, the section breakdown is as follows: 154 responses were from university staff members involved in teaching, 129 responses were by university staff members involved in both teaching and research, 25 responses were ICT directors in the university, and one from the EthERNet CTO.

5.1. Introduction

The data were collected and processed in response to the questions posed in chapter one. The research objectives drove the collection of data and hence, data analysis and interpretation. The study focused on identifying essential NREN services that not only meet end-user needs in Ethiopian public higher education to improve the quality of education and research output but also to create an EthERNet service portfolio and roadmap recommendation for future implementation. The study also identifies the impact of an effective NREN, and the main challenges faced by Ethiopian higher education institutions with regards to their networks and their use of the EthERNet to enhance the quality of education and research output. Finally, based on study results, recommendations are offered, which are deemed useful to create a suitable NREN service portfolio and roadmap.

The primary data analysis deals with a detailed statistical analysis of the data, followed by the presentation of results and findings. The recent version of SPSS (v24) is used to analyse the questionnaires, and then pie charts, bar graphs, and histograms are generated to present the data.

Next, the construct reliability, convergent and discriminant validity of the “reflective” model measurements are put to the test. Subsequently, convergent and discriminant validity and constructs reliability of the formative model measurement is put to the test. WarpPLS, the recent version (v6), was used to do the Structural Equation Modelling (SEM) by adopting Partial Least Squares (PLS) SEM. The final part of the chapter presents and analyses the findings and outcomes of the proposed structural models. These outcomes and findings are separated into two key points: (1) The relationships from the NREN Service for Education (NSE), the Institutional Network for Education (INE), the EthERNet for education (EthNet), the Electronic Device for Education (EDE) and Research Output (RO) to Quality of Education (QE) and (2) the relationships from Institutional Network for Research (INR), the NREN Service for Research (NSR), the Electronic Device for Research (EDR), High-Performance Computing (HPC) and Remote Computing Facilities (RCF) to Research Output (RO). The study focuses on examining the proposed structural models to identify essential NREN services that do not meet the needs of the end-users. Lastly, the GoF (Global Goodness of Fit) of the model is verified. Thus, a survey of 29 Ethiopian public universities was created to validate the theoretical framework. The respondents were majorly those working at these institutions. The responses were analysed, while the evaluation was limited to the context of Ethiopia’s higher education and research output, together with Ethiopia’s NREN (EthERNet)

The results are presented in the following sections.

The survey yielded complete responses from 29 Ethiopian Public Universities, as shown in Table 5. 1 and Figure 5. 1.

Table 5. 1: List of participating Universities and the number of complete responses

No.	Name of the University	Number of Responses
1	Adama Science and Technology University	3
2	Addis Ababa Science and Technology University	2
3	Addis Ababa University	32
4	Adigrat University	7
5	Aksum University	1
6	Ambo University	3
7	Arba Minch University	10
8	Arsi University	14
9	Bahir Dar University	6
10	Bule Hora University	1
11	Debre Berhan University	18
12	Debre Markos University	7
13	Debre Tabor University	10
14	Dilla University	1
15	Dire Dawa University	4
16	Ethiopian Civil Service University	1
17	Haramaya University	12
18	Hawassa University	8
19	Jimma University	2
20	Kotebe Metropolitan University	1
21	Madawalabu University	3
22	Mekelle University	10
23	Mettu University	1
24	Mizan–Tepi University	4
25	University of Gondar	4
26	Wachemo University	2
27	Woldia University	1
28	Wolkite University	3
29	Wollo University	1
Total		**172**

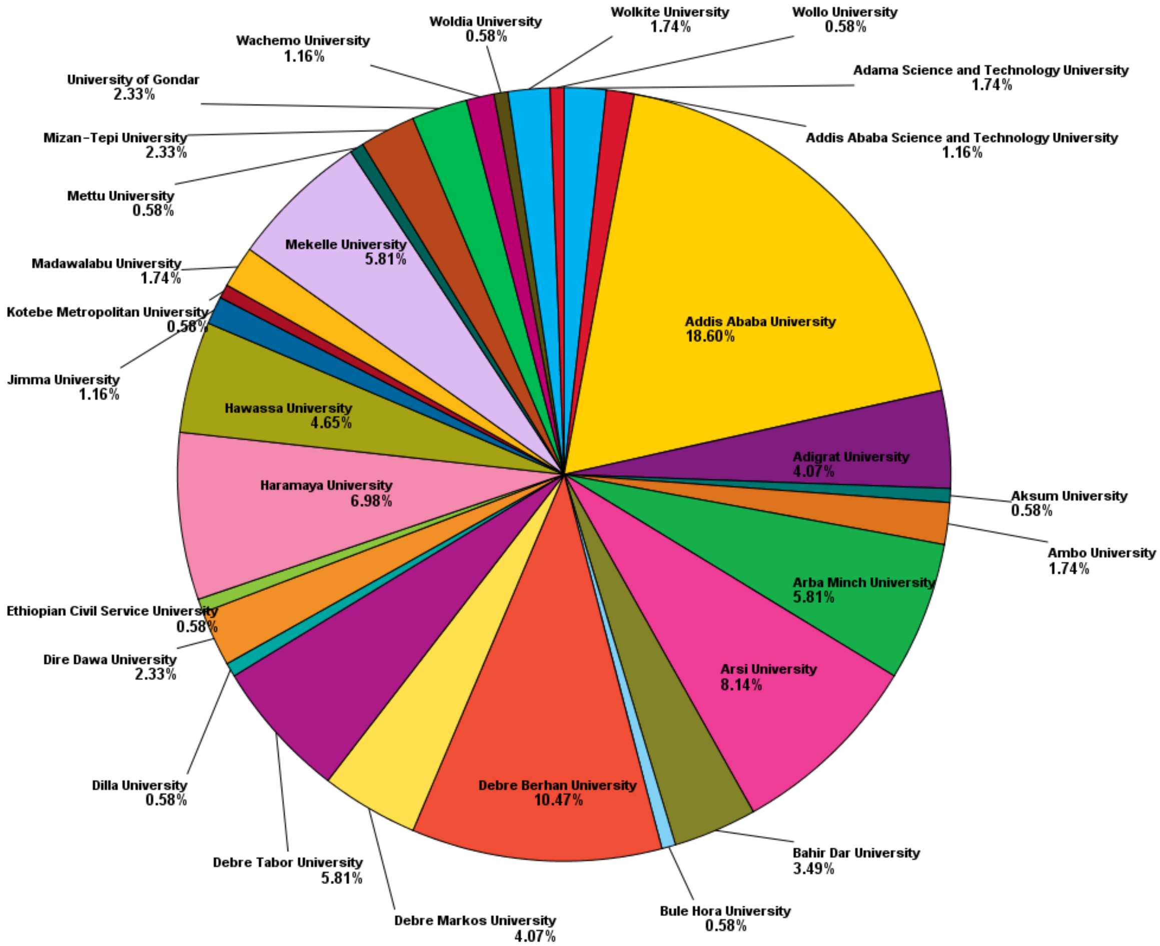


Figure 5. 1: Breakdown of participating Universities in percentage

5.2. NREN Service for Education

This is for University staff members involved in the teaching and learning process and highlights the findings concerning different aspects of the NREN Services for Education. Of the usable responses, 154 respondents (89.53%) opted to fill in this part of the questionnaire, as indicated in Figure 5. 2.

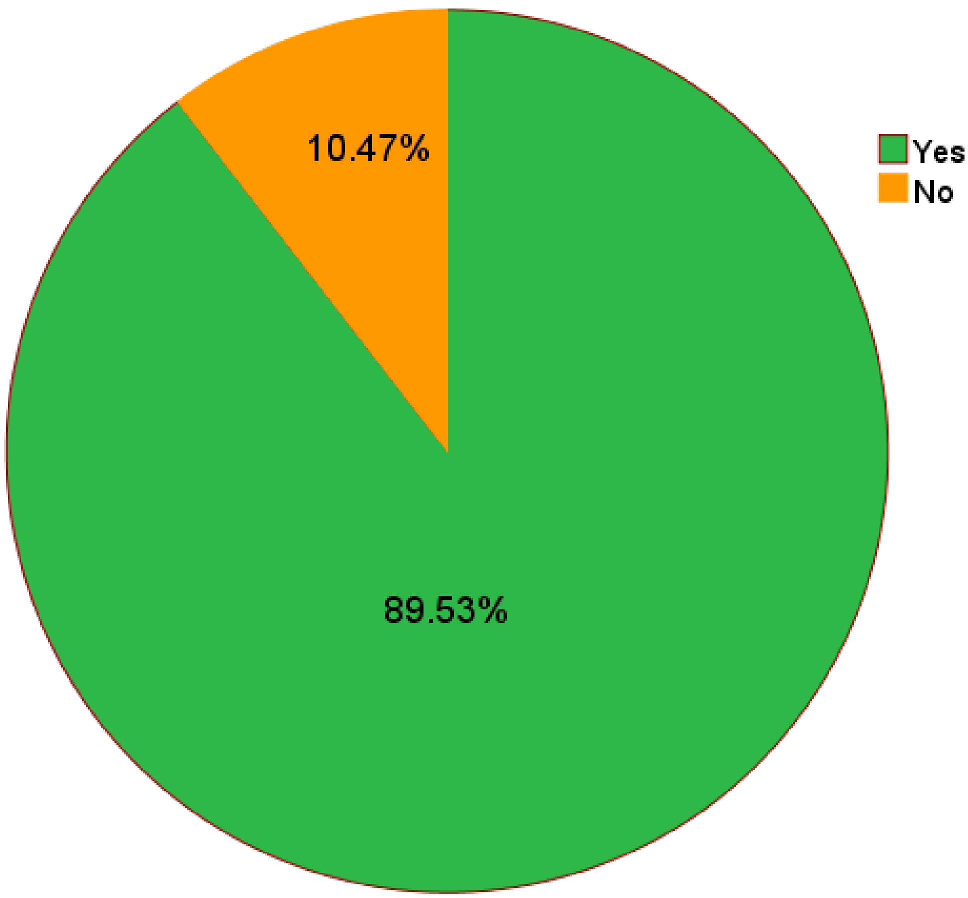


Figure 5. 2: Breakdown of responses from staff involved in teaching and learning

5.2.1. Main Subject Being Taught by Participant (Q.1)

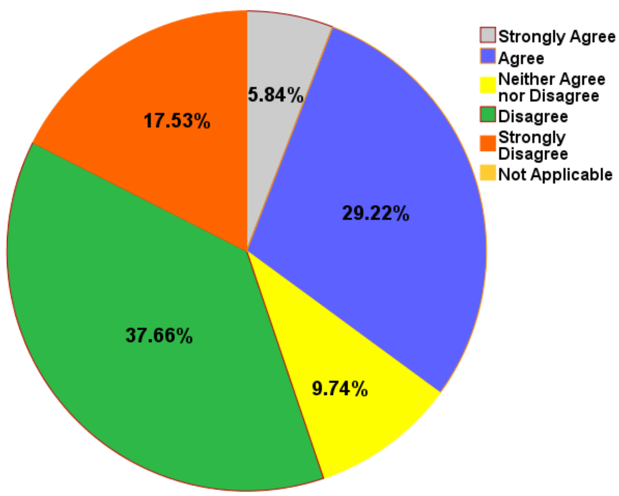
The distribution of the main subjects being taught by participants in Ethiopian higher education is shown in Table 5. 2. The responses show that the respondents are involved in a wide range of different disciplines.

Table 5. 2: List of main subjects being taught by participants

Agriculture	Mechanical and Chemical Engineering
Architecture and Urban Planning	Mechanical and Chemical Engineering
Biological Sciences	Mechanical system and vehicle Engineering
Business and Management Studies	Medicine and Health Science
Chemistry	Natural Resources Management
Civil and Environmental Engineering	Pharmacy
Computer Science, Information System, and Informatics	Physics
Economics	Psychology
Education	Software Engineering, Information Technology
Electrical and Computer Engineering	Statistics
Geography and Environmental studies	Textile Engineering
Law	Water Resources and Irrigation Engineering

5.2.2. Online Materials Access, Network Reliability and Examples of Materials Accessed Online by Lecturers (Q.2, 2.1 and 2.2)

On the frequency of accessing online materials and/or data to support the teaching and learning process, most of the responses revealed that academicians in Ethiopia would like to have access materials online combining "very often" and "often" responses (92.21%) as shown in Figure 5. 4. A majority of academics 'Disagreed' and 'Strongly Disagreed' with the statement on accessing online materials without any network problem meaning that their institution's network caused them problems and was, therefore, less reliable when they try to access online materials and/or data (55.19%) as shown in Figure 5. 3.



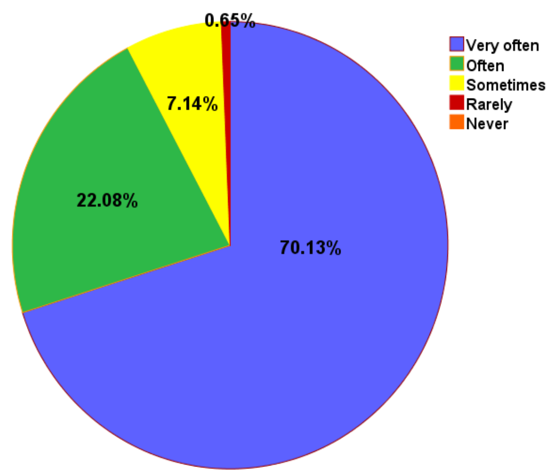


Figure 5. 3: Reliability of the institution's network

Statement: "I can easily access online materials without any network problem."

Figure 5. 4: Frequency of access to online material

Regarding online materials frequently accessed or those that the lecturers would like to access, the findings revealed that most users would like to access the below:

- Online resources both subscribed and open access (such as, INSAP, Hinari, Agora Science Direct, Elsevier, DOAR, Sage, Research4life, EBSCO, IEEE DL, and PubMed)
- Local learning management systems (e.g., teaching materials, lecture materials and software's and FTP) and institutional repositories
- MOOCs (Such as, MIT OpenCourseware2, Stanford Udacity, Coursera, Cairn.info, revue.org, UdemyBig Data course from IBM, erudit.org, openclassrooms.com, and courses.coreservlets.com)
- Online academic materials (e.g., Academic societies' websites and Virtual laboratories)

The below resources are also required:

- Public websites (e.g., YouTube, Google, and news)
- Online class management systems

5.2.3. Providing of Online Materials, Network reliability and Examples of Materials delivered online (Q.3, 3.1 and 3.2)

Most of the respondents combining "very often" and "often" (72%) mentioned that they want to provide materials online regularly to support their students, as shown in Figure 5.5. Above half of the academics (60%) expressed that the institution's network causes them problems when they try to upload online material and/or data for their students, as shown in Figure 5. 6.

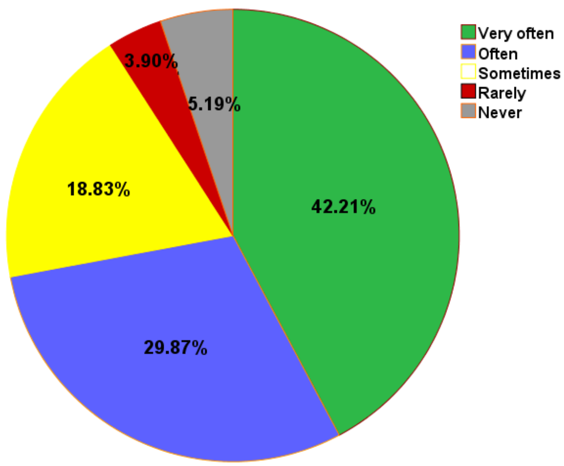


Figure 5. 5: Online frequency of materials delivery

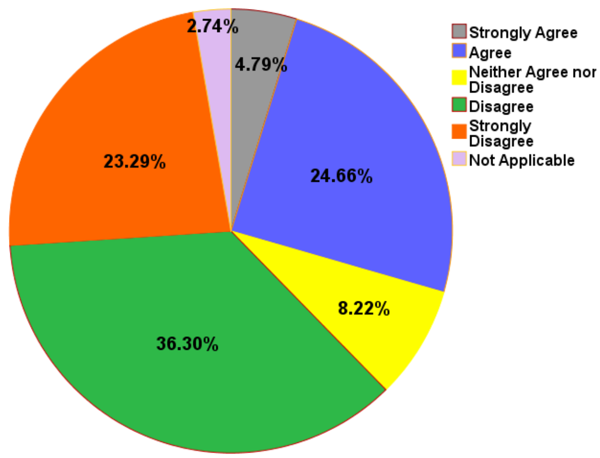


Figure 5. 6: Institution's network reliability

Statement: "I can easily put materials online without any network problem."

Looking at examples of online materials and/or data provided by lecturer's answers, the findings suggested that these fell into three major categories:

1. Lecture notes, assignments, and reference materials
2. Laboratory materials and experiments manual
3. 3. Supporting different resources including:
    - E-books
    - Institutional repositories and digital libraries (including theses and dissertations)
    - Internet links
    - LMS/Moodle
    - MOOCs
    - Online speeches and news
    - Personal archival records
    - Published articles
    - Scanned copies of scholarly articles
    - Software

5.2.4. Student Online Materials access frequency, Network Reliability and Online Materials categories (Q.4, 4.1 and 4.2)

Combining "very often" and "often" responses, more than half of the academic staff (59.09%) says students want to have access materials online to support their education, as shown in Figure 5.7. Regarding the reliability of the network, combining "strongly disagree" and "disagree" responses, 65.79% of the academicians claims institution's network have a problems for students, as shown in Figure 5. 8.

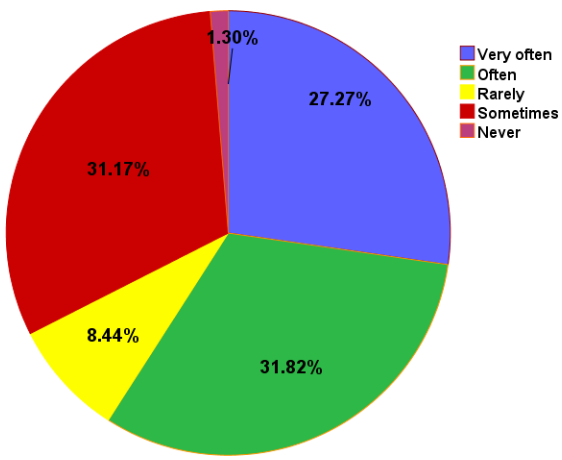


Figure 5. 7: Student access frequency to online materials

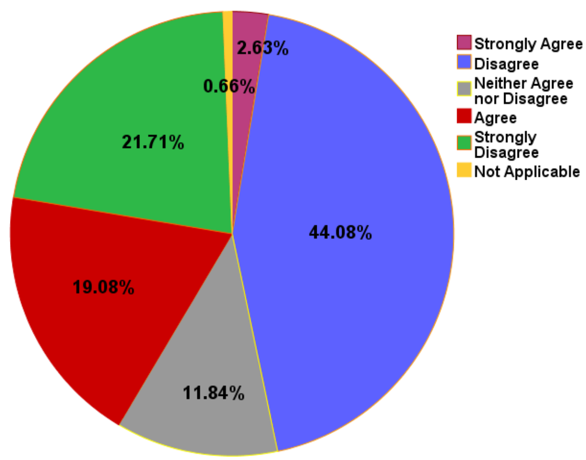


Figure 5. 8: Institution's network reliability

Statement: "My student can easily access online materials online without any network problems."

Access to e-learning materials and open education were the most commonly used resources by students, in spite of having a functional network connectivity to transfer those resources available online.

According to the respondents, specific subject related resources include:

- For continuous assessment, assignment, and model exam samples
- Presentations, lab manuals, and lecture related references

Below are the other materials commonly accessed by students:

- Articles, journals, E-books dissertations, and theses
- Learning Management System (LMS) platform, mainly Moodle
- Microsoft 365 mainly for email purposes

5.2.5. Online Software access by Lecturers, Network reliability and Online Software categories (Q.5, 5.1 and 5.2)

Combining "very often" and "often" responses, the majority of the respondents (57.79%) says that they want to have access to online resources frequently, as shown in Figure 5.9. Combining "strongly disagree" and "disagree" responses, 62.33% respondent says they cope with problems while accessing online software and applications because of the institution's connectivity, as shown in Figure 5. 10.

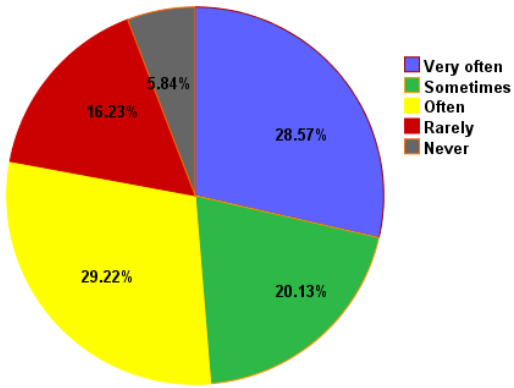


Figure 5. 9: Online software access frequency by the lecturer

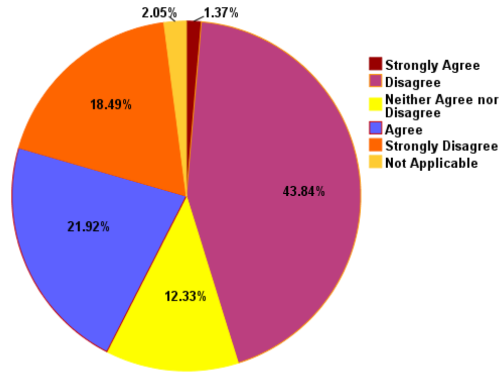


Figure 5. 10: Institution's network reliability

Statement: "I can easily access online software without any network problem."

SPSS is the most required software, in addition to Plagiarism Checker. Other required software also shown in Table 5. 3.

Table 5. 3: List of software/resources

Software/ Resources	Frequency	Per cent
ArcGIS	8	4.7
AutoCAD	1	0.6
CATIA	1	0.6
Chemdraw	1	0.6
ChemOffice	1	0.6
Compilers and interpreters Internet Services	1	0.6
CROPWAT	2	1.2
DATABASE server	1	0.6
Document Converter Software	1	0.6
Epi info	1	0.6
ERP, APS, SCOR-model and other Inventory management software	1	0.6
Gaussian	2	1.2
GitHub	1	0.6
GitHub, Azure	2	1.2
GNS3, SQL server 2012/14, Oracle 11g	1	0.6
Google Apps	7	4.1
Google Survey	1	0.6
HPC	1	0.6
Hydrologic Engineering Centre (HEC)	1	0.6
Json Parser	1	0.6
LATEX	1	0.6
Linux's update repositories, Java technologies from oracle.com	1	0.6
MATLAB	6	3.5
Medscape, PubMed	1	0.6
MEGA 6, ClustalW, Design Expert, etc	1	0.6
Mendeley	3	1.7

Micromedex, Medscape, Lexicomp, ChemDraw	1	0.6
MOOCS	2	1.2
Moodle	5	2.9
NetBeans, MySQL, wamp, java tutorial apps, Dreamweaver, J2ME, Prolog.	1	0.6
Office and design software	1	0.6
Office365 - Class Notebook, SharePoint, Team, etc Plagiarism Detector Online Datasets	1	0.6
Online Survey tools like Google Apps	2	1.2
Piazza Big data analysers	1	0.6
Plagiarism Checker	10	5.8
Power point	1	0.6
Python	1	0.6
Quantum Espresso	1	0.6
Quincy, Turbo C++	1	0.6
R	5	2.9
R, SAS, MINITAB, SPSS	1	0.6
R, SAS, STATA, CANOCO	1	0.6
RevMan, Ginger, and Itincate.	1	0.6
SAS	3	1.7
SAS, SPSS, R, Linux, Bio Linux	1	0.6
SAS, STATA, SPSS	1	0.6
SCADA	1	0.6
Science Direct, Google Scholar, PLOS ONE, Science and Technology of Advanced Materials	1	0.6
SciFinder	1	0.6
Skype	1	0.6
SPSS	15	8.7
SunCalc (Sun Path Calculator Software)	1	0.6

VASISTA	1	0.6
VB. Net, Oracle, server	2	1.2
Virtual Classrooms	1	0.6
Water Evaluation and Planning System	1	0.6
Weka	1	0.6
Weka, research tools, statistical packages	1	0.6
WHO Anthro, EPI INFO	1	0.6

5.2.6. Online Software access frequency by Students, Network Reliability and Online Software variety (Q.6, 6.1 and 6.2)

With respect to online access to software, combining “very often” and “often” responses, 42.1%, academics shows that their students, want to have access online software/resources regularly, while 30.92% access occasionally accounted in total 73.02% as shown in Figure 5. 11. Concerning the institution’s network reliability, combining “strongly disagree” and “disagree” responses, 69.72% said that the institution’s network case problems for students from having access to resources online as shown in Figure 5. 12.

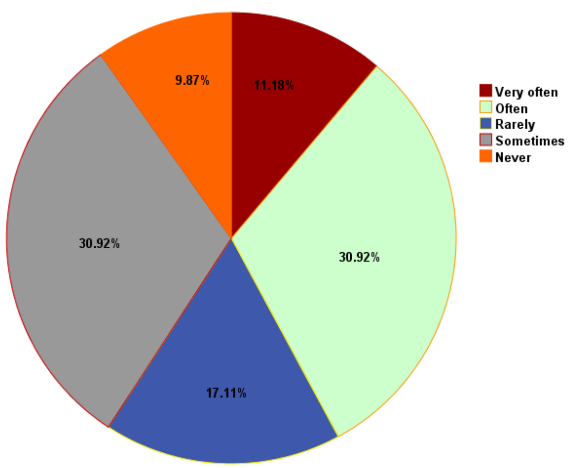


Figure 5. 11: Online software access frequency by students

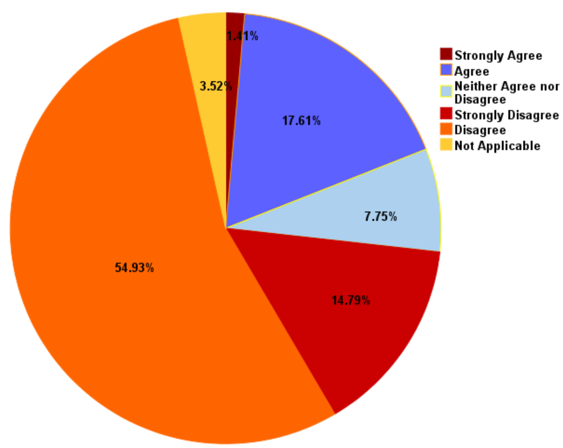


Figure 5. 12: Institution’s network Reliability

Statement: “My students can easily access online software without any network problem.”

Lecture notes and reference materials, Massive Open Online Courses (MOCCs), Learning Management System (LMS), modelling/statistical software, and search engines.

5.2.7. Networked Services Use and Usefulness for Education (Q.7, 7a, and 7b)

In dealing with several learning-related network technologies, the questions to the respondents were meant to help in understanding their views on the use of technology, and how it improves teaching. Figure 5. 13 illustrates the usage of ICT related services used for educational purposes. The responses included, "Yes, I am using the service," "No, I am not using the service" and "Uncertain, I am not sure about the availability and usefulness. Bellows are the analysis for the questions

Usage of the services

- 83% of the users said that the networked services for education were useful as shown in Figure 5. 13.
- The highest-rated were.
    - Online library resources (96.11%), as shown in Figure 5. 13 (g).
    - Online (web-based) teaching and learning resources (95.45%), as shown in Figure 5. 13 (d).
    - Recording tools to make lectures (94.81%), as shown in Figure 5. 13 (c).
    - Online teaching and learning environments (93.46), as shown in Figure 5. 13 (e).
    - The capability to use their credentials to log in at another institution was rated at 83%, as shown in Figure 5. 13(h).

Institutional email service and teaching and learning environments via online is rated highest. Compared to other services, respondents indicated less use for "the ability to log in at another institution" and "MOOCs.

Use and Usefulness of Social Media

Regarding on social media use, ResearchGate (68.18%) and LinkedIn (55.56%) were the highest used for teaching with Facebook (37.66%) and Twitter (26.80%) being used by some of the educators. ResearchGate, with 90.73% was most useful. LinkedIn, another social media platform was also perceived useful for education, with 61.69% agreeing with the statement.

Other services that could be provided and considered useful for the learning and teaching process. These are:

- Cloud computing
- Exam banks
- File transfer and sharing platforms/services
- The institutional and national repository system
- Multimedia tools
- National datasets such as statistics agency, telecom, higher education institutions, transport, energy, and agriculture
- Online computational labs and simulations
- The Office 365 package and similar tools

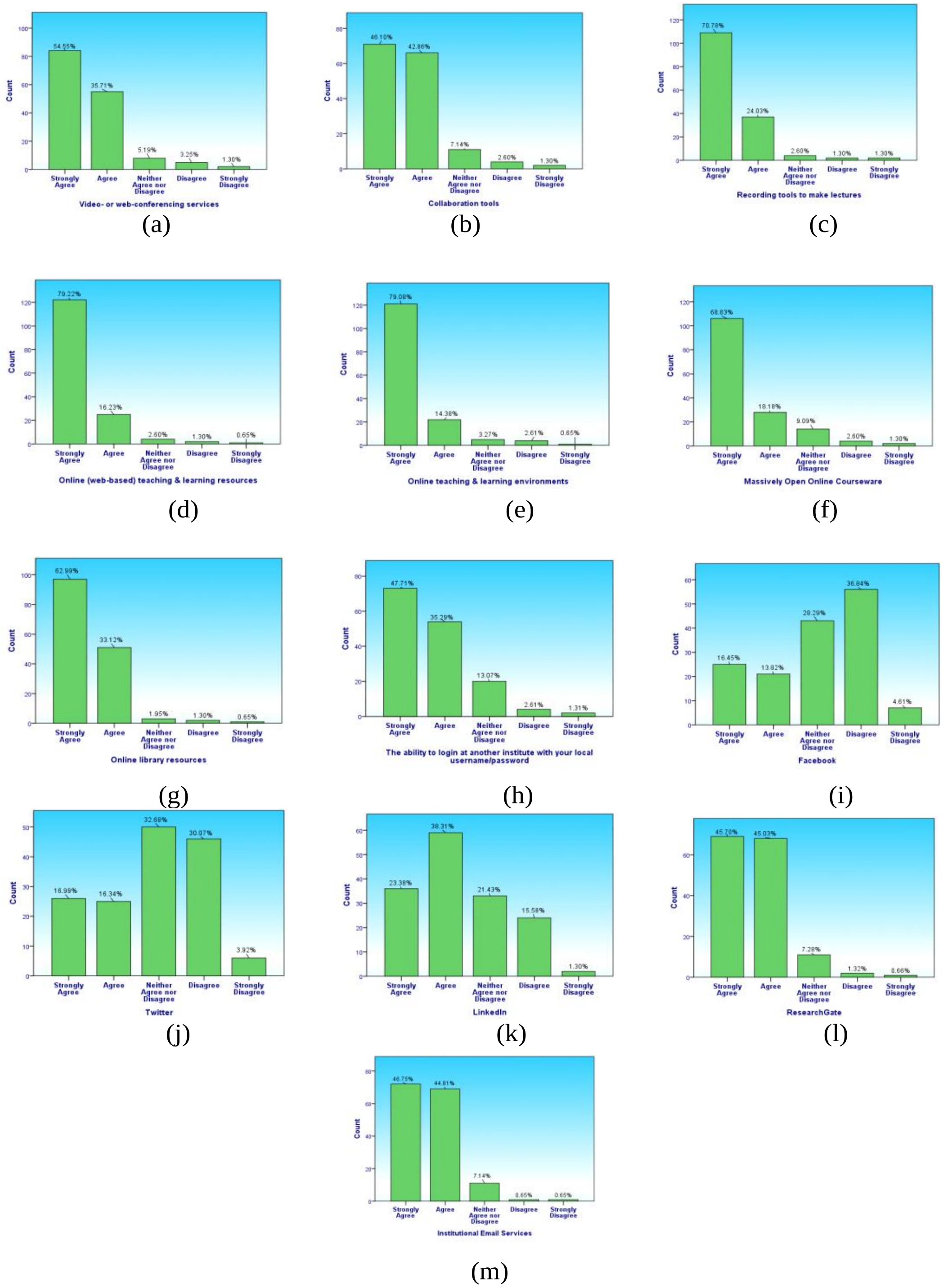


Figure 5. 13: Usefulness of networked services in a variety of aspects in education

Statement: "The services mentioned above would be useful in the teaching and learning process."

5.2.8. Distance Learning Programmes and Potential Number of Students via EthERNet (Q.8,8.1 and 8.2)

As per Figure 5. 14 and Figure 5. 15, using EthERNet respondents want to have distance learning programs both nationally and internationally. 87.02% (national) and 83.12% (international) combining both ‘strongly agree’ and ‘agree’.

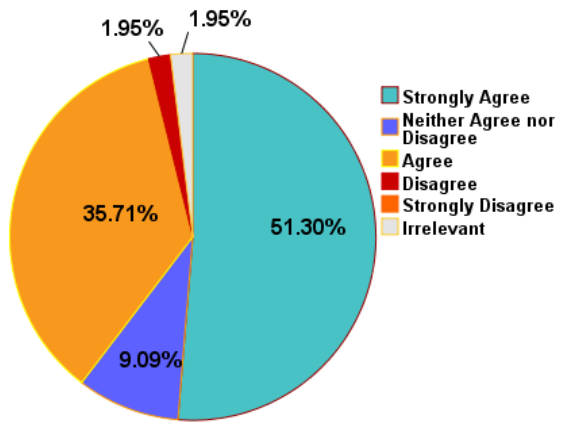


Figure 5. 14: Lecturers opportunities to create national DLs

Statement: “I can create distance learning programs in Ethiopia using EthERNet.”

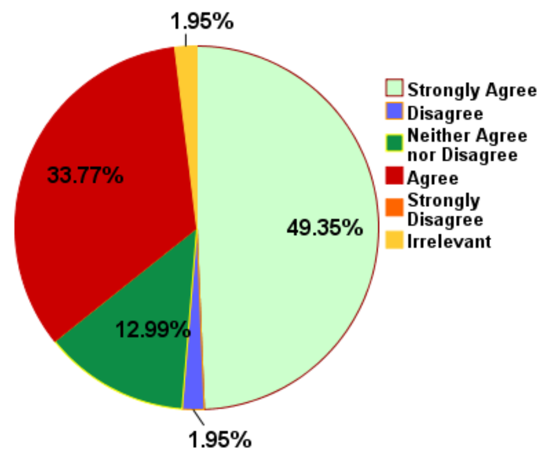


Figure 5. 15: Lecturers opportunities to create international DLs

Statement: “I can create international distance learning programs using EthERNet.”

The number of potential students that might be accommodated by national or international distance learning programs is shown in Figure 5. 17 and Figure 5. 18. As shown in Figure 5. 17, 41.12% of said they can reach 500 students nationally, with 37.04% indicating over 1000. Regarding 48.89% indicated that they would reach up to 50 students international student numbers and over 1000 with 23.7%

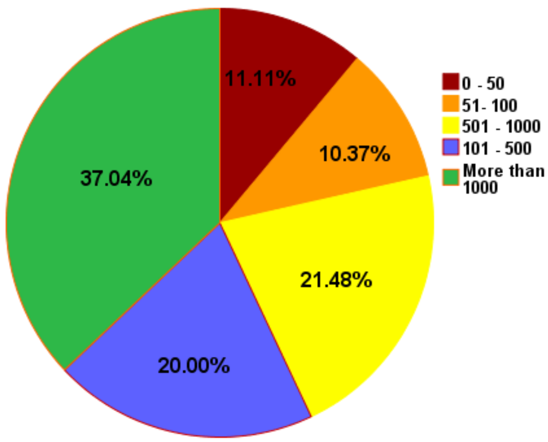


Figure 5. 16: Number of potential home students subject to a sufficient distance learning

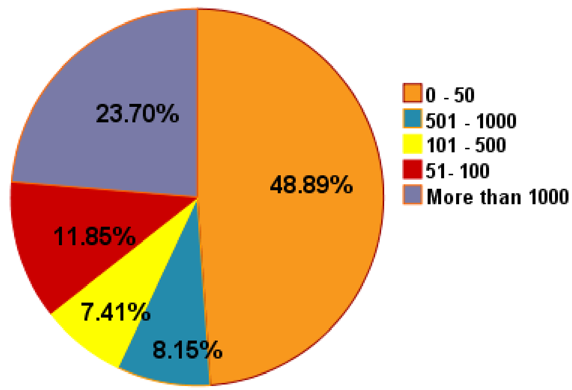
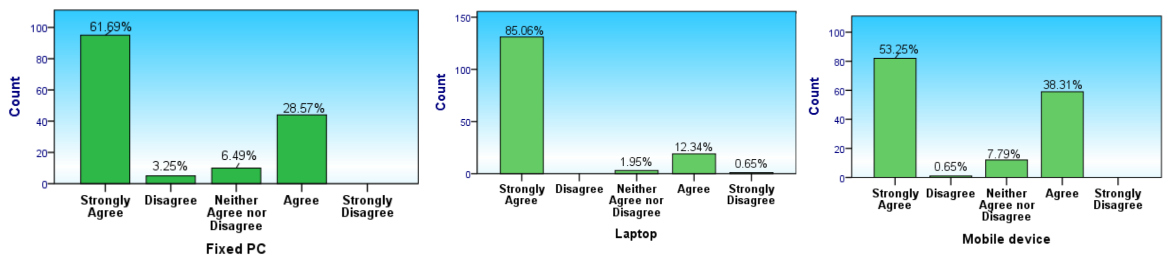


Figure 5. 17: Number of potential international students subject to a sufficient distance learning

5.2.9. Use of Electronic Devices for Education (Q.9)

Figure 5. 18 illustrate electronic devices usefulness to enable students to access educational resources online. All electronic devices are valuable which includes laptop devices constitutes (97.4%), smart handheld mobile constitutes (91.56%), and personal computers constitutes (90.26%) taking of strongly agree and agree . In terms of "strongly agree," laptops are more useful than PCs (85.06% vs 61.69%), followed by mobile devices (53.25%).

Other types of devices used to access educational services includes tablets and Virtual Desktop Environment (VDI) or thin client could be an alternative.



(a) (b) (c)

Figure 5. 18: Use of electronic devices for education

Statement: "The devices mentioned above are useful to access online educational resources for students."

5.2.10. Existing Major Problems with Network (Q.10)

Figure 5. 19 illustrates academics' views on the current institutional networking problems for education. Most of them are agreed that their existing institutional network has a problem in supporting the learning and teaching process. Below are explained as follows:

- The network is unreliable (83.11%, 3.9%), as shown in Figure 5. 19 (c)
- Students are not able to connect easily to the network (80.52%, 3.25%), as shown in Figure 5. 19 (b)
- My students cannot quickly get access devices such as computers or smart mobiles (79.87%, 6.49%), as shown in Figure 5. 19 (d)
- I cannot easily connect to the network (70.78%, 4.55%), as shown in Figure 5. 19 (a)
- I cannot guarantee data privacy (70.13%, 16.23%), as shown in Figure 5. 19 (e)
- The network is not secure (68.18%, 16.23%), as shown in Figure 5. 19 (f)

Between 68% and 83.11% of respondents agreed that the existing institutional network has a problem in supporting education. Access devices with 79.87% is the other problem. Data privacy 70.13% and network security 68.18% is also additional problem.

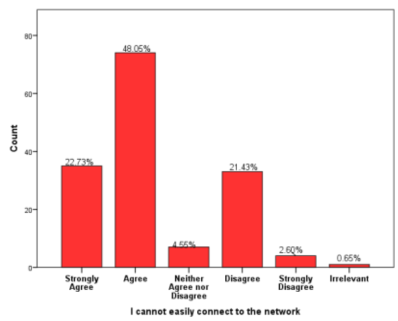
In addition, bellows are the other problems raised:

- Filtering/proxy from both the Internet Service Provider (ISP) and campus network
- Frequent power outage
- Lack of a standard campus network
- Limited technical support/ ICT staff with inadequate skills
- Low/insufficient internet bandwidth

One respondent, for example, commented:

"Demand from the education community and the service provider is not well balanced. The service provider should work more on expansion, reliability, accessibility, affordability, and technical support during interruptions."

Overall, these results indicate that the majority of educators need reliable and adequate bandwidth in addition to access to devices for the students for education. Providing Wi-Fi hotspots and securing the network might also be considered. While issues such as frequent power outage, limited technical support, and content filtering concerns are essential, such issues are perhaps outside the influence of network service providers.



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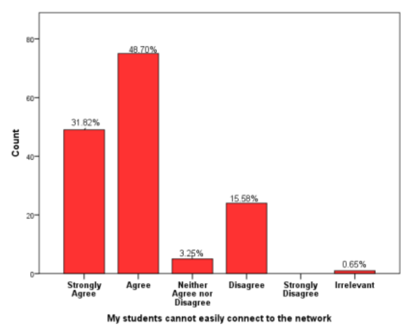

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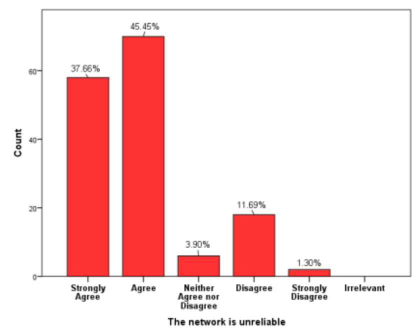

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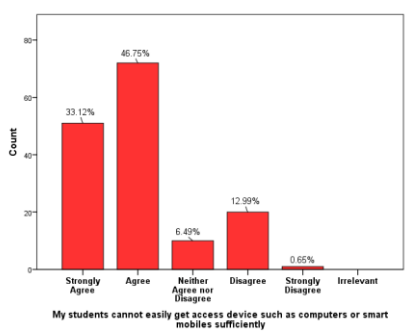

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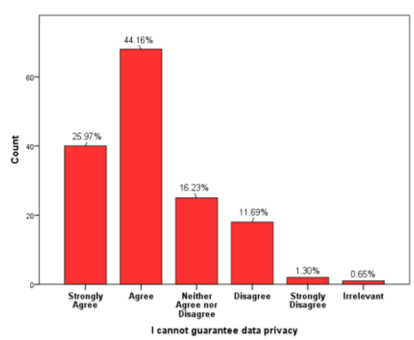

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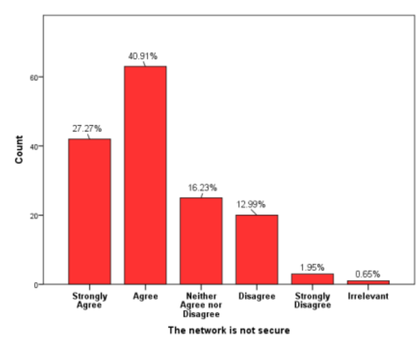


(f)

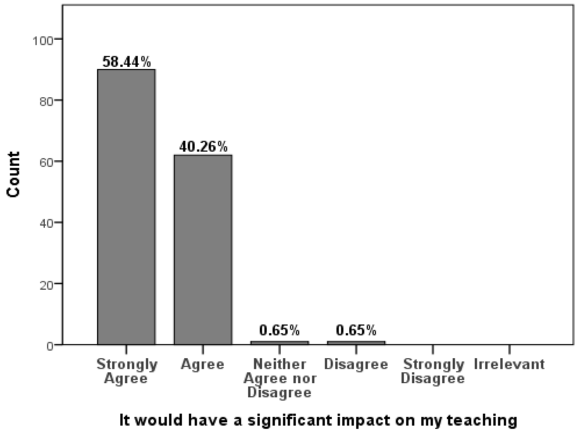
Figure 5. 19: Networking concerns for academicians

5.2.11. Impact of Reliable Network on Education (Q.11)

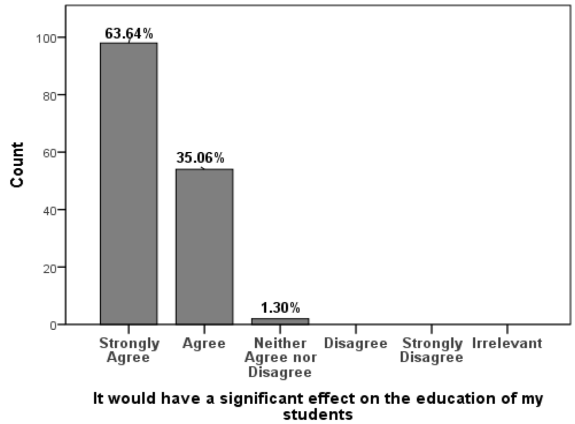
Figure 5. 20 show the potential impact of a reliable network on education. Combining “agree” and “strongly agree” responses, over 93% of respondents agreed with all of the following.

- 98.7% the survey participants say it has an impact to deliver on education, as shown in Figure 5. 20 (a)
- It would have a significant impact on student education (98.7%), as shown in Figure 5. 20 (b)
- It would facilitate life-long learning (95.42 %), as shown in Figure 5. 20 (e)

Overall, these figures show that a reliable network would have a significant impact on improving the quality of education in Ethiopia higher education institutions.



(a)



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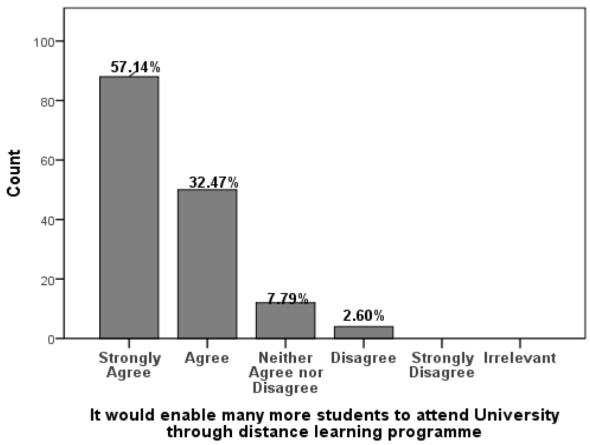

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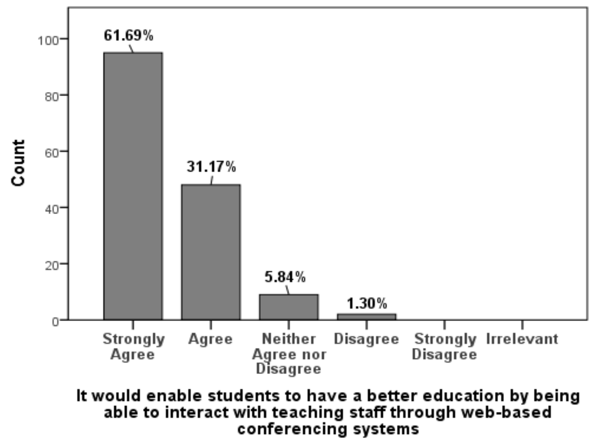

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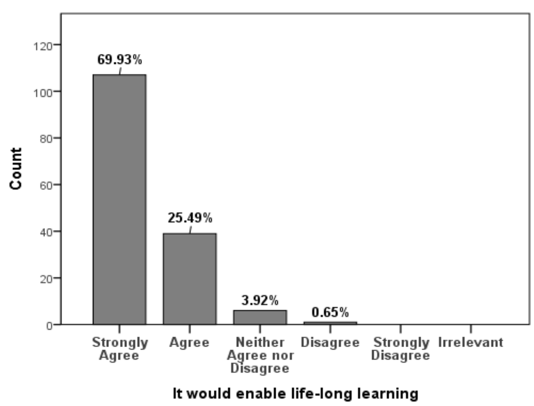

(f)

Figure 5. 20: Reliable and secured NREN and its impact on education

Below are areas that the EthERNet should provide:

- Collaboration
- Provide access to big data processing infrastructure
- Provide digital literacy training for the users
- Provide training and platforms to create and manage online courses

5.3. NREN Service for Research

This section of the deliverables highlights the findings to different aspects of NREN services for research. Of the usable responses, 129 (75%) were able to respond to this part of the questionnaire.

5.3.1. Main Research Area (Q.1 and 2)

Table 5. 4 lists the main research areas and some brief outlines.

Table 5. 4: Main areas of research

Discipline	Area of research
Computer Science and Informatics	Information retrieval, mGovernment, Network Intrusion Detection, Knowledge Mining from Clinical dataset, Artificial Intelligence and big data, Security, Wireless ad hoc networking, Web technology, Data Mining, MOBILE app development, Semantic Web, Information Retrieval (IR) and mobile networking, Big data analytics IoT and Cloud Computing.
Public Health, Medicine, Health Services and Primary Care	Physics Education, Astrophysics, Public Health, Clinical neurosurgery, clinical trial and phytomedicine, Community health, Sexual and reproductive health, Internal Medicine, Public Health, management of chronic diseases, herbal medicine, Chronic non-communicable diseases, HIV, Infant feeding, and Nutrition.
Education	ICT in education, Internationalization of Education.
Agriculture, Veterinary and Food Science	Animal feeding and nutrition, Trace Elements (micronutrients) Research in Food Quality Agriculture and Human Health, Agricultural Biochemistry, Nutritional Biochemistry, Clinical

	Biochemistry, Animal health, animal production, Horticultural crops, Genetics and Breeding, Plant Sciences, Animal feeding and nutrition.
Chemistry	Inorganic and Coordination, Chemistry Biological Inorganic Chemistry and Organic Chemistry.
Geography, Environmental Studies, and Archaeology	GPS Trajectories Analysis, Environmental Impact Assessment, Remote sensing, GIS, Application of GIS for the Assessment of Road Traffic Accident (RTA), Applications of GIS and RS in different disciplines.
Economics and Econometrics	Macroeconomics, Agricultural Economics related research and health education economics.
Architecture, Built Environment and Planning	Architecture and Design, Construction Technology, Landscape, Planting design, Environmental biotechnology (applied research), Environmental Studies and remote sensing.

5.3.2. Researchers Using the EthERNet Network and Reasons for not Using it (Q.3)

When asked about the current use of the EthERNet, the majority of researchers (83.46%) at Ethiopian higher education institutions confirmed that currently, they are not using the network, as shown in Figure 5. 21.

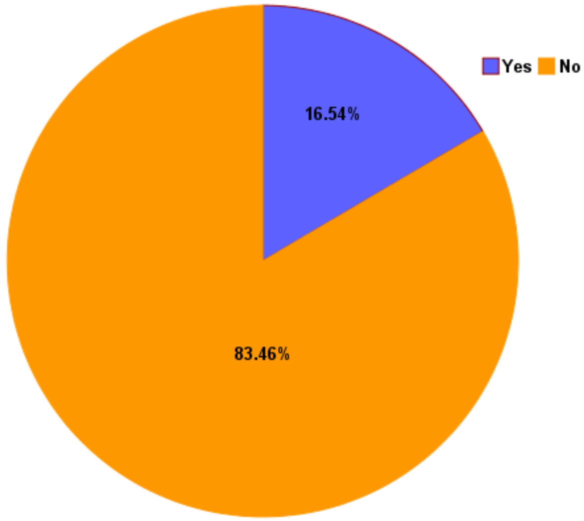

Figure 5. 21: Researchers using EthERNet network

When asked to provide reasons for not using the EthERNet, these were the main reasons:

- I just started my research, and I do not have enough information on how the EthERNet could assist me in my research
- Intermittent connection problems cause internal issues like power interruption, configuration, accessibility, and others
- My institution is not yet connected to the network
- EthERNet does not provide required services
- Not aware of EthERNet and/or the network
- Not aware of the services provided by EthERNet
- Orientation not provided as to how to use the network
- Power interruption
- Skill problem to use the network

5.3.3. Research Collaboration Involves Large File Transfer and Size of the Files (Q.4 and 4.1)

Figure 5. 22 show that research collaboration with project partners involves large file transfer over a data communication network. Most of the respondents (69.77%) who collaborate with a project partner say that this involves large file transfer.

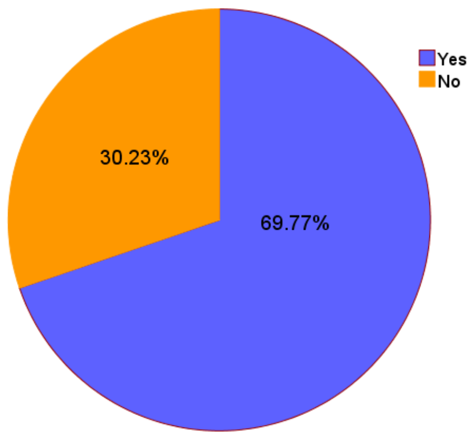

Figure 5. 22: Research collaboration involves large file transfer

The sizes of the files transferred during collaboration are shown in Figure 5. 23, 37.78 % of respondents indicated that they needed to transfer files that are more than 1GB.

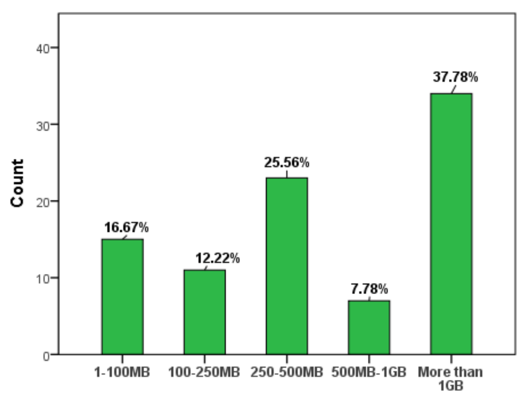

Figure 5. 23: Research collaboration involves large file transfer

5.3.4. Collaboration Frequency with Scholars both National and International (Q.5 and 6)

Figure 5. 24 and Figure 5. 25 shows the frequencies of collaborations researchers. Accordingly, 31.78% and 43.41% of researchers are working together with both national and international counterpart (very often/often), while 58.14% and 35.66% of researchers sometimes work together nationally/internationally with their counterpart. Most respondents collaborate nationally at one time or another.

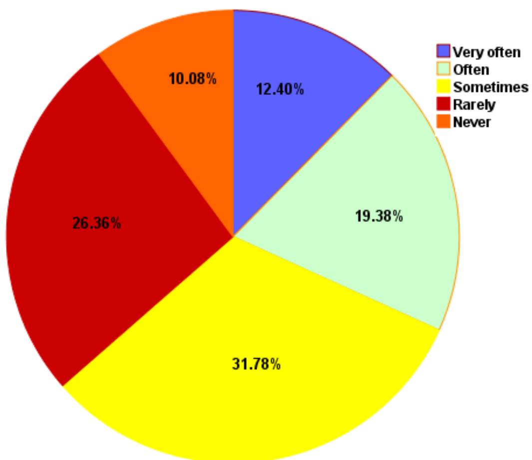

Figure 5. 24: Researchers' collaborations frequency nationally

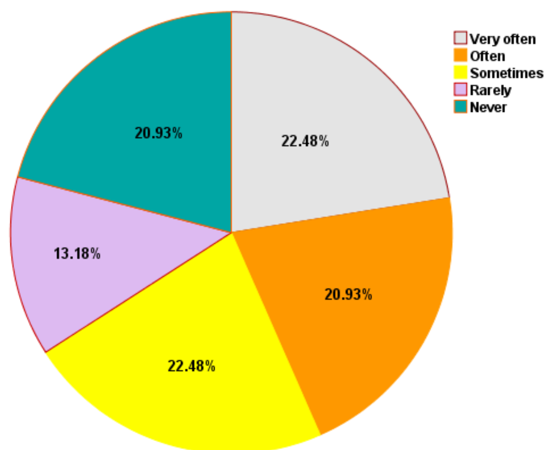

Figure 5. 25: Researchers' collaboration frequency internationally

5.3.5. Collaborating Countries with Ethiopian Researchers (Q.7)

The top seven countries are the USA, Sweden, Germany, Netherlands, India, UK, and South Africa. Most of them are situated in Europe, North America and India as show in Figure 5. 26.

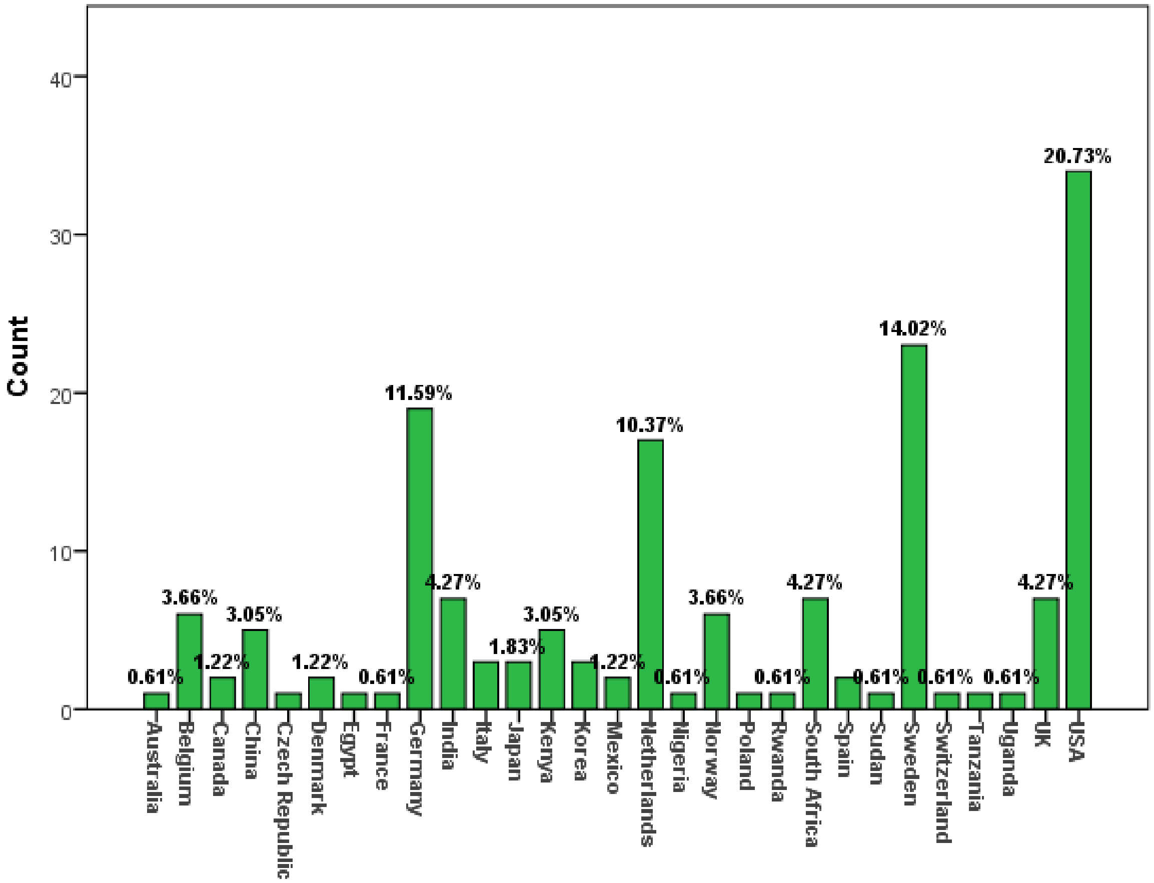

Figure 5. 26: List of international collaboration countries (% by response)

5.3.6. Network Reliability to Collaborate Internationally (Q.8)

Figure 5. 27 represent the users' views on network reliability to collaborate internationally. Combining "strongly disagree" and "disagree," (71.43%) participants said network reliability is a concern to collaborate with internationally counterpart.

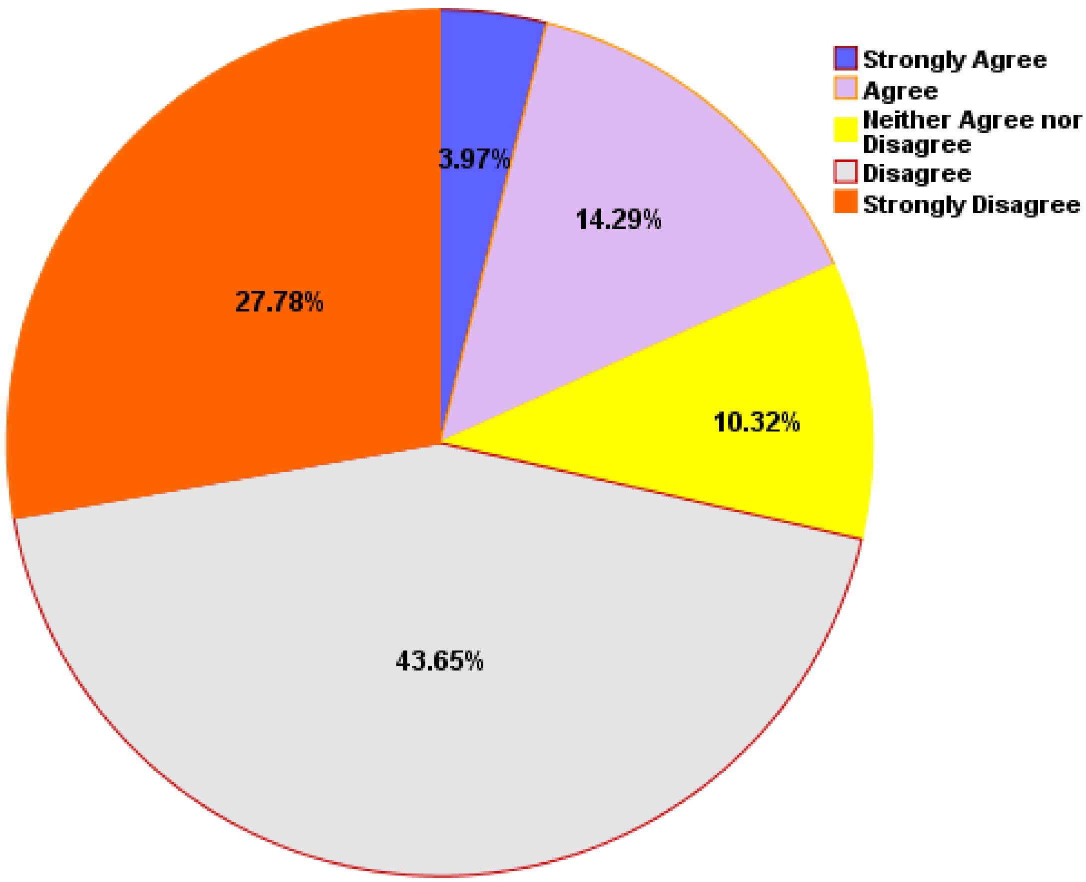

Figure 5. 27: Network's reliability for international collaborations

Statement: "I can be able to work with other international researchers without a network problem."

5.3.7. Limitations of the Network to Collaborate Internationally (Q.9)

The following tasks are the main limitation of the network to collaborate with their international peers actively:

- Getting shared storage platform issues
- Development of a joint research project
- Difficulty in uploading data for publication
- The difficulty of collaboration via video/web conferencing, chat IM, online discussion, webinar, sending emails
- Less possibility to have remote access on their virtual labs and facilities like HPC
- Difficulty to transfer large files
- Meeting, review, remote access to their library
- Participation in online courses/ discussion forums
- Real-time data analysis
- Some protocols are blocked and thus inhibit access to some sites like GitHub

5.3.8. Frequency of Searching Online for Conference and Scientific Articles and Network Reliability (Q.10 and 11)

As shown in Figure 5. 28, combining “very often” and “often” responses, 91.47 % of researchers are searching online journals, articles, and online conferencing to support their research work.

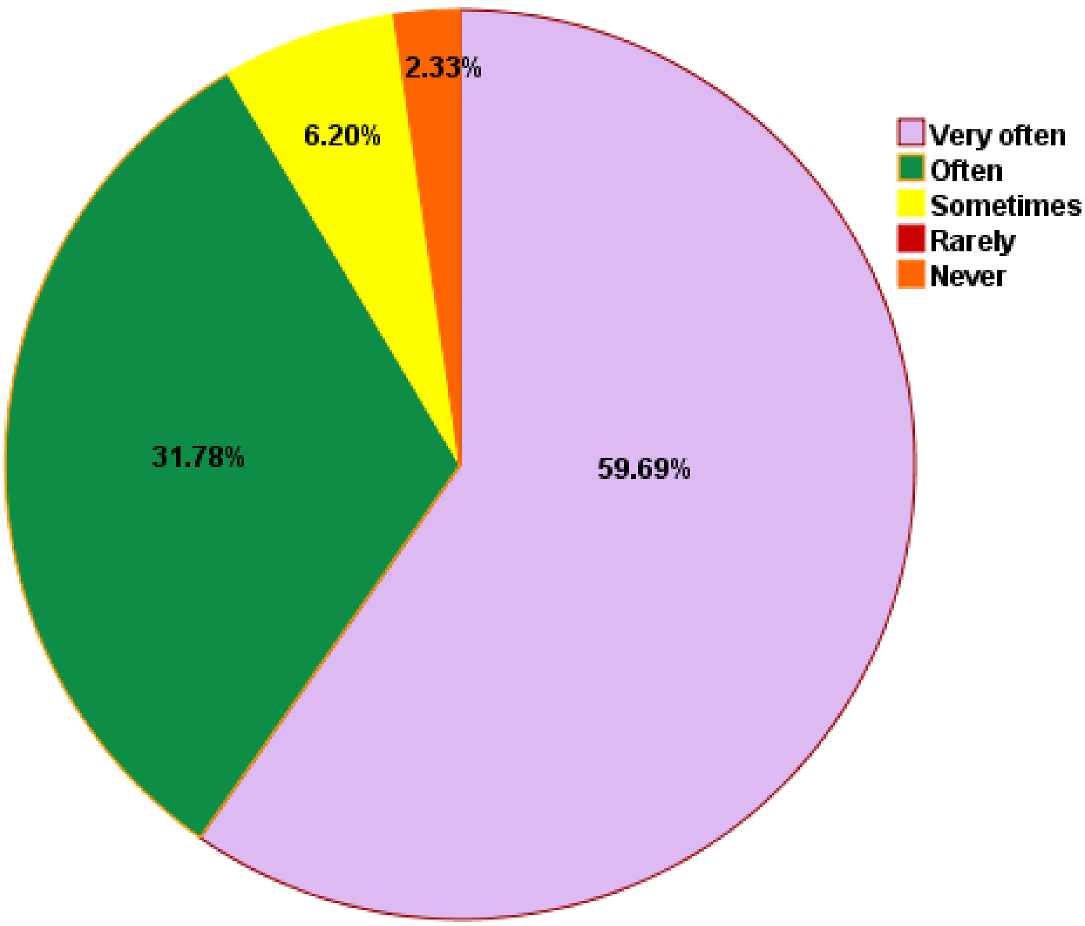

Figure 5. 28: Frequency of searching online conferencing and journal articles

Figure 5. 29 show the opinions of the respondents regarding the connectivity of the campus network. Combining strongly disagree and disagree, 61.11% of them think that to search online articles and conference, the institution's network is not reliable.

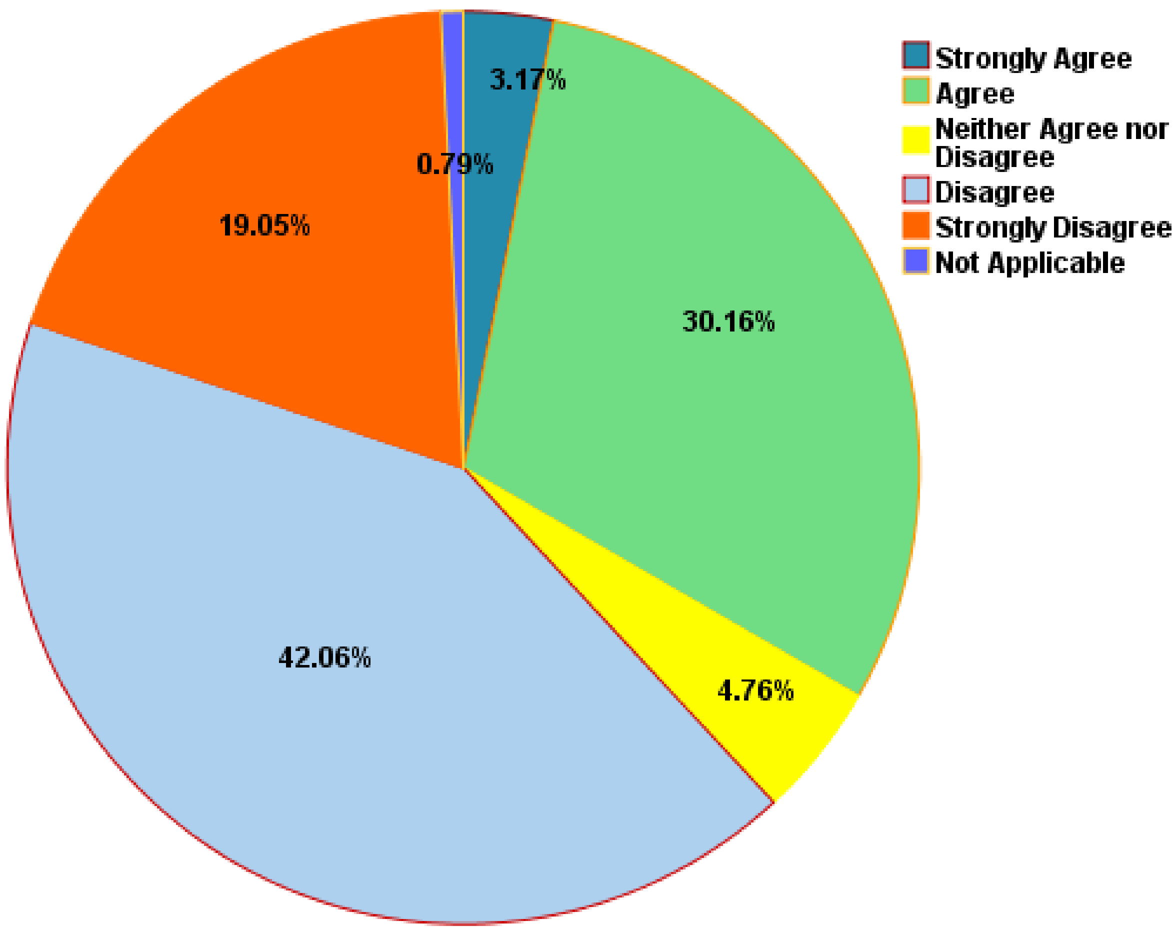

Figure 5. 29: Reliability of the institution's network

Statement: "I am easily able to search online journal articles and online conferences using my network."

5.3.9. Search Tools commonly used by Ethiopian Researchers of Public University (Q.12)

As shown in Figure 5. 30 Google and Google Scholar are highly used constitutes for 29.59% and 26.53% of responses, respectively.

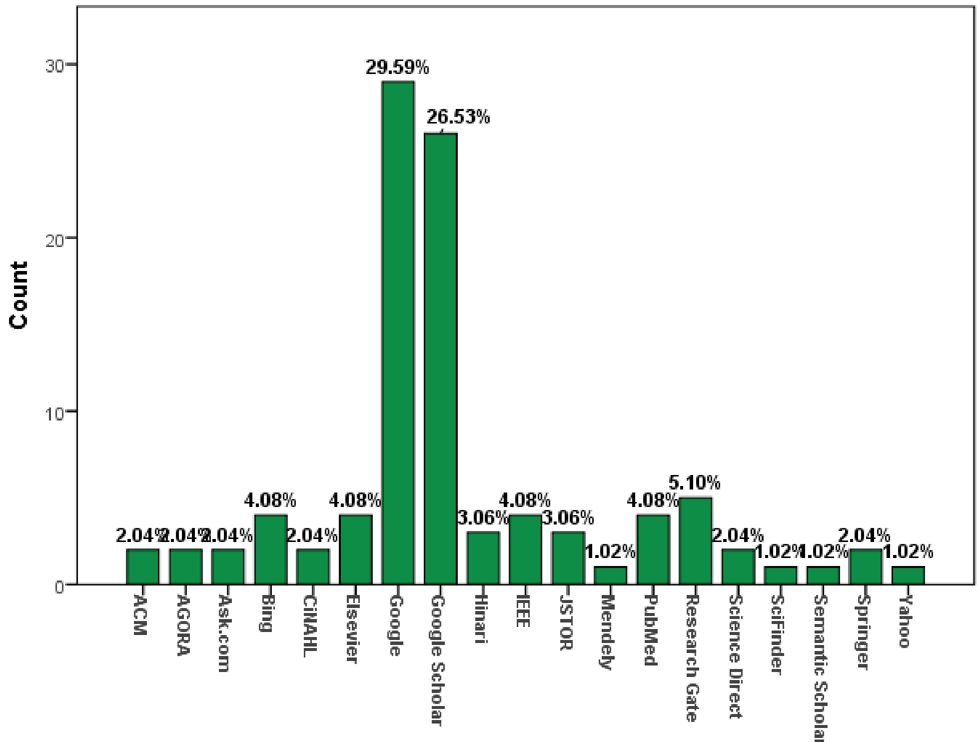

Figure 5. 30: Example of search tools used by researchers

As shown in Figure 5. 30, the other most used search engines/databases are:

- Bing, PubMed, and Elsevier – 4.08%
- Hinari and JSTOR – 3.06%
- IEEE – 4.08%
- Research Gate – 5.10%

5.3.10. Journal Articles Access, Network Reliability and Example of Articles (Q.13, Q13.1 and 13.2)

Figure 5. 31 and Figure 5. 32 shows the frequency journal articles access and institution's network reliability view . As shown in Figure 5. 32, combining "very often" and "often", (89.92%) frequently access conferences and articles online, combining "strongly disagree" and "disagree", (61.72%) said that there is a problem with their institution's network as shown in Figure 5. 32.

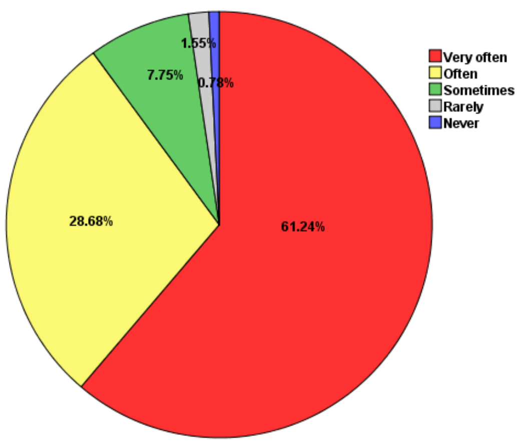

Figure 5. 31: Journal articles access Frequency

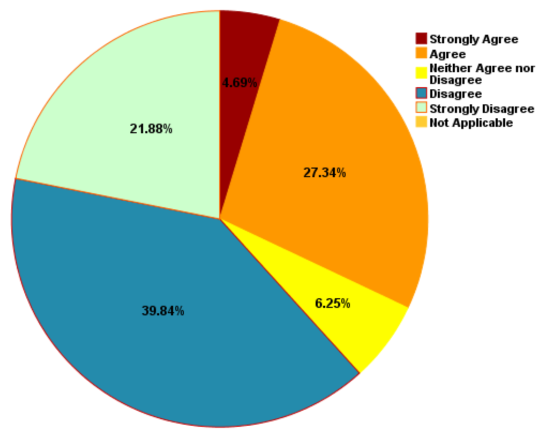

Figure 5. 32: Network Reliability

Statement: "I am easily able to access online journals, articles, and conferences using my network."

Some of the examples of “typical” articles that researchers want to download are:

- A correlational study to determine fracture depression level and dural tear
- Accessibility analysis using GIS and RS
- Age-appropriate vaccination against measles and DPT-3 in India – closing the gaps Starch-based nanoparticles as drug-carriers
- Application of GIS and remote sensing technologies in spatial analysis
- Articles focusing on the area of traditional medicinal plants
- Articles from Springer, Elsevier, IEEE, Science Direct, ACM, and other academic journals
- Articles on disaster prediction, machine learning, wireless sensor network
- Challenges of horticultural crops in Ethiopia
- Content-based information retrieval system for agricultural images
- Healthcare waste management
- IEEE Transaction on antennas and propagation, Journal of selected topics in applied earth observations and remote sensing and transactions on geoscience and remote sensing
- Journal articles on water management
- Journal of chemistry education
- Journals associated with environmental biotechnology
- OECD guideline for animal studies
- Physical review letters
- Research on African university students HIV/AIDS-related facts
- Teaching reading through cooperative learning
- Web usage mining

5.3.11. Data Sets Access, Network Reliability and Examples of these Data Sets (Q.14.14.1 and 14.2)

As shown in Figure 5. 33, combining “very often” and “often” responses, 53.49% of respondents regularly access online data sets. As shown in Figure 5. 34, combining “strongly disagree” and “disagree” responses, around 58% of them believe that the institution’s network is unreliable.

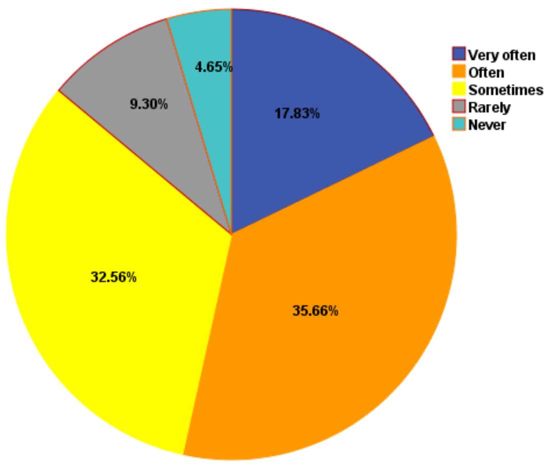

Figure 5. 33: Data sets access frequency among researchers

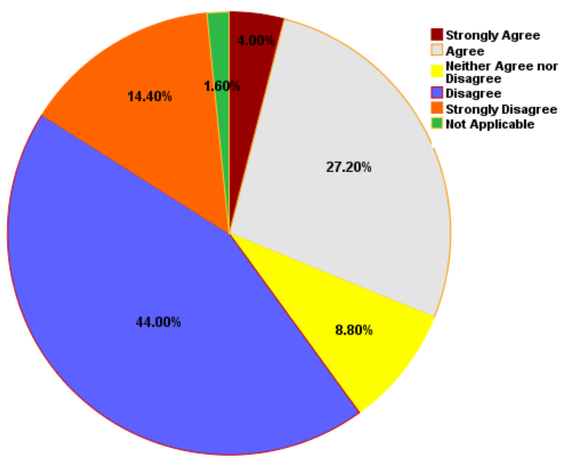

Figure 5. 34: Institution’s network Reliability

Statement: “I am able to access data sets easily using my network.”

Other datasets access by researchers includes:

- Digital Elevation Models (DEM) - GIS
- Ethiopian Central Statistics Agency (CSA)
- Ethiopian ministry of education: education statistics annual abstract
- Food and Agriculture Organization (FAO) datasets
- Genesis
- ITU - The World Telecommunication
- MIT-Common Data Set (CDS)
- NASA
- PubMed
- The DHS Program
- The International Livestock Research Institute (ILRI)
- UN human development index datasets
- UNESCO Institute for Statistics (UIS)
- University of California Irvine (UCI) Knowledge Discovery in Databases (KDD)
- WHO data sets
- World Bank World Development Indicators (WDI)

5.3.12. Open Access Research Publishing, Network Reliability and Examples of Research Work Published Online (Q.15,15.1 and 15.2)

Figure 5. 35 and Figure 5. 36 shows user interest to make publicly accessible of their research and the opinions on the reliability of network. Combining "very often" and "often" response and as can be seen from Figure 5. 35, 62.79% of researchers publish open access research/data and, combining "strongly disagree" and "disagree" responses, 57.25% of them think that the institution's network is not reliable.

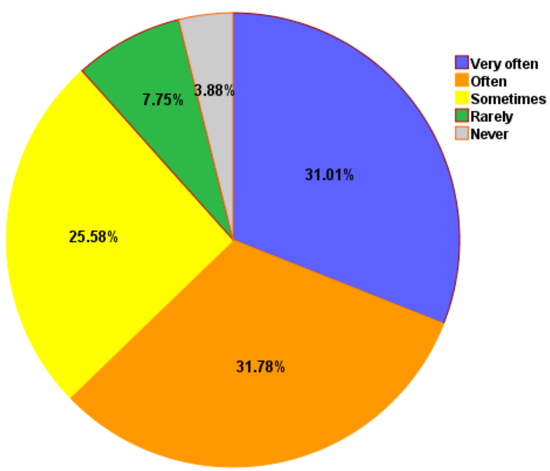

Figure 5. 35: Open access research publishing Frequency

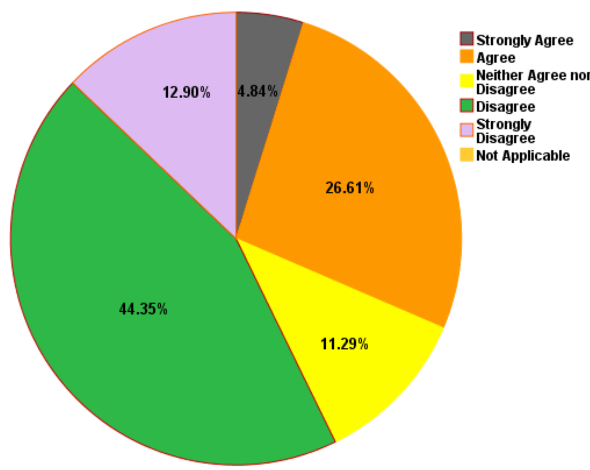

Figure 5. 36: Institution's network Reliability

Statement: "I can easily publish open access research online with my network."

Some of the examples of research output and found research data that researchers want to publish online are:

- Analysis of tomato value chain in the case of Zeway Dugda District, East Shoa Zone, Oromia region, Ethiopia.
- Assessing the economic, environmental, and social impacts of irrigation schemes, a case study from the Rift valley basin, Ethiopia.
- Healthcare waste management.
- Information literacy skill training on health professionals for improved use of E-resources
- Interactive voice response for Ethiopian market information system articles.
- Storage of effect of mango varieties to prolong its shelf life.
- The cardiovascular effects of Khat: a systematic review with meta-analysis.
- The defects of cooperative learning on students' social skills performance.
- Value chain analysis of tomato in the central rift valley.

5.3.13. Most Required Software by Researchers, Online Access, and Network Reliability (Q.16,16.2 and 16.3)

Figure 5. 37 illustrate the most needed software by respondents. The most required software were R and SPSS. Others including forecasting, modelling and statistical applications are also required by researchers.

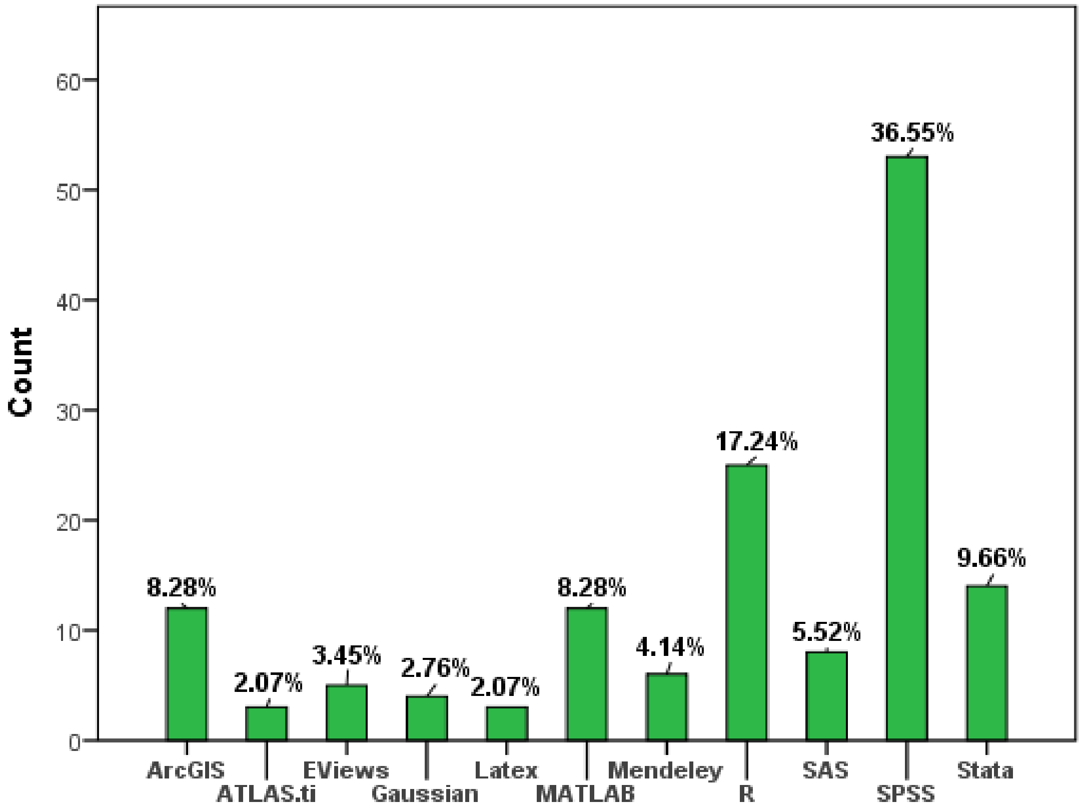

Figure 5. 37: Most required software by researchers

In addition, the below list is also required presented in Table 5. 5.

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Table 5. 5: list of required software packages by researchers

Adobe Creative Suite	FileSender	MiniTab	RC-MAP
Adobe Package	GeoStudio	Multiphysics	RefWorks
ANSYS	Ginger Software	Octave	RevMan
CADAM	GitHub	Office 365 online	SISTA
Canoco	Java	OneDrive	Speech Recognition
ChemOffice	Language Simulations	Online modelling	SWAT
Comsol	LaTeX	Online Survey Tools	SWAT
Dropbox	LIMDEP	Origin	SWIM
EndNote	MathType	OriginLab	Ubidots
Epi Info	Microsoft Azure	PHP	VASP
EpiInfo	MIKE HYDRO Basin	Plagiarism Checker	Weka
ERDAS Imagine	MIKE-SHE	Quantum ESPRESSO	Zotero

Figure 5. 38 and Figure 5. 39 shows online software access frequency by researchers' and their view on the network reliability. As expected, (68.99%) of respondents, combining "very often" and "often" response regularly access software online, many of them (60.46%) combining "strongly disagree" and "disagree" responses indicated that their institution's network causes access problems.

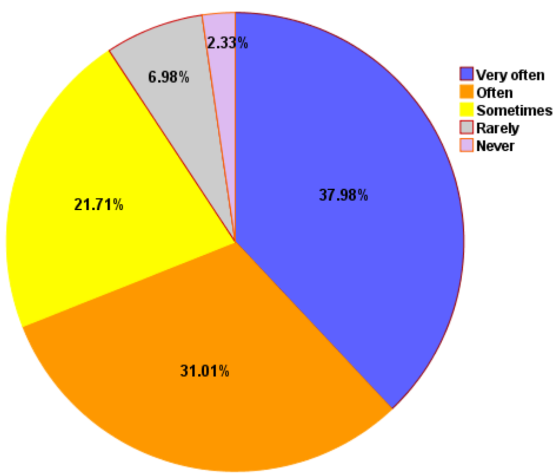


Figure 5. 38: Frequency of Software access online

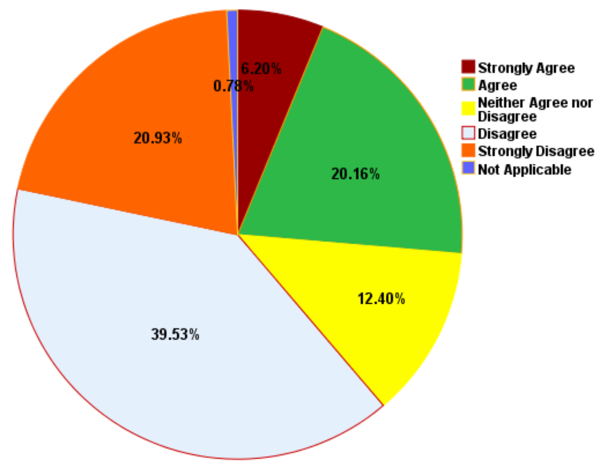


Figure 5. 39: Network reliability

Statement: "I am able to access software online easily with my network."

5.3.14. Software Publishing, Network Reliability and Examples of Published Software (Q.17,17.1 and 17.2)

Figure 5. 40 and Figure 5. 41 shows researchers are not willing to publish software, and network reliability is not a concern. However, as shown in Figure 5. 40, 10.23% of researchers, did publish software either very often or often.

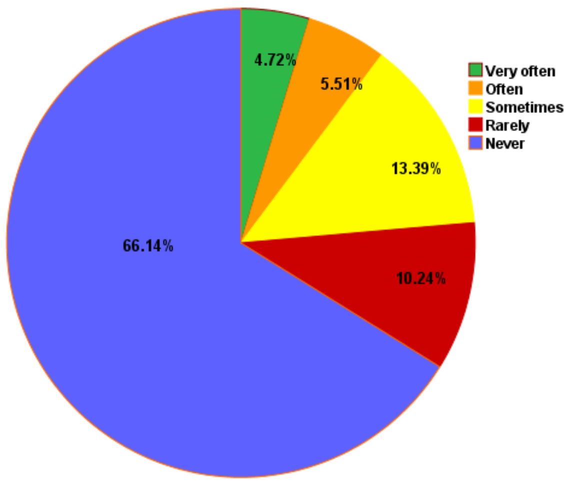


Figure 5. 40: Software publishing frequency

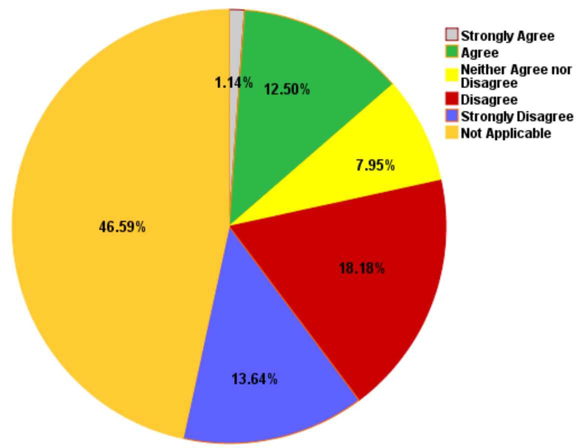


Figure 5. 41: Institution's network Reliability

Statement: "I can publish software online easily using my network."

Examples of the published software online are:

- Document management information system
- E-commerce marketing system
- Mobile apps for Android, Windows, and IOS
- Student information management system
- Web design

5.3.15. Remote Sensors Access, Network Reliability and Examples of these Sensors (Q.18, 18.1 and 18.2)

Considering "never" response in Figure 5. 42, 58.91% of researchers in the survey were never accessed remote sensors online, and network reliability is not an issue for (58.24%) combining "not applicable" and "agree" as shown in Figure 5. 42.

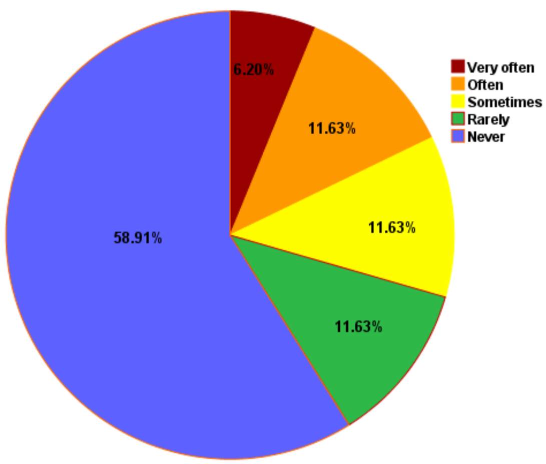


Figure 5. 42: Remote sensors access Frequency

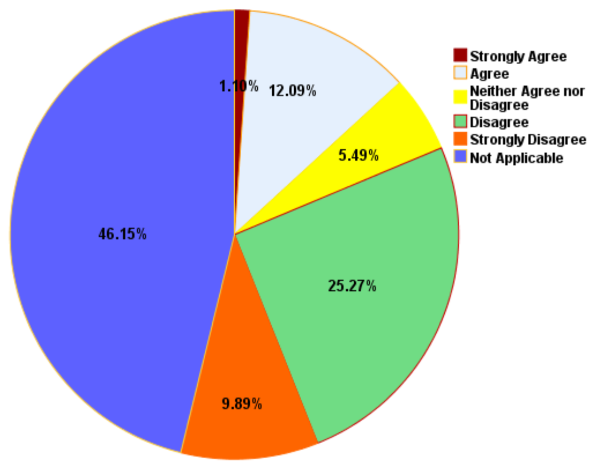


Figure 5. 43: Institution's network Reliability

Statement: "I can access remote sensors online easily using my network."

Some examples of remote sensors include:

- Communication sensor
- Optical sensor
- PH sensor
- Sensors for pollution monitoring and control
- Smart agriculture sensors
- Temperature sensors
- Water level sensor

5.3.16. Research requirements issues related to the network (Q.19)

Below are issues related with network to support the research work as per shown in Figure 5. 44:

- 64.85 % agreed that there is a local support by providing computing infrastructure for research work combining "agree" and "strongly agree," while combining "disagree" and "strongly disagree," 27.35% indicated that this support was inadequate as shown in Figure 5. 44 (a)
- As shown in Figure 5. 44 (b and c), combining "agree" and "strongly agree," 91.48% of the respondents indicated that providing access to have computing facilities remotely and HPC would assist researchers in doing research activities that are currently impossible. Which indicates that the lack of both facilities (91.48%) is a potential inhibitor to research accessibility and enablement.
- As indicated in Figure 5. 44 (d), combining "agree" and "strongly agree," only 29.45% of the respondents indicated that they can easily get storage for their data during the research; however, most of them do not have access to the data storage to support their research activities. Accordingly, combining "agree" and "strongly agree," 89.92% of researchers agreed that, having more storage support them to do more research, that is not possible to conduct research currently as shown in Figure 5. 44 (e).
- Concerning the ability to share data, as shown in Figure 5. 44 (f), combining "agree" and "strongly agree", 90.62% want to share data online with others and as shown in Figure 5. 45 (g), combining "agree" and "strongly agree", 86.72% agreed that by sharing their data online, they would be able to do research which may not be possible to do right now.
- As shown in Figure 5. 44 (h), combining "agree" and "strongly agree," 91.47% agreed that using their local credentials to log in at another institution to access their resources would enhance their research work.
- Intermittent network connection cause problems for researchers to take part in conferences conducted internationally as indicated in Figure 5. 44 (j), (79.89 % agreed), as indicated in Figure 5. 44 (i).
- As indicated in Figure 5. 45 (k). Finally, and most importantly, combining "agree" and "strongly agree," 96.9% agreed that participating in international academic communities and collaborating with them is useful for their career, as shown in Figure 5. 45 (l).

- Access to participation in international conferences, access to subscribed Journals and articles, access to licensed software, and Remote Access Services (RAS).

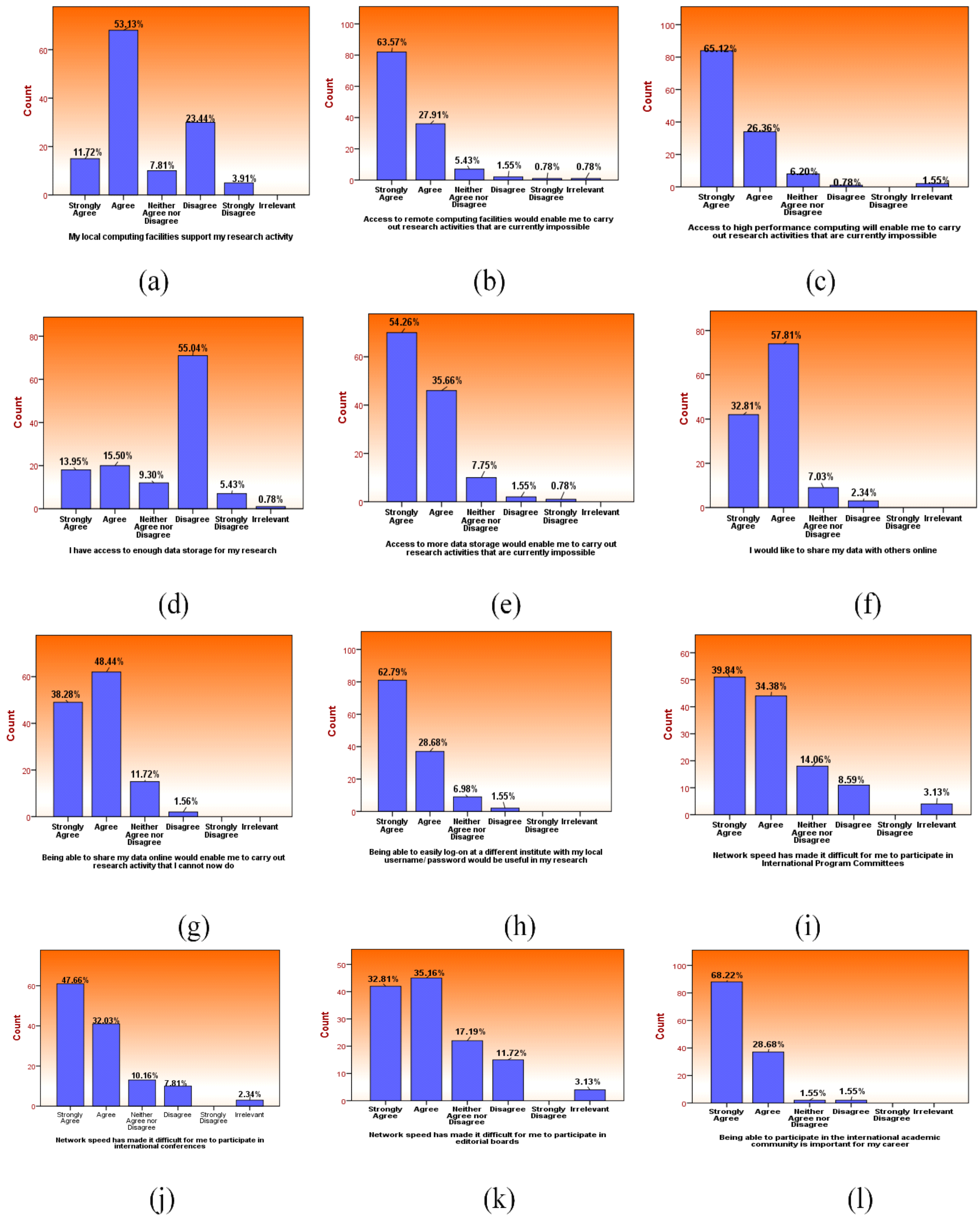


Figure 5. 44: General network support for research

5.3.17. Use and Usefulness of Networked Services for Research (Q.20)

Figure 5. 45 show the use of networked related services that can be provided for research use. The responses from the participants including “I am using the service” and “I am not using the services ” which shows the usage of the services. In Figure 5. 455 the participants mentioned services are helpful for their research, accordingly, the below conclusions are draw

<u>The usage of a service</u>

- Considering “yes,” the most available and used services were.
    - Institutional email services (83.72%), as shown in Figure 5. 45 (b).
    - Online Library Resources (77.52%), as shown in Figure 5. 45 (e).
    - Video or web conferencing services (33.33%), as shown in Figure 5. 45 (a).
- On the other hand, considering “no,” the results indicated that the services that were not used included.
    - Login to other organisations using their local credentials or single sign-on (72.87%), as shown in Figure 5. 45 (f).
    - Access to storage space (70.54%), as shown in Figure 5. 45 (g).
    - Web-based portals or remote access to institutional resources including but not limited to; teaching and learning materials, research materials, computing resources, and sensor services to support the community (67.19%), as shown in Figure 5. 45 (d).
    - Collaboration and communication tools (65.63%), as shown in Figure 5. 45 (c).

<u>Use and Usefulness of Social Media</u>

Combining “agree” and “strongly agree,” participants widely agreed that LinkedIn 71.87 % was the most useful in research compared to Facebook 31.78% and Twitter 35.94%, as shown in Figure 5. 45 (j), (h) and (i) respectively. ResearchGate was considered the most useful, with 93.02% to the statement, as shown in Figure 5. 45 (k).

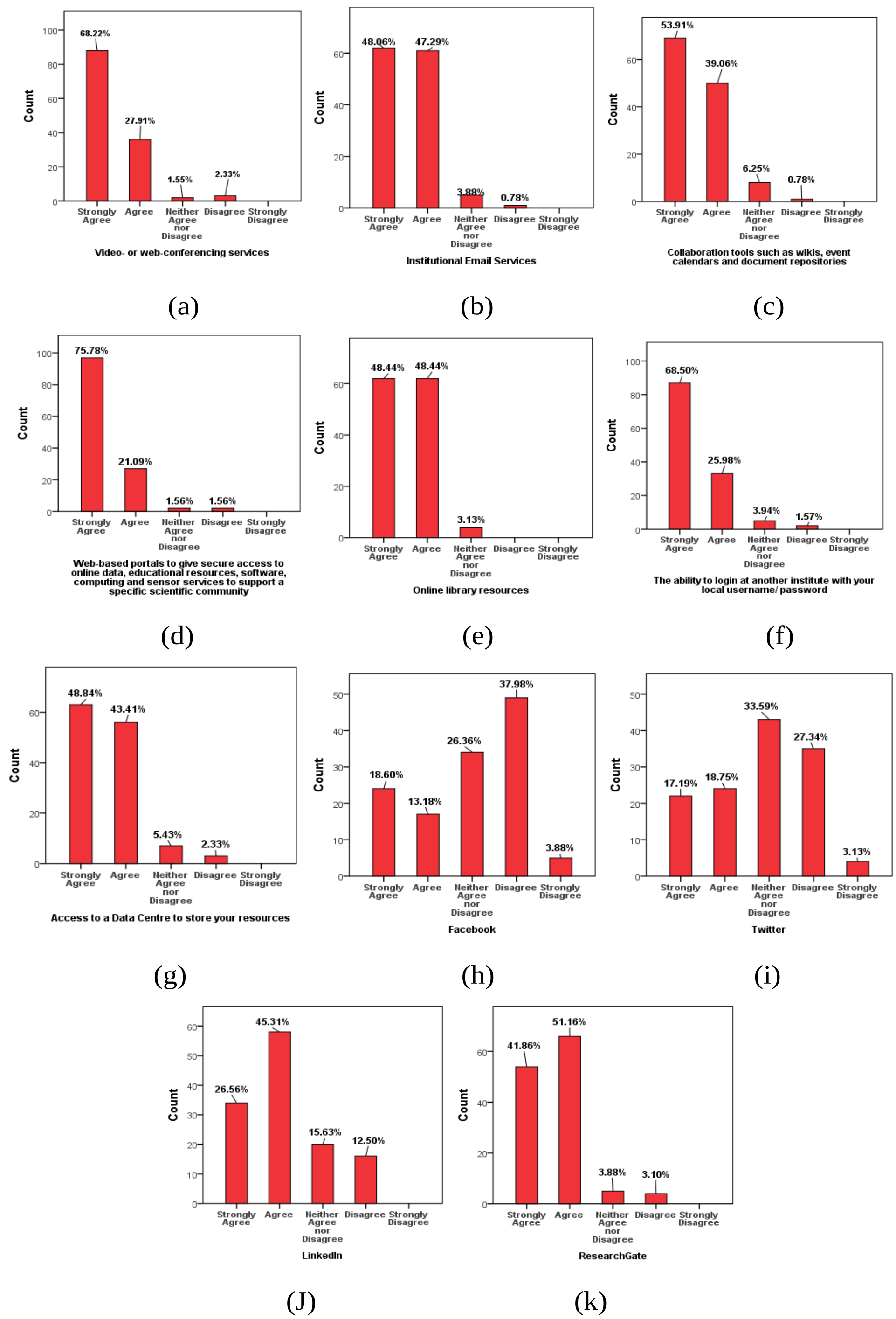


Figure 5. 45: Usefulness of networked services for research

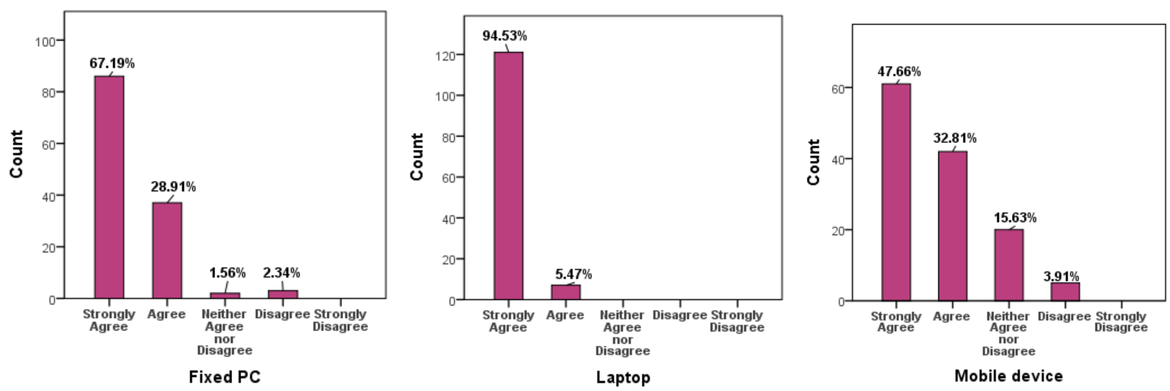
Statement: "These networked services are helpful for my research activities."

When requested to specify any other services that researchers would like to use, these were the responses:

- Access to journals and articles
- Accessing other universities/research centre resources (library and laboratory)
- Access to Licensed software

5.3.18. The usefulness of Electronic Devices and Preferred Devices for Research (Q.21 and 21.1)

Figure 5. 46 show the electronic devices usage to have an online access for researchers. Most of the electronic devices are valuable for research work, for instance Laptops constitutes 100%, Fixed PC constitutes 96.1% and Mobile Devices constitutes 80.47% as shown in Figure 5. 46 (b), (a) and (c) respectively.



(a) (b) (c)

Figure 5. 46: Usefulness of electronic devices for research purposes

Statement: "These electronic devices are helpful to gain online access for the research work."

Other electronic devices used for researcher includes:

- Tablet
- Tablets (iPad, Kindle, Notepad)
- VDI (Virtual Desktop Environment)

As shown in Figure 5. 47, concerning researchers' preferred devices, 76.09% of the researchers want to use laptop for their research related work.

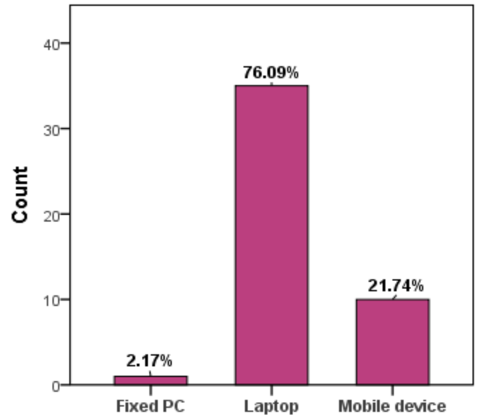


Figure 5. 47: Most preferred Device

5.3.19. Existing Network Current Problems (Q.22)

Figure 5. 48 show institutional network problem for researchers.

Combining “agree” and “strongly agree” responses.

- It is hard to connect to the network (74.42%), as shown in Figure 5. 48 (a).
- The network is intermittent (89.15%), as shown in Figure 5. 48 (b).
- Data privacy could not be guaranteed (82.95%), as shown in Figure 5. 48 (c).
- Security is an issue for the network (77.51%), as shown in Figure 5. 48 (c).

Most respondents agreed that the existing institutional network has a problem in supporting their research work, and security and privacy were perceived to be necessary.

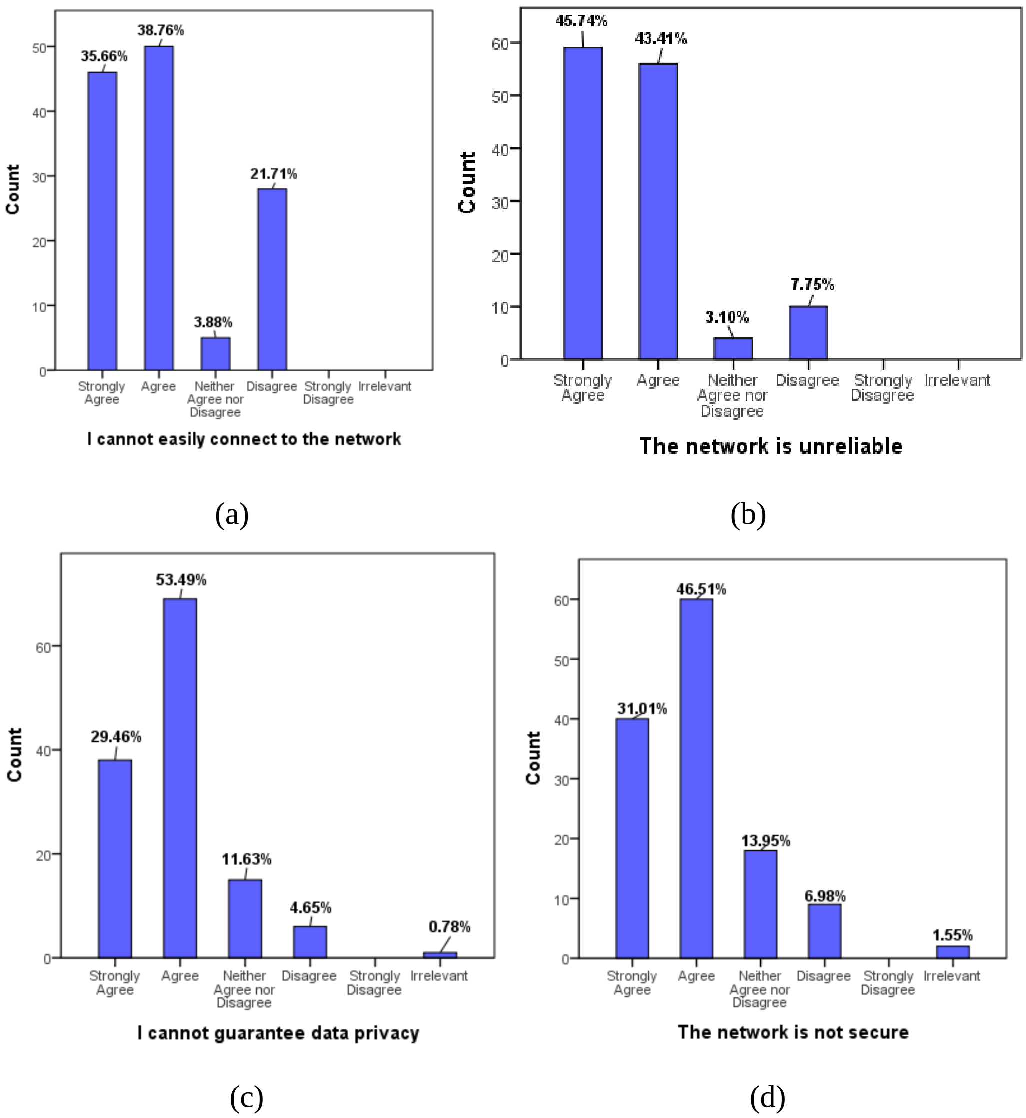


Figure 5. 48: Understanding of the main concerns with the network

Other network related problems for researchers includes:

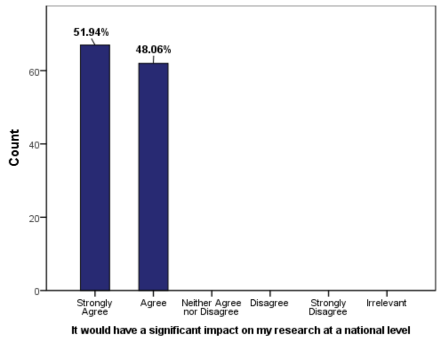
- Availability and affordability for off-campus accessibility
- Intermittent Internet connection
- Low/insufficient Internet bandwidth
- Poor support and maintenance
- Power supply issues/ no constant electricity

5.3.20. Impact of Reliable Network on the Research (Q.23)

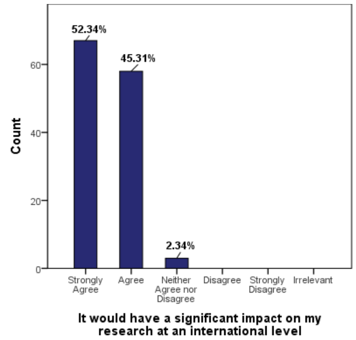
Figure 5. 49 show the impact of a reliable network on research. Combining “agree” and “strongly agree” responses, over 93% of respondents agreed with the below.

- It supports research related activities at national level (100%), as shown in Figure 5. 49 (a).
- It supports research related activities at international level (97.65%), as shown in Figure 5. 49 (b).
- Local research can make impact at a national level (99.23%), as shown in Figure 5. 49 (c).
- Local research can make impact at international level (95.35%), as shown in Figure 5. 49 (d).
- It would enable the establishment of new partnerships (100%), as shown in Figure 5. 49 (e).
- It would enable them to work with their counterparts around the globe (99.22%), as shown in Figure 55. 49 (f).
- For researchers, they can collaborate and work together with their counterpart in the world (93.9%), as shown in Figure 5. 49 (g).

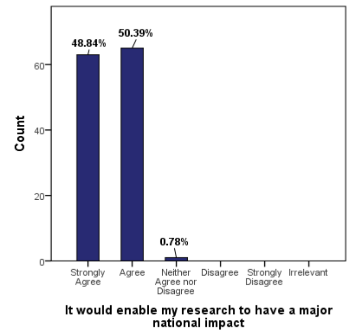
Overall, these figures show that a reliable network would have a significant impact on improving the research output in Ethiopia higher education institutions.



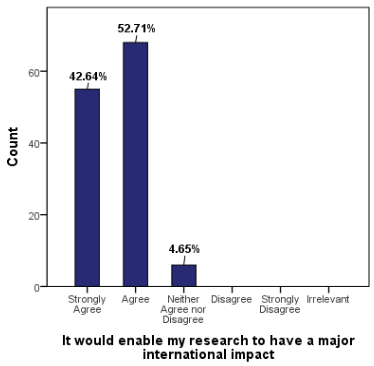
(a)



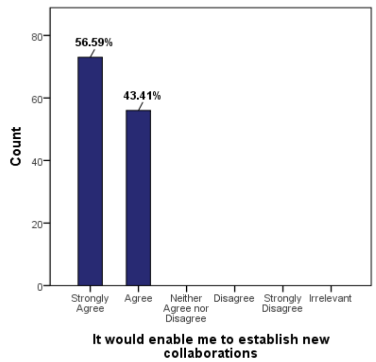
(b)



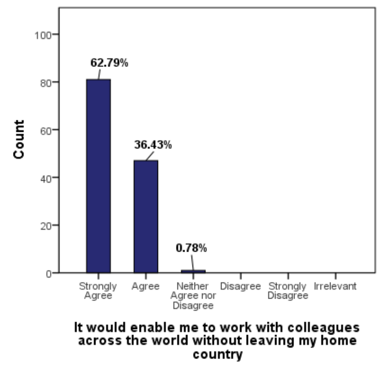
(c)



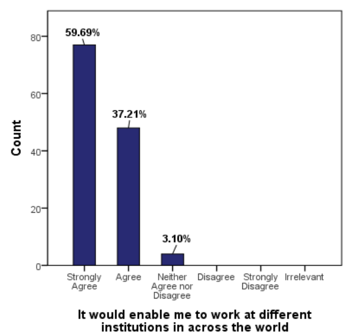
(d)



(e)



(f)



(g)

Figure 5. 49: Impact of a reliable network on research

When the participants were asked to add any other issues that they would like to be considered, they added the following:

- Improve digital literacy
- It will improve the visibility of the research work
- Provide plagiarism checker

5.4. Network Infrastructure Related Issues

This part of involve ICT teams manages the university network. It mainly involves the ICT directors of the universities and EthERNet staff. The objective is to find the existing technologies or services provided by the ICT Directorate of the university, the current trends, and the challenges/barriers in using the EthERNet. Of the usable responses received from the 36 universities, 25 university ICT directors requested to take part in the survey and EthERNet CTO.

5.4.1. Available ICT Infrastructure and Services (Q.1 and 1.1)

As per the survey regarding the existing technologies/networked services provided by the university ICT directorate. Their main effort is to provide standard campus network and related services for end users. Accordingly, the most available ICT Infrastructure and Services were.

- Online library resources.
- Campus networks, both LAN and WLAN.
- End user and network Security.
- Video or web conferencing services.

On the other hand, considering “yes,” the results indicated that the technologies or services that were less available included.

- Massive open online courseware.
- IP Telephony /VoIP.
- Collaboration tools.
- Digital contents for teaching and learning.
- Learning Management System.

Some of the services such as institutional networks claimed available by ICT directors, is not to the satisfaction of their end-user (teachers and researchers), as most of them are complaining about the reliability and security of the existing institutional network in supporting the quality of education and research output.

Concerning the ‘other services currently provided’ category, the responses were as follows:

- Application development
- Balanced Scorecard (BSC) application software, property management system
- Computer maintenance
- Digital signage and outdoor screens disaster recovery site (on-campus)
- E-commerce
- E-learning, FTP, mail, web services
- Institutional E-Mail Service (O-365)
- IP telephoning and technical support for business partners
- Online journal system
- Online teaching and learning resources
- A platform for online sales
- Providing support for Office 365
- Smart classroom preparation
- Student information management system
- Virtualisation
- Warehouse information management system
- Website development

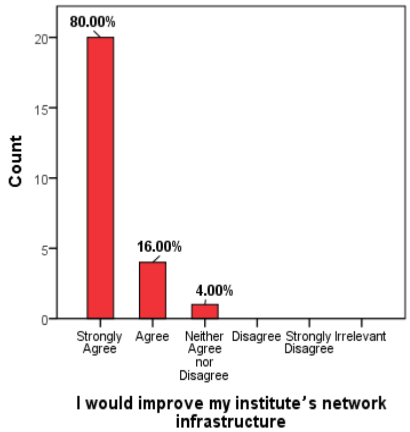
According to EthERNet CTO’s responses, currently, EthERNet is providing cloud services, which is a hybrid cloud. The public cloud-only provides Microsoft O.365 email services, using the university’s domain, in collaboration with Microsoft. However, the original plan for EthERNet is to provide more private cloud services and to be the host for the member intuitions, mainly for Ethiopian public higher education institutions. However, EthERNet is not yet providing the majority of services expected by end-users, including but not limited to; tools for file sharing, storage backup disaster recovery, web hosting, federated identity management, and single sign-on, network peering, E-learning, and education services, and file storage.

5.4.2. Reliable Network Impact and other Network Technology or Applications that could be Provided (Q.2 and 2.1)

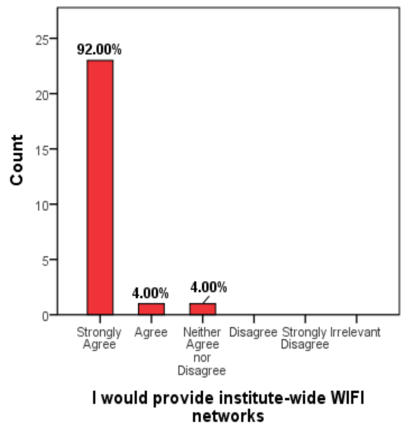
Figure 5. 50 shows the reliable network impact. Combining “agree” and “strongly agree” responses, over 92% of respondents agreed with all of the following.

- Institutional network/campus network could be improved (96%), as shown in Figure 5. 50 (a).
- Campus-wide Wi-Fi could be provided (96%), as shown in Figure 5. 50 (b).
- Security (network and application) could be provided (96%), as shown in Figure 5. 50 (c).
- Collaboration tools could easily be provided (96%), as shown in Figure 5. 50 (f).
- Voice over IP services could easily be provided (95.83%), as shown in Figure 5. 50 (d).
- Web-based teaching and learning resources could easily be provided (92%), as shown in Figure 5. 50 (f).
- Unified communication tools (video- or web-conferencing) services could easily be provided (92%), as shown in Figure 5. 50 (e).

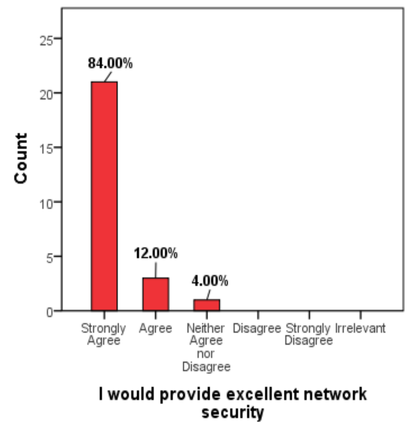
Overall, the main focus is to provide standard campus network and provide collaboration tools (96% agreement). Over 92% indicates that all other services are highly important.



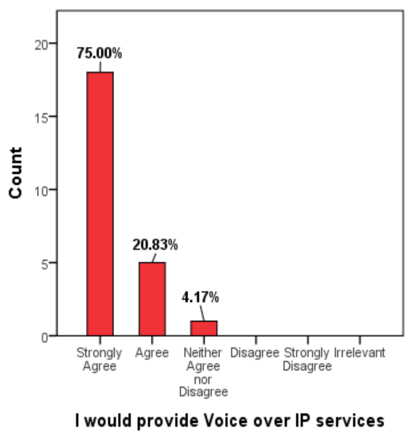
(a)



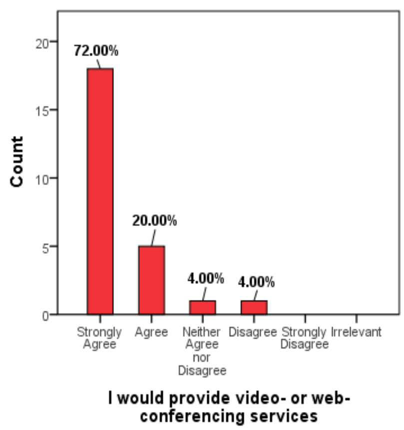
(b)



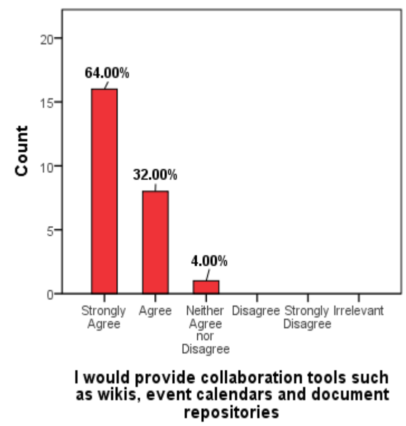
(c)



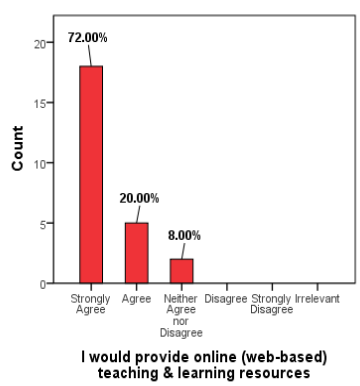
(d)



(e)



(f)



(f)

Figure 5. 50: Potential interests for networking technology and application management

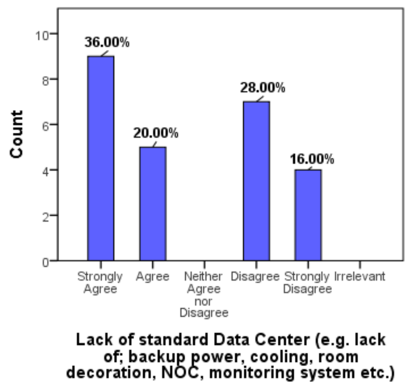
Other network technology or applications that it was hoped would be provided in the future were:

- Campus video surveillance system /CCTV
- Digital signage
- Fleet management system
- ICT incubation centre
- Integrated university management system (one card system),
- IP telephoning
- IPTV (IP Television)
- Virtual desktop infrastructure
- Webhosting for the nearest communities

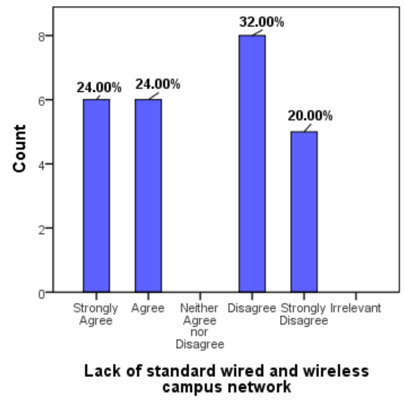
5.4.3. Main Challenges/Barriers in using EthERNet and Other Issues to be Considered (Q.3 and 3.1)

Figure 5. 51 illustrate the main challenges/barriers in using the EthERNet to provide ICT services used for research and education purposes. Mixing strongly agree and agree, respondents agreed that all the below mentioned problems are barriers to use the EthERNet to provide ICT services.

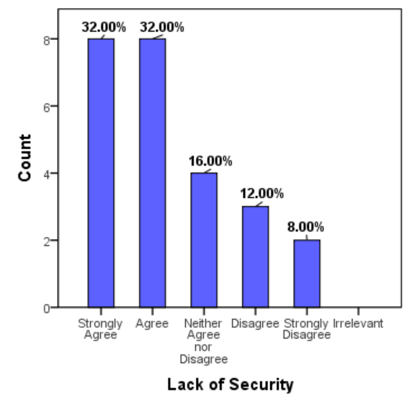
- The institutional network could be improved (96%), as shown in Figure 5. 51 (a).
- Unavailability of Institutional ICT Policy (80%), as shown in Figure 5. 51 (h).
- Institutional ICT Policy is not implemented (80%), as shown in Figure 5. 51 (i).
- Lack of a retention mechanism for ICT staff (80%), as shown in Figure 5. 51 (o).
- Lack of skilled ICT staff (76%), as shown in Figure 5. 51 (n).
- The difficulty of ICT strategy implementation (64%), as shown in Figure 5. 51 (l).
- Insufficient Internet bandwidth (64%), as shown in Figure 5. 51 (d).
- Insufficient support from the network provider /Ethio Telecom (64%), as shown in Figure 5. 51 (e).
- Lack of security (64%), as shown in Figure 5. 51 (c).
- Lack of sufficient budget allocation for ICT (64%), as shown in Figure 5. 51 (m).
- Unavailability of institutional ICT strategy (60%), as shown in Figure 5. 51 (j).
- Lack of standard data centre (e.g., lack of; backup power, cooling, room decoration, NOC, and monitoring system) (56%), as shown in Figure 5. 51 (a).
- Institutional ICT strategy is not aligned to the corporate strategy (52%), as shown in Figure 5. 51 (k).
- Lack of support and commitment from top-level management (52%), as shown in Figure 5. 51 (f).
- Lack of standard wired and wireless campus networks (48%), as shown in Figure 5. 51 (b).
- Unavailability of Last mile connectivity for remote campuses (the branch campuses are not connected to the main campus) (48%), as shown in Figure 5. 51 (g).


Count
36.00%
20.00%
28.00%
16.00%
Strongly Agree
Agree
Neither Agree nor Disagree
Disagree
Strongly Disagree
Irrelevant
Lack of standard Data Center (e.g. lack of; backup power, cooling, room decoration, NOC, monitoring system etc.)

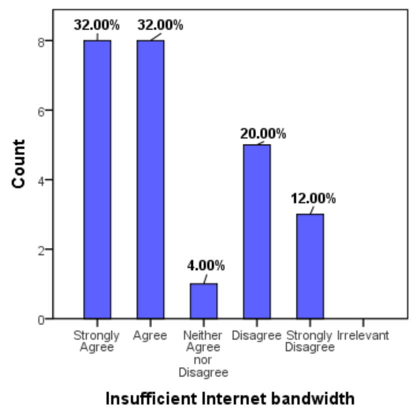
(a)


Count
24.00%
24.00%
32.00%
20.00%
Strongly Agree
Agree
Neither Agree nor Disagree
Disagree
Strongly Disagree
Irrelevant
Lack of standard wired and wireless campus network

(b)


Count
32.00%
32.00%
16.00%
12.00%
8.00%
Strongly Agree
Agree
Neither Agree nor Disagree
Disagree
Strongly Disagree
Irrelevant
Lack of Security

(c)


Count
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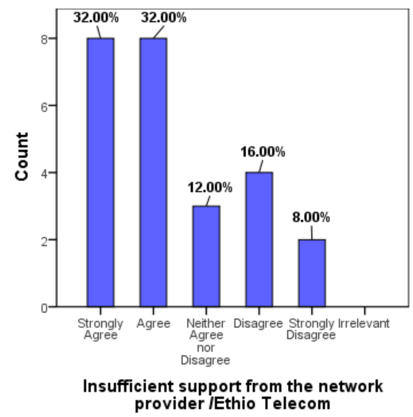
32.00%
4.00%
20.00%
12.00%
Strongly Agree
Agree
Neither Agree nor Disagree
Disagree
Strongly Disagree
Irrelevant
Insufficient Internet bandwidth

(d)


Count
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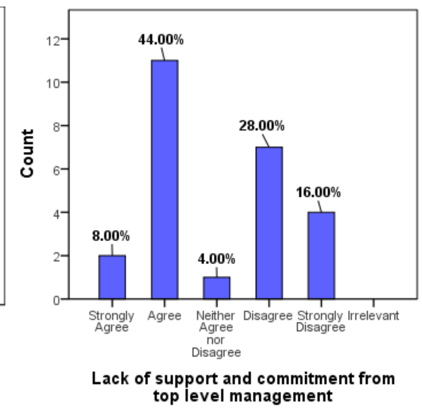
32.00%
12.00%
16.00%
8.00%
Strongly Agree
Agree
Neither Agree nor Disagree
Disagree
Strongly Disagree
Irrelevant
Insufficient support from the network provider /Ethio Telecom

(e)


Count
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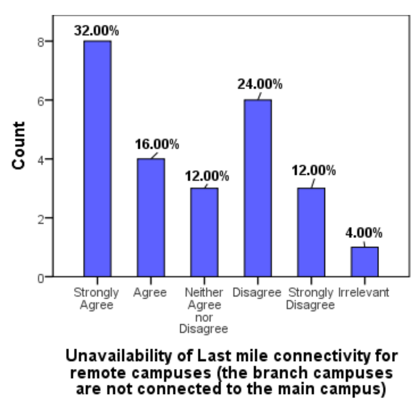
44.00%
4.00%
28.00%
16.00%
Strongly Agree
Agree
Neither Agree nor Disagree
Disagree
Strongly Disagree
Irrelevant
Lack of support and commitment from top level management

(f)


Count
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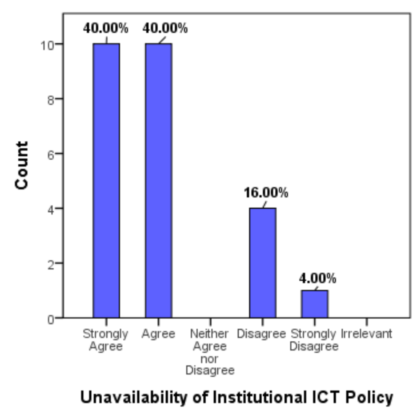
12.00%
24.00%
12.00%
4.00%
Strongly Agree
Agree
Neither Agree nor Disagree
Disagree
Strongly Disagree
Irrelevant
Unavailability of Last mile connectivity for remote campuses (the branch campuses are not connected to the main campus)

(g)


Count
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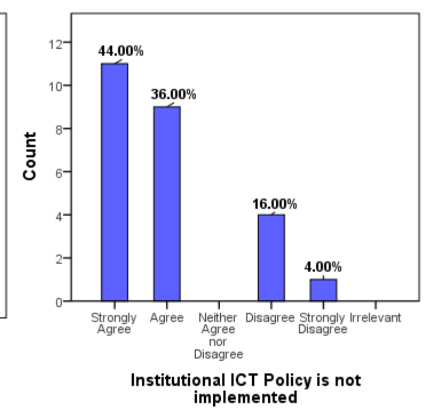
40.00%
16.00%
4.00%
Strongly Agree
Agree
Neither Agree nor Disagree
Disagree
Strongly Disagree
Irrelevant
Unavailability of Institutional ICT Policy

(h)


Count
44.00%
36.00%
16.00%
4.00%
Strongly Agree
Agree
Neither Agree nor Disagree
Disagree
Strongly Disagree
Irrelevant
Institutional ICT Policy is not implemented

(i)

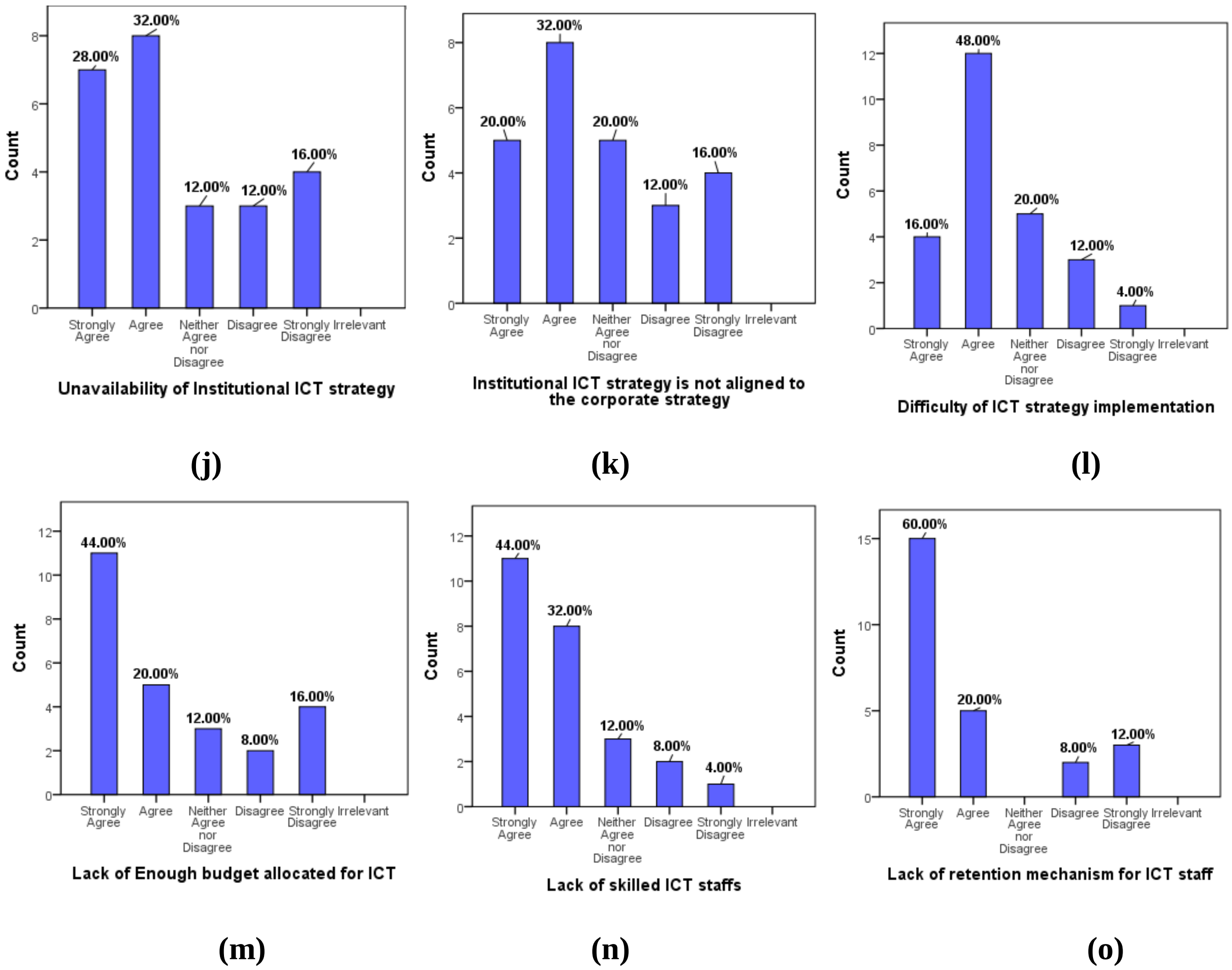


Figure 5. 51: Main challenges/barriers in using EthERNet

Other issues participants mentioned to be considered as challenges/barriers to using the EthERNet to provide ICT services that are needed for research and education purposes are indicated below:

- Frequent power outage
- Lack of awareness on the national ICT policy by both ICT staff and higher officials.
- Lack of capacity building for ICT staff
- Lack of commitment to ICT staff
- Lack of coordination and collaboration among public universities in ICT
- There is no application provided by EthERNet other than connectivity (Cloud, HPC, DNS and Network monitoring)

For EthERNet to provide cloud services, the main concerns are security, privacy, reliability, location, availability, and technical support from the cable provider, Ethio Telecom.

Currently, the main challenges/barriers for the EthERNet to provide ICT services that are needed for research and education purposes are insufficient internet bandwidth, reliability of the network, insufficient support from the cable provider /ISP, unavailability of national ICT policy and strategy, lack of sufficient budget allocation, lack of skilled ICT staff and lack of a retention mechanism for staff.

5.5. Structural Equation Model Results

According to Credé and Harms (2015), the structural and measurement models constitutes SEM. The measurement model explains the kind of association between clear indicators and latent constructs, as well as the provision of a statistical measure for the latent constructs (Rose, Wagner, Mayer and Nagengast, 2019). Meanwhile, the measurement model denotes the Confirmatory Factor Analysis (CFA), and the structured model considers the causal relations between the unobserved variables (Marsh, Morin, Parker, and Kaur, 2014; Khine, 2013).

5.5.1. Measurement Model in PLS-SEM

The measurement model is a pre-cursor to structural equation modelling. The constructs of a measurement model cannot be validated by definition; the confirmation of the validity and reliability of the developed scales is the rationale used to label a measurement model as valid (Marsh, Morin, Parker and Kaur, 2014). According to Gao, Feng, Liu, and Hu (2016), the measurement model enables the researcher to assess how the newly developed latent variables fit together and whether they are linked sufficiently to their indicators. This means, the measurement model help to evaluate aspects of the latent variables' validity and reliability concerns (Watkins, 2018). These include latent variable validity (discriminant and convergent) and Cronbach's alpha and composite reliability for both reflective and formative latent variables, as described in **Sections 4.9.2** of the measurement methodology.

The analysis in WarpPLS 6.0 created the basis for this research study (Kock, 2016), as explained in **Section 4.9**. The Missing data imputation algorithm was Arithmetic Mean Imputation. The outer model analysis algorithm was **PLS Regression**. The default inner model analysis algorithm was **Warp3**. The re-sampling methodology used in the analysis was **Stable3**. A total of 100 samples data were used in the study, with a model data of 154 case (rows) numbers. Eleven latent variables and 51 indicators were also used in the model. Moreover, the number of iterations to obtain estimates was seven. To handle the issue of outliers, the researcher decided to include already ranked data.

The section below contains illustrations of the internal consistency and reliability of the research methodology, as well as the construct validity, convergence, and Averaged Variance Extracted (AVE) from both the formative and the reflective models of measurement.

5.5.1.1. Discriminant Validity of the Reflective Measurement Model

According to Heale and Twycross (2015), construct validity comes into use when measuring constructs and their interrelations with relative indicators. To assess validity, Henseler, Ringle, and Sarstedt (2015) stressed that there are two validity subtypes, which are regularly tested: convergent validity and discriminant validity. Discriminant validity is assumed to hold when the extracted variance is greater than the squared correlation (Kock, 2016b; Henseler, Ringle, and Sarstedt, 2015). These authors continue to advise that it is recommended that the measurement indicators' loadings on their assigned constructs should be an order of magnitude larger than their loadings on the other constructs. Discriminant validity comes into play when alienating latent variables to measure different phenomena.

According to Blau, Pred, Drennan, and Kapanjie (2016), discriminant validity is used to distinguish among latent variables that are expected to measure different phenomena; hence, to achieve sufficient discriminant validity, the latent variables must be able to measure different objects. The CFA (Confirmatory Factor Analysis) was used in categorizing the latent variables into formative and reflective, except for **NSE_11**. All the constructs included in the proposed theoretical framework are either formative or reflective variables. Not only were the items adequate for this study, but they also led to the measurement of expected latent variables. Although the factor loading of all the reflective indicators passed the 0.5 marks, the model was sufficient in achieving convergent validity. A look at the loadings indicators reveals that none of the latent variables was high, meaning that the study used the right discriminant validity, as shown in Table 5. 6. According to the table, the reflective indicator's loadings, and cross-loadings, as well as their P-values, reveal the discriminant and convergent validity for all the measurements. Nonetheless, the study used different columns to show reflective constructs and their indicators to ease the differentiation of the formative constructs.

Table 5. 6: Combined Loadings and Cross-Loadings

	NSE	INE	EthNet	EDE	RO	INR	NSR	RCF	HPC	EDR	QE	Type (as define)	SE	P-value
NSE	0.75	-0.033	0.093	-0.075	-0.06	-0.086	-0.043	-0.335	0.264	0.038	-0.137	Reflect	0.068	<0.001
NSE_2	0.791	0.024	-0.03	0.019	0.038	-0.06	0.013	-0.051	0.057	-0.075	-0.029	Reflect	0.068	<0.001
NSE_3	0.771	-0.029	0.044	0.089	-0.021	-0.068	-0.065	-0.082	0.073	-0.045	-0.008	Reflect	0.068	<0.001
NSE_4	0.868	-0.032	0.002	0.037	0.052	0.012	-0.077	-0.225	0.271	0.144	-0.043	Reflect	0.067	<0.001
NSE_5	0.842	-0.048	0.103	0.033	0.066	0.071	-0.037	-0.084	0.087	0.21	-0.109	Reflect	0.067	<0.001
NSE_6	0.771	-0.083	0.107	0.014	0.108	-0.021	-0.087	-0.38	0.339	0.045	0.074	Reflect	0.068	<0.001
NSE_7	0.747	0.062	-0.162	-0.041	-0.065	0.048	0.097	0.579	-0.524	-0.1	0.021	Reflect	0.068	<0.001
NSE_8	0.713	-0.1	-0.062	0.054	-0.109	0.08	0.08	-0.323	0.263	-0.137	0.13	Reflect	0.069	<0.001
NSE_11	0.108	0.216	-0.17	0.036	-0.067	-0.086	0.038	0.243	-0.104	-0.027	0.096	Reflect	0.079	**0.086**
NSE_12	0.454	0.191	-0.089	-0.16	-0.063	-0.058	0.178	0.691	-0.714	-0.062	0.063	Reflect	0.073	<0.001
NSE_13	0.383	0.199	-0.069	-0.098	0.025	0.14	0.057	0.968	-0.857	-0.176	0.147	Reflect	0.074	<0.001
INE	-0.04	0.847	0.021	-0.018	-0.118	0.05	0.076	-0.087	0.056	0.127	-0.062	Reflect	0.067	<0.001

INE_2	0.012	0.873	0.063	0.003	0.12	-0.032	-0.103	0.229	-0.277	0.046	0.001	Reflect	0.067	<0.001
INE_5	0.034	0.691	-0.105	0.018	-0.007	-0.021	0.037	-0.183	0.282	-0.215	0.074	Reflect	0.069	<0.001
EthERNe	-0.012	0.083	0.927	0.049	-0.004	0.035	0.05	0.176	-0.095	-0.073	0.058	Reflect	0.066	<0.001
EthERNe	0.012	-0.083	0.927	-0.049	0.004	-0.035	-0.05	-0.176	0.095	0.073	-0.058	Reflect	0.066	<0.001
ED_2	-0.042	-0.023	-0.016	0.784	0.202	-0.035	-0.164	-0.098	0.211	-0.047	-0.084	Reflect	0.068	<0.001
ED_3	0.042	0.023	0.016	0.784	-0.202	0.035	0.164	0.098	-0.211	0.047	0.084	Reflect	0.068	<0.001
RO	0.074	-0.022	0.033	-0.133	0.767	-0.067	0.128	0.147	-0.345	-0.014	-0.046	Formative	0.068	<0.001
RO_2	-0.047	-0.108	0.055	-0.13	0.8	-0.057	-0.066	0.205	-0.326	-0.013	-0.044	Formati	0.068	<0.001
RO_3	-0.013	0.059	0.092	-0.104	0.778	-0.017	0.044	0.288	-0.42	0.125	-0.177	Formati	0.068	<0.001
RO_4	-0.006	0.128	0.057	-0.154	0.732	0.031	-0.007	0.094	0.108	-0.034	-0.06	Formati	0.069	<0.001
RO_5	-0.044	-0.067	-0.076	0.117	0.784	-0.04	-0.065	-0.412	0.367	0.082	0.07	Formati	0.068	<0.001
RO_6	0.004	0.046	-0.077	0.228	0.747	0.066	0.008	-0.097	0.215	-0.073	0.167	Formati	0.068	<0.001
RO_7	0.035	-0.024	-0.087	0.18	0.762	0.091	-0.039	-0.229	0.425	-0.08	0.094	Formati	0.068	<0.001
INR	-0.005	-0.026	-0.053	-0.048	-0.06	0.626	0.124	-0.228	-0.008	0.112	-0.003	Reflect	0.07	<0.001
INR_2	0.015	-0.01	0.017	-0.055	0.104	0.9	-0.143	-0.256	0.366	-0.006	0.014	Reflect	0.066	<0.001

INR_3	0.017	-0.063	0.031	0.024	0.067	0.863	-0.107	-0.02	0.069	-0.051	-0.043	Reflect	0.067	<0.001
INR_4	-0.046	-0.008	0.142	0.008	-0.053	0.879	0.081	-0.104	0.109	-0.038	-0.056	Reflect	0.066	<0.001
INR_5	0.022	0.06	-0.062	-0.136	0.064	0.851	0.039	0.061	-0.049	-0.046	0.034	Reflect	0.067	<0.001
INR_6	-0.006	0.049	-0.114	0.235	-0.171	0.714	0.054	0.601	-0.614	0.073	0.065	Reflect	0.069	<0.001
NSR	0.087	-0.094	0.038	0.14	-0.153	-0.057	0.584	-0.085	0.428	-0.078	0.007	Reflect	0.071	<0.001
NSR_2	-0.055	-0.107	-0.2	0.031	0.098	0.118	0.576	-0.508	0.294	0.091	-0.003	Reflect	0.071	<0.001
NSR_3	0.004	0.22	-0.038	0.067	-0.108	-0.036	0.575	0.187	0.274	0.035	0.081	Reflect	0.071	<0.001
NSR_4	0.053	0.029	-0.047	0.142	-0.048	0.055	0.47	0.267	0.224	0.107	-0.056	Reflect	0.073	<0.001
NSR_5	-0.115	0.056	-0.073	-0.071	0.136	-0.085	0.661	-0.076	-0.138	0.084	-0.023	Reflect	0.07	<0.001
NSR_6	0.104	-0.073	-0.074	-0.277	0.219	-0.098	0.575	0.512	-0.335	-0.11	-0.045	Reflect	0.071	<0.001
NSR_7	-0.042	0.068	-0.12	-0.081	-0.136	-0.068	0.808	0.373	-0.267	0.111	0.064	Reflect	0.068	<0.001
NSR_8	0.048	0.021	0.125	-0.09	-0.024	0.173	0.656	-0.123	-0.126	-0.029	-0.049	Reflect	0.07	<0.001
NSR_9	0.115	0.017	0.108	0.043	-0.01	0.011	0.655	-0.457	0.252	-0.093	-0.046	Reflect	0.07	<0.001
NSR_10	0.051	-0.117	0.163	0.138	0.044	0.069	0.537	-0.214	-0.003	-0.128	-0.025	Reflect	0.072	<0.001
NSR_11	-0.203	-0.056	0.132	0.035	0.016	-0.046	0.644	0.09	-0.41	-0.016	0.065	Reflect	0.07	<0.001

RCF	0	0	0	0	0	0	0	1	0	0	0	Reflect	0.065	<0.001
HPC	0	0	0	0	0	0	0	0	1	0	0	Reflect	0.065	<0.001
ED_5	-0.02	-0.003	0.142	0.058	-0.048	0.023	-0.034	0.256	-0.203	0.777	-0.043	Reflect	0.068	<0.001
ED_6	0.02	0.003	-0.142	-0.058	0.048	-0.023	0.034	-0.256	0.203	0.777	0.043	Reflect	0.068	<0.001
QE	0.041	0.122	-0.148	-0.015	-0.112	-0.032	0.13	0.791	-0.846	0.012	0.774	Formati	0.068	<0.001
QE_2	0.042	0.1	-0.039	-0.007	-0.214	-0.015	0.155	0.327	-0.356	0.009	0.804	Formati	0.068	<0.001
QE_3	0	-0.096	0.051	-0.045	0.098	0.035	-0.056	-0.475	0.616	-0.115	0.743	Formati	0.068	<0.001
QE_4	-0.075	0.003	0.017	-0.02	0.089	-0.026	-0.078	-0.327	0.247	0.004	0.844	Formati	0.067	<0.001
QE_5	-0.002	-0.136	0.119	0.087	0.143	0.042	-0.151	-0.316	0.352	0.084	0.779	Formati	0.068	<0.001

Notes: Loadings are unrotated, and cross-loadings are oblique-rotated. SEs and P values are for loadings. For reflective indicators, P values should be less than < 0.05.

This study based its investigations on Kock (2016), Hair, Hult, Ringle, and Sarstedt (2016) and Nitzl (2016), who states that two criteria are recommended as a basis for the conclusion that a measurement model has adequate convergent validity: that the P-values associated with the loadings are lower than 0.05 and that the loadings are greater than or equal to 0.5. Thus, it can be concluded that each reflective item loaded higher on the latent variable it was intended to measure than on any of the other constructs. Moreover, each block of reflective indicators loaded higher on its respective latent variables than did the indicators of all the other latent variables. Indicators for which these criteria are not satisfied may be removed. This does not apply to formative latent variable indicators, which are assessed in part based on P values associated with indicator weights (Kock, 2014a). Moreover, the P-values for all reflective indicators are significant ($P<0.05$) except **NSE_11** (0.086), which should be removed. As per Kock (2016), it is additionally prescribed to test the Average Variance Extracted (AVEs) to decide if an investigation has discriminant validity.

Table 5. 7 illustrates the square roots of the AVEs and their latent variables. The connections are given diagonally. According to Hair, Hult, Ringle, and Sarstedt (2016) and Henseler, Ringle, and Sarstedt (2015), to guarantee discriminant legitimacy for each construct, the square roots of the AVEs ought to be bigger than any of the relationships including that of the latent construct. Table 5.8 also reveals that the AVEs of each latent variable, regardless of whether formative or reflective, remain above the constructs. The individual square roots underlying the foundations of the AVEs are higher than any of the relationships that appeared underneath or above them. Along these lines, it can be reasoned that the reflective latent variable has fitting discriminant validity.

Table 5. 7: Correlations among latent variables and errors

	NSE	INE	EthNet	EDE	RO	INR	NSR	RCF	HPC	EDR	QE
NSE	0.692	-0.043	0.251	0.078	0.012	0.2	0.013	-0.055	-0.066	0.401	0.209
INE	-0.043	**0.808**	-0.1	0.057	0.043	0.146	-0.002	-0.166	-0.064	-0.061	-0.142
EthNet	0.251	-0.1	**0.927**	-0.038	-0.011	-0.024	0.035	-0.008	0.031	0.17	0.303
EDE	0.078	0.057	-0.038	**0.784**	0.269	-0.038	0.282	0.02	0.013	-0.089	0.038
RO	0.012	0.043	-0.011	0.269	0.767	-0.113	0.512	0.145	0.176	0.016	0.074
INR	0.2	0.146	-0.024	-0.038	-0.113	**0.812**	-0.167	-0.13	-0.085	0.092	-0.032
NSR	0.013	-0.002	0.035	0.282	0.512	-0.167	**0.618**	-0.084	-0.019	0.032	0.03
RCF	-0.055	-0.166	-0.008	0.02	0.145	-0.13	-0.084	**1**	0.87	0.071	-0.003
HPC	-0.066	-0.064	0.031	0.013	0.176	-0.085	-0.019	0.87	**1**	0.078	-0.003
EDR	0.401	-0.061	0.17	-0.089	0.016	0.092	0.032	0.071	0.078	**0.777**	0.285
QE	0.209	-0.142	0.303	0.038	0.074	-0.032	0.03	-0.003	-0.003	0.285	0.79

Note: Square roots of Average Variances Extracted (AVEs) shown on the diagonal. Shaded cells are reflective latent variables.

The study obtained full co-linearity Variance Factors (VIFs) for all the available latent inconsistencies. It adopted the discriminant validity measure, as well the overall co-linearity, as shown in Table 5. 8 (Kock, 2017). The estimation of the VIFs relies on the full co-linearity tests that allow the identification of both lateral and vertical similarities to include the assessment in the construct. In individual latent variability block, both classic and vertical co-linearity is predictor-predictor constructs. In this situation, VIF refers to the degree or measure of vertical co-linearity, also known as redundancy, existing within the lateral constructs, which undergo a hypothesis to impact another latent construct (Kock, 2017). It is important to note that lateral co-linearity is a relatively new phrase used to explain the predictor-criterion lateral variability, a type of co-linearity that can result in the presence of bias in research studies (Kock, 2017; Heale and Twycross, 2015). Conservative studies recommend the statistical figures for VIF to remain under the digit **5**.

Nonetheless, a more comfortable standard should maintain the figure anywhere under **10** (Hair, Hult, Ringle, and Sarstedt, 2016). According to Table 5. 8, full co-linearity for any latent variable remains under 5. Meaning, the model achieves the VIFs required for the reflective latent inconsistencies; this exhibits the presence of adequate discriminant validity. Kock (2017) believes that it is critical to assess block VIFs.

Table 5. 8: Full collinearity VIFs

NSE	INE	EthNet	EDE	RO	INR	NSR	RCF	HPC	EDR	QE
1.337	1.118	1.176	1.158	1.481	1.132	1.516	4.585	4.395	1.308	1.213

Note: Reflective latent variables are shown in a shaded construct

Additionally, Table 5. 8 illustrates VIFs for every construct with more than two predictors, a VIF for every latent variable block. Each VIF has a link to one predictor and associates the correlation amongst the latent variable criterion and the predictors. According to the explanation given above, the testing of VIFs can occur through two thresholds, the more relaxed **10** or, the more conservative **5**.

Table 5. 9: Block variance inflation factors

	NSE	INE	EthNet	EDE	RO	INR	NSR	RCF	HPC	EDR	QE
RO						1.052	1.032	2.175	2.146	1.056	
QE	1.11	1.012	1.084	1.023	1.072						

Note: The VIFs on each column are reflective of the latent variables (predictors), with an allusion to the latent variables found on each row (criteria).

Table 5. 9 provide the block VIFs for all latent variables as fewer than 5. Therefore, it is evident that the achievement of sufficient VIFs occurs when the latent variables align with discriminant validity.

5.5.1.2. Convergent Validity of the Reflective Measurement Model

According to Henseler, Ringle, and Sarstedt (2015), convergent validity shows that an arrangement of things speaks to the same fundamental inactive variable, which can be outlined through their uni-dimensional set of items. In this segment, convergent validity is tried by removing the factor loadings and cross-loadings of the considerable number of things on their development, as shown in Table 5. 11. It was represented that the legitimacy of the estimation scale was joined due to the big thing loadings (i.e., more noteworthy than or equivalent to 0.5) on their related idle factors aside from not many, which prescribed to be evacuated, (for example, NSE_11).

Hair, Hult, Ringle, and Sarstedt (2016) prescribes utilising the AVE as a paradigm for the convergent validity of reflective markers. For convergent validation appraisal, the AVE limit frequently suggested for satisfactory legitimacy is 0.5 (Kock, 2016), and applies just too intelligent dormant factors. According to Table 5. 10, most of the reflective latent variables are above 0.5, which shows to signify adequate convergent validity; this means that a latent construct can explain more than half of the variance of its indicators on average.

Table 5. 10: Convergent Validity test using AVE

NSE	INE	EthNet	EDE	RO	INR	NSR	RCF	HPC	EDR	QE
0.479	0.653	0.859	0.614	0.589	0.659	0.382	1	1	0.604	0.623

Note: Reflective latent variables are shown in shaded construct

Table 5. 10 illustrates all the reflective latent variables' AVEs apart from NSR above or equal to the 0.5 mark, which implies an adequate convergent validity.

Table 5. 11: Structure loadings and cross-loadings

	NSE	INE	EthNet	EDE	RO	INR	NSR	RCF	HPC	EDR	QE
NSE	0.75	-0.029	0.236	-0.041	-0.094	0.108	-0.043	-0.059	-0.066	0.304	0.076
NSE_2	0.791	-0.008	0.168	0.097	0.07	0.112	0.058	-0.045	-0.04	0.269	0.121
NSE_3	0.771	-0.055	0.206	0.097	-0.016	0.098	-0.016	-0.032	-0.068	0.259	0.169
NSE_4	0.868	-0.025	0.211	0.056	0.034	0.194	-0.005	-0.015	0.005	0.442	0.183
NSE_5	0.842	-0.046	0.261	0.068	0.041	0.224	0.024	-0.015	-0.02	0.445	0.156
NSE_6	0.771	-0.076	0.298	0.07	0.075	0.131	0.025	-0.042	-0.032	0.339	0.278
NSE_7	0.747	-0.036	0.066	0.062	-0.009	0.174	-0.004	-0.035	-0.061	0.224	0.099
NSE_8	0.713	-0.073	0.169	0.11	-0.047	0.208	0.047	-0.124	-0.118	0.227	0.218
NSE_11	**0.108**	0.101	-0.046	0.07	0.018	-0.028	0.001	0.06	0.072	0.055	0.026
NSE_12	0.454	0.032	0.079	-0.01	-0.009	0.033	0.053	-0.086	-0.116	0.168	0.086
NSE_13	**0.383**	0.042	0.055	0.002	0.033	0.16	-0.054	0.045	-0.001	0.111	0.114
INE	-0.025	0.847	-0.071	0.01	-0.045	0.18	-0.001	-0.167	-0.071	0.012	-0.15
INE_2	0.005	0.873	-0.042	0.057	0.085	0.103	-0.041	-0.137	-0.073	-0.021	-0.084
INE_5	-0.097	0.691	-0.143	0.078	0.068	0.061	0.046	-0.094	-0.001	-0.161	-0.112
EthERNe	0.208	-0.046	0.927	0.023	0.036	-0.017	0.074	0.038	0.066	0.116	0.302
EthERNe	0.257	-0.14	0.927	-0.094	-0.056	-0.028	-0.01	-0.053	-0.009	0.2	0.259
ED_2	-0.026	0.05	-0.075	0.784	0.317	-0.061	0.18	0.1	0.102	-0.147	-0.056
ED_3	0.148	0.04	0.016	0.784	0.104	0.002	0.262	-0.068	-0.082	0.007	0.116
RO	0.065	0.001	0.029	0.172	0.767	-0.139	0.482	-0.004	0.013	0.003	0.053
RO_2	-0.044	-0.076	0.015	0.146	0.8	-0.161	0.369	0.077	0.075	-0.019	0.05
RO_3	0.03	0.072	0.016	0.169	0.778	-0.099	0.42	0.076	0.075	0.062	-0.037
RO_4	-0.029	0.115	-0.005	0.122	0.732	-0.053	0.326	0.238	0.284	-0.016	-0.002
RO_5	-0.001	0.007	-0.034	0.25	0.784	-0.113	0.4	0.089	0.122	0.068	0.11
RO_6	0.02	0.083	-0.027	0.311	0.747	-0.031	0.398	0.117	0.146	-0.014	0.138
RO_7	0.024	0.036	-0.054	0.274	0.762	-0.004	0.355	0.197	0.24	-0.003	0.083
INR	0.153	0.088	-0.041	-0.044	-0.099	0.626	-0.018	-0.218	-0.178	0.11	-0.003
INR_2	0.185	0.139	-0.001	-0.102	-0.061	0.9	-0.229	-0.022	0.042	0.101	-0.007
INR_3	0.169	0.077	0.002	-0.011	-0.086	0.863	-0.202	-0.064	-0.026	0.051	-0.055
INR_4	0.145	0.13	0.072	-0.026	-0.112	0.879	-0.087	-0.148	-0.089	0.055	-0.06
INR_5	0.156	0.172	-0.062	-0.096	-0.05	0.851	-0.117	-0.11	-0.07	0.056	-0.03
INR_6	0.173	0.096	-0.112	0.116	-0.162	0.714	-0.13	-0.108	-0.143	0.087	0.009
NSR	0.05	-0.101	0.123	0.219	0.274	-0.164	0.584	0.121	0.172	0.025	0.028
NSR_2	-0.014	0.007	-0.126	0.186	0.325	0.04	0.576	-0.157	-0.092	0.01	-0.006
NSR_3	-0.008	0.116	0.012	0.207	0.326	-0.135	0.575	0.186	0.239	0.055	0.06
NSR_4	0.068	-0.017	0.021	0.227	0.302	-0.037	0.47	0.198	0.25	0.11	-0.017
NSR_5	-0.095	0.062	-0.038	0.171	0.375	-0.162	0.661	-0.176	-0.122	-0.01	-0.019
NSR_6	-0.001	-0.113	-0.037	0.031	0.41	-0.208	0.575	0.072	0.053	-0.041	-0.027
NSR_7	-0.025	-0.002	-0.043	0.168	0.341	-0.204	0.808	-0.037	-0.008	0.095	0.054
NSR_8	0.099	0.042	0.09	0.121	0.272	0.063	0.656	-0.187	-0.138	0.041	0

NSR_9	0.101	0.066	0.078	0.211	0.308	-0.067	0.655	-0.17	-0.088	-0.002	0.003
NSR_10	0.074	-0.053	0.095	0.237	0.288	-0.041	0.537	-0.119	-0.085	-0.033	0.032
NSR_11	-0.124	-0.045	0.08	0.174	0.286	-0.186	0.644	-0.205	-0.209	-0.037	0.079
RCF	-0.055	-0.166	-0.008	0.02	0.145	-0.13	-0.084	1	0.87	0.071	-0.003
HPC	-0.066	-0.064	0.031	0.013	0.176	-0.085	-0.019	0.87	1	0.078	-0.003
ED_5	0.337	-0.074	0.219	-0.066	-0.046	0.082	-0.024	0.075	0.048	0.777	0.228
ED_6	0.286	-0.021	0.046	-0.072	0.07	0.061	0.074	0.035	0.073	0.777	0.215
QE	0.176	-0.086	0.129	0.034	0.006	-0.061	0.033	-0.05	-0.112	0.235	0.774
QE_2	0.203	-0.077	0.245	0.024	-0.067	-0.023	0.039	-0.086	-0.088	0.248	0.804
QE_3	0.119	-0.143	0.271	-0.001	0.138	-0.012	0.023	0.122	0.153	0.16	0.743
QE_4	0.11	-0.075	0.238	0.013	0.089	-0.046	0.024	-0.054	-0.042	0.196	0.844
QE_5	0.22	-0.186	0.314	0.082	0.13	0.017	-0.002	0.07	0.092	0.285	0.779

Note: Loadings and cross-loadings are unrotated.

5.5.1.3. Construct Reliability for the Reflective Measurement Model

Reliability denotes the quality of the instruments used in measurements, citing the fact that the instrument is a question-statements set. According to Kock (2017), the quality of an instrument is said to be useful when the question-statements related to the individual latent variable maintain user understanding in the same manner as when used by different participants. Heale and Twycross (2015) state that construct reliability deals with the internal quality of a measurement model. Fullwood, Quinn, Kaye, and Redding (2017) state that, to estimate the measure of internal consistency, researchers use both composite reliability and Cronbach's alpha, which should always be higher than 0.7 for acceptance, 0.80 for adequacy and 0.9 for excellence.

Table 5. 12 is a tabulation of Cronbach's alpha coefficients and the composite reliability, as used in the variables of the reflective latent. Composite reliability coefficients are said to be high when they range from 0.753 to 1 away from the suggested threshold, and above 0.7 of the coefficients as explained by Cronbach's alpha, which ranges from 0.729 to 1, and over 0.7, apart from the **EDR (0.344)** and **EDE (0.373)**. This can be attributed to the fact that most devices were more likely to associate with various difficulties that might affect its effectiveness, such as interconnectivity, portability, and knowledge on using these devices in research.

Table 5. 12: Reflective Constructs - Reliability Coefficients

Composite Reliability Coefficients										
NSE	**INE**	**EthNet**	**EDE**	**RO**	**INR**	**NSR**	**RCF**	**HPC**	**EDR**	**QE**
0.9	0.848	0.924	0.761	0.909	0.919	0.87	1	1	0.753	0.892
Cronbach's Alpha Coefficients										
NSE	**INE**	**EthNet**	**EDE**	**RO**	**INR**	**NSR**	**RCF**	**HPC**	**EDR**	**QE**
0.874	0.729	0.836	0.373	0.884	0.893	0.834	1	1	0.344	0.848

Note: Shaded cells are reflective latent variables

5.5.1.4. Formative Measurement Model - Discriminant and Convergent Validity

Henseler, Ringle, and Sarstedt (2015) claim that classical test presumptions and traditional validity do not take precedence in the manifestation of variables within the concepts of reliability and formative measurements. They further added that the variance occurs when no necessity requires formative indicators to maintain relations with a latent variable score if they both remain devoid of errors. Nonetheless, Cizek, Andrade, and Bennett (2019) and Kock (2017) insist on the establishment of the reliability of the instruments used informative measurements.

Benitez, Henseler, Castillo, and Schuberth (2019) suggest the use of weight and the assessment of significance in the evaluation of formative reliability of measurement instruments, all of which should maintain a P-value of below **0.05**. The testing of each indicator is necessary. This study tested the validity of the formative indicators.

The weights of the indicators are provided in Table 5. 13. The recurrence of zero-weights stems from the use of the PLS regression in the calculations. The calculation of each construct score is because of linear combinations. The calculated weights are resultant features of multiple regression coefficients that link the constructs to their indicators (Kock, 2017).

Table 5. 13 illustrates the significance of all P-values, under **0.05** of formative indicator weights that maintain a correlation with the latent variables. The tabulated values are an indication that the construction of the measurements of the latent variables was correct. The VIFs of all latent variables' indicators are also provided in the table. Conservative researchers advise that VIFs

remain under the **5**-digit threshold, a more comfortable mark compared to the **10-digit** level. Therefore, the digits captured in the table all remain under **5** (Blau, Pred, Drennan and Kapanjie, 2016). The provision of all standard errors is visible in the table, and the sufficient nature of the formative indicators is evident in the description of both the convergent and discriminant validities.

Table 5. 13: Indicator Weights

	NSE	INE	EthNet	EDE	RO	INR	NSR	RCF	HPC	EDR	QE	Type	SE	P value	VIF	WLS	ES
NSE	0.142	0	0	0	0	0	0	0	0	0	0	Reflect	0.078	0.035	2.301	1	0.107
NSE_2	0.15	0	0	0	0	0	0	0	0	0	0	Reflect	0.078	0.028	2.652	1	0.119
NSE_3	0.146	0	0	0	0	0	0	0	0	0	0	Reflect	0.078	0.031	3.262	1	0.113
NSE_4	0.165	0	0	0	0	0	0	0	0	0	0	Reflect	0.078	0.018	6.043	1	0.143
NSE_5	0.16	0	0	0	0	0	0	0	0	0	0	Reflect	0.078	0.021	4.372	1	0.134
NSE_6	0.146	0	0	0	0	0	0	0	0	0	0	Reflect	0.078	0.031	2.402	1	0.113
NSE_7	0.142	0	0	0	0	0	0	0	0	0	0	Reflect	0.078	0.036	2.479	1	0.106
NSE_8	0.135	0	0	0	0	0	0	0	0	0	0	Reflect	0.078	0.043	1.949	1	0.097
NSE_11	0.021	0	0	0	0	0	0	0	0	0	0	Reflect	0.08	0.398	1.463	1	0.002
NSE_12	0.086	0	0	0	0	0	0	0	0	0	0	Reflect	0.079	0.138	1.878	1	0.039
NSE_13	0.073	0	0	0	0	0	0	0	0	0	0	Reflect	0.079	0.18	1.383	1	0.028
INE	0	0.432	0	0	0	0	0	0	0	0	0	Reflect	0.073	<0.001	1.754	1	0.366
INE_2	0	0.446	0	0	0	0	0	0	0	0	0	Reflect	0.073	<0.001	1.855	1	0.39
INE_5	0	0.353	0	0	0	0	0	0	0	0	0	Reflect	0.075	<0.001	1.226	1	0.244
EthNet	0	0	0.539	0	0	0	0	0	0	0	0	Reflect	0.072	<0.001	2.068	1	0.5
EthNet	0	0	0.539	0	0	0	0	0	0	0	0	Reflect	0.072	<0.001	2.068	1	0.5
ED_2	0	0	0	0.638	0	0	0	0	0	0	0	Reflect	0.07	<0.001	1.055	1	0.5
ED_3	0	0	0	0.638	0	0	0	0	0	0	0	Reflect	0.07	<0.001	1.055	1	0.5
RO	0	0	0	0	0.186	0	0	0	0	0	0	Format	0.077	0.009	2.804	1	0.143
RO_2	0	0	0	0	0.194	0	0	0	0	0	0	Format	0.077	0.006	2.621	1	0.155
RO_3	0	0	0	0	0.189	0	0	0	0	0	0	Format	0.077	0.008	2.845	1	0.147
RO_4	0	0	0	0	0.178	0	0	0	0	0	0	Format	0.078	0.012	2.043	1	0.13
RO_5	0	0	0	0	0.19	0	0	0	0	0	0	Format	0.077	0.008	2.599	1	0.149
RO_6	0	0	0	0	0.181	0	0	0	0	0	0	Format	0.077	0.01	4.609	1	0.135
RO_7	0	0	0	0	0.185	0	0	0	0	0	0	Format	0.077	0.009	4.054	1	0.141
INR	0	0	0	0	0	0.158	0	0	0	0	0	Reflect	0.078	0.022	1.418	1	0.099
INR_2	0	0	0	0	0	0.228	0	0	0	0	0	Reflect	0.077	0.002	3.678	1	0.205

INR_3	0	0	0	0	0	0.218	0	0	0	0	0	Reflect	0.077	0.003	2.887	1	0.188
INR_4	0	0	0	0	0	0.222	0	0	0	0	0	Reflect	0.077	0.002	3.313	1	0.196
INR_5	0	0	0	0	0	0.215	0	0	0	0	0	Reflect	0.077	0.003	2.564	1	0.183
INR_6	0	0	0	0	0	0.181	0	0	0	0	0	Reflect	0.077	0.01	1.615	1	0.129
NSR	0	0	0	0	0	0	0.139	0	0	0	0	Reflect	0.078	0.039	1.816	1	0.081
NSR_2	0	0	0	0	0	0	0.137	0	0	0	0	Reflect	0.078	0.041	1.536	1	0.079
NSR_3	0	0	0	0	0	0	0.137	0	0	0	0	Reflect	0.078	0.041	1.783	1	0.079
NSR_4	0	0	0	0	0	0	0.112	0	0	0	0	Reflect	0.079	0.078	2.097	1	0.053
NSR_5	0	0	0	0	0	0	0.157	0	0	0	0	Reflect	0.078	0.023	1.86	1	0.104
NSR_6	0	0	0	0	0	0	0.137	0	0	0	0	Reflect	0.078	0.041	1.846	1	0.079
NSR_7	0	0	0	0	0	0	0.192	0	0	0	0	Reflect	0.077	0.007	2.641	1	0.155
NSR_8	0	0	0	0	0	0	0.156	0	0	0	0	Reflect	0.078	0.024	3.944	1	0.102
NSR_9	0	0	0	0	0	0	0.156	0	0	0	0	Reflect	0.078	0.024	3.669	1	0.102
NSR_10	0	0	0	0	0	0	0.127	0	0	0	0	Reflect	0.078	0.053	1.968	1	0.068
NSR_11	0	0	0	0	0	0	0.153	0	0	0	0	Reflect	0.078	0.026	1.747	1	0.098
RCF	0	0	0	0	0	0	0	1	0	0	0	Reflect	0.065	<0.001	0	1	1
HPC	0	0	0	0	0	0	0	0	1	0	0	Reflect	0.065	<0.001	0	1	1
ED_5	0	0	0	0	0	0	0	0	0	0.643	0	Reflect	0.07	<0.001	1.045	1	0.5
ED_6	0	0	0	0	0	0	0	0	0	0.643	0	Reflect	0.07	<0.001	1.045	1	0.5
QE	0	0	0	0	0	0	0	0	0	0	0.248	Format	0.076	<0.001	2.513	1	0.192
QE_2	0	0	0	0	0	0	0	0	0	0	0.258	Format	0.076	<0.001	2.693	1	0.208
QE_3	0	0	0	0	0	0	0	0	0	0	0.238	Format	0.076	0.001	1.708	1	0.177
QE_4	0	0	0	0	0	0	0	0	0	0	0.271	Format	0.076	<0.001	2.577	1	0.228
QE_5	0	0	0	0	0	0	0	0	0	0	0.25	Format	0.076	<0.001	2.087	1	0.195

Notes: ES = indicator effect size VIF = indicator variance inflation factor. WLS = indicator weight-loading sign.

For formative indicators, P values should be less than 0.05, and VIFs value should be less than 5.

5.5.1.5. Formative Construct Validity

The square roots of all the AVEs in the calculation of discriminant validity and formative construct are in Table 5. 14**.** The table also demonstrates that the variable of the formative latent remains higher than that of the squared correlation, meaning that discriminant validity is reliable.

Table 5. 14: Correlations among latent variables and errors

	NSE	INE	EthNet	EDE	RO	INR	NSR	RCF	HPC	EDR	QE
NSE	0.692	-0.043	0.251	0.078	0.012	0.2	0.013	-0.055	-0.066	0.401	0.209
INE	-0.043	0.808	-0.1	0.057	0.043	0.146	-0.002	-0.166	-0.064	-0.061	-0.142
EthNet	0.251	-0.1	0.927	-0.038	-0.011	-0.024	0.035	-0.008	0.031	0.17	0.303
EDE	0.078	0.057	-0.038	0.784	0.269	-0.038	0.282	0.02	0.013	-0.089	0.038
RO	0.012	0.043	-0.011	0.269	**0.767**	-0.113	0.512	0.145	0.176	0.016	0.074
INR	0.2	0.146	-0.024	-0.038	-0.113	0.812	-0.167	-0.13	-0.085	0.092	-0.032
NSR	0.013	-0.002	0.035	0.282	0.512	-0.167	0.618	-0.084	-0.019	0.032	0.03
RCF	-0.055	-0.166	-0.008	0.02	0.145	-0.13	-0.084	1	0.87	0.071	-0.003
HPC	-0.066	-0.064	0.031	0.013	0.176	-0.085	-0.019	0.87	1	0.078	-0.003
EDR	0.401	-0.061	0.17	-0.089	0.016	0.092	0.032	0.071	0.078	0.777	0.285
QE	0.209	-0.142	0.303	0.038	0.074	-0.032	0.03	-0.003	-0.003	0.285	**0.79**

Note: The diagonal part of the table shows the Square roots of average variances extracted. Formative latent variables are shaded in colour.

According to the figures in Table 5. 15, which shows the entire co-linearity, the formative latent variables remain under the 5-digit mark. The statistical data means that the formative variables achieve sufficient VIF's, leading to the equivalence of discriminant validity.

Table 5. 15: Latent Variables -: Full Collinearity

VIFs										
NSE	**INE**	**EthNet**	**EDE**	**RO**	**INR**	**NSR**	**RCF**	**HPC**	**EDR**	**QE**
1.337	1.118	1.176	1.158	1.481	1.132	1.516	4.585	4.395	1.308	1.213

Note: Formative latent variables are shaded in colour.

5.5.1.6. Formative Measurement Model: Reliability

To test the formative construct's reliability, the study used both Cronbach's alpha coefficients to assess the internal consistency and composite reliability, as illustrated in Table 5. 16. The value of the coefficients remains high, ranging from 0.848 to 0.909, which means that they all rank above the recommended threshold of 0.7 except for two variables, namely EDE and EDR. These two aspects are not likely to profoundly impact on the reliability since most research output does not rely on the use of such devices. Therefore, it is safe to conclude that most latent variables used in this research exhibit adequate reliability.

Table 5. 16: Formative Constructs - Reliability Coefficients

CRC										
NSE	**INE**	**EthNet**	**EDE**	**RO**	**INR**	**NSR**	**RCF**	**HPC**	**EDR**	**QE**
0.9	0.848	0.924	0.761	**0.909**	0.919	0.87	1	1	0.753	**0.892**
Cronbach's Alpha Coefficients										
NSE	**INE**	**EthNet**	**EDE**	**RO**	**INR**	**NSR**	**RCF**	**HPC**	**EDR**	**QE**
0.874	0.729	0.836	0.373	**0.884**	0.893	0.834	1	1	0.344	**0.848**

Note: Formative latent variables are shaded in colour.

5.5.1.7. *Formative Measurement Model - Nomological Validity*

According to Henseler, Ringle and Sarstedt (2015), nomological validity refers to the relationship between latent variables and the formative index in the model path. The same process used in the evaluation of reflective and formative items can also be used to analyse nomological validity. The first step is to link nomological validity with its hypothesised consequent and antecedent constructs. The second step involves the use of evidence to enhance the linkages of the hypothesis of the latent variable and enhance its significance to a higher value than zero in the anticipated causal direction. Along these lines, building up adequate discriminant and convergent validity with noteworthy patch coefficients (more noteworthy than zero) will confirm nomological legitimacy to this investigation.

5.5.2. Structural Model Result

The motivation behind the structural model is to examine the fit of the hypothesised research model (Credé and Harms, 2015). Figure 5. 53 demonstrate the hypothesised theoretical structural model, illustrating the latent variables of the current study and their indicators as per explained in Section 3.4. From the result, it is evident that the theoretical model, via its framework, conforms with the result obtained using the structural model. This is evidence to back-up the constructs and measures utilized during the development of the model. In this investigation, the structural model examines the effect of NREN services benefit for education (NSE), EthERNet (EthNet), Electronic gadget (EDE) and institutional network (INE) in enhancing the quality of teaching and learning (QE). It additionally inspects the effect of NREN service benefit for research (NSR), High-Performance Computing for research (HPC), remote access (RCF), electronic gadgets (EDR) and institutional network (INR) in enhancing the output of the research (RO).

The WarpPLS programming 6.0 utilized as a part of this investigation gives Ten worldwide models fit and quality records are given (Kock, 2014a; 2015d) as shown in Table 5. 17: normal way coefficient (APC), normal R-squared (ARS), Average Balanced R-squared (AARS), Average Piece VIF (AVIF), Average Full Collinearity VIF (AFVIF), Tenenhaus (GoF), Sympson's Mystery Proportion (SPR), R-squared commitment proportion, Statistical concealment proportion and non-linear bivariate causality course proportion. For the APC, ARS, and AARS, P esteems are likewise given. These P esteems computed through a procedure that includes resampling estimations combined with adjustments to counter the standard mistake pressure impact related to irregular factors, in a route comparable to Bonferroni remedies (Kock, 2014a). This is essential since the model fit and quality records are figured as midpoints of different parameters. While surveying the model's fit with the information, the accompanying gauges are prescribed:

1) It is suggested that the P esteems for the APC, ARS, and AARS all be equivalent to or lower than 0.05; that is, huge at the 0.05 level (Kock, 2016). A more casual value would be that the P esteems for the APC and ARS be equivalent to or lower than 0.05.
2) It is prescribed (preferably) that both the AVIF and AFVIF be equivalent to or lower than 3.3, especially in models where most of the factors are estimated through at least two

markers. A more casual (adequate) standard is that both files be equivalent to or lower than 5, especially in models where most factors are single-pointer factors (and along these lines, not "genuine" dormant variables).

3) GoF. Also, to the ARS, the GoF list, alluded to as "Tenenhaus GoF" out of appreciation for Michel Tenenhaus, is a measure of a model's illustrative power (see, e.g., Kock, 2015d). Richter, Cepeda, Roldán and Ringle (2015) likewise proposed the accompanying edges for the GoF: little if equivalent to or more noteworthy than 0.1, medium if equivalent to or more prominent than 0.25, and vast if equivalent to or more noteworthy than 0.36. They did as such by expecting a base adequate normal AVE of 0.5, and utilising Henseler, Hubona and Ray (2016) limits for little, medium, and substantial impact sizes. Esteem lower than 0.1 for the GoF proposes that the logical energy of a model might be too low to be viewed as adequate possibly.
4) The SPR file is a measure of the degree to which a model is free from Simpson's oddity occurrences (Kock, 2015e; Kock and Gaskins, 2016).

   In a perfect world the SPR should measure up to 1, implying that there are no cases of Simpson's Catch 22 out of a model; satisfactory estimations of SPR are equivalent to or more prominent than 0.7, implying that no less than 70 per cent of the ways in a model is free from Simpson's conundrum.
5) The RSCR file is a measure of the degree to which a model is free from negative R-squared commitments, which happen together with Simpson's Catch 22 occasions (Kock, 2015e; Kock and Gaskins, 2016). In a perfect world, the RSCR should break even with 1, implying that there are no negative R-squared commitments in a model; satisfactory estimations of RSCR are equivalent to or more noteworthy than 0.9, implying that the aggregate of positive R-squared commitments in a model makes up no less than 90 per cent of the aggregate whole of the total R-squared commitments in the model.
6) The SSR list is a measure of the degree to which a model is free from factual concealment occurrences (Kock and Gaskins, 2016). Satisfactory estimations of SSR are equivalent to or more noteworthy than 0.7, implying that no less than 70 per cent of the ways in a model is free from factual concealment.

7) One fascinating property of nonlinear calculations is that bivariate nonlinear coefficients of affiliation fluctuate contingent upon the speculated heading of causality. Adequate estimations of NLBCDR are equivalent to or more noteworthy than 0.7, implying that in no less than 70 per cent of way related examples in a model the help for the turned around conjectured bearing of causality is powerless or less. Here "less" may imply that the help for switched conjectured heading of causality is not as much as powerless (e.g., unbiased), or that the theorised course of causality is bolstered.

Table 5. 17 and **Figure 5. 52** illustrates that all the ten worldwide models align, and quality records are met in the present investigation.

Table 5. 17: Model align and quality record test

Standard	**Valuation**	**P. Values**	**Not Supported /Supported**
APC	0.173	P=0.007	**Supported**
ARS	0.278	P<0.001	**Supported**
AARS	0.254	P<0.001	**Supported**
AVIF	1.276		**Supported**
AFVIF	1.856		**Supported**
GoF	0.434		**Supported**
SPR	0.900		**Supported**
RSCR	0.976		**Supported**
SSR	1.000		**Supported**
NLBCDR	0.750		**Supported**

APC - Average path coefficient. ARS - Average R-squared. AARS -Average adjusted R-squared. AVIF - Average block VIF. AFVIF - Average full collinearity VIF. GoF - Tenenhaus GoF. SPR - Sympson's paradox ratio. RSCR - R-squared contribution ratio. SSR - Statistical suppression ratio. NLBCDR - Nonlinear bivariate causality direction ratio.

Figure 5. 52. Depicts the Model fit and quality record test.

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Model fit and quality indices
----------------------------------------------------------

Average path coefficient (APC)=0.173, P=0.007
Average R-squared (ARS)=0.271, P<0.001
Average adjusted R-squared (AARS)=0.247, P<0.001
Average block VIF (AVIF)=1.277, acceptable if <= 5, ideally <= 3.3
Average full collinearity VIF (AFVIF)=1.856, acceptable if <= 5, ideally <= 3.3
Tenenhaus GoF (GoF)=0.432, small >= 0.1, medium >= 0.25, large >= 0.36
Sympson's paradox ratio (SPR)=0.800, acceptable if >= 0.7, ideally = 1
R-squared contribution ratio (RSCR)=0.964, acceptable if >= 0.9, ideally = 1
Statistical suppression ratio (SSR)=1.000, acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)=0.750, acceptable if >= 0.7
```

Figure 5. 52: Model fit, and quality indices as-is from WarpPLS.

Besides, Figure 5. 54 demonstrate the research outcomes of the path analysis, which depicts the impact of the structural model on both latent variables and the correlations, in a hypothesised manner.

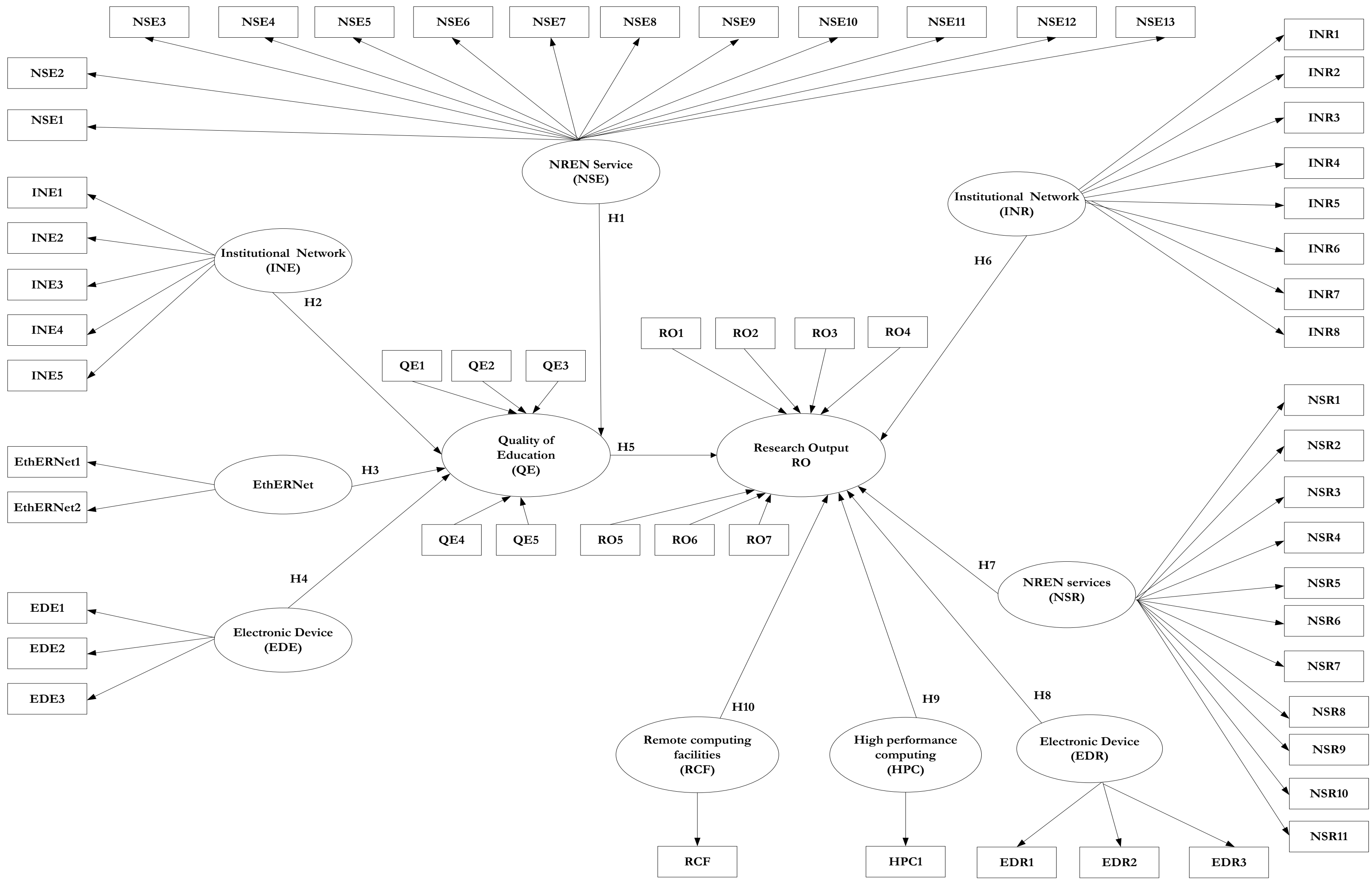

Figure 5. 53: The hypothesised theoretical framework

After a successful evaluation using the measurement model, the next phase is the use of the structural model in estimations. According to Hair, Hult, Ringle and Sarstedt (2016), the most critical criteria of analysis for the structural methodology involve the use of the R^2 values, coupled with their importance in the path coefficients. For instance, authors Henseler, Ringle and Sarstedt (2015) advise that 0.10 should be the least measure of R^2. On the other hand, Hair, Hult, Ringle and Sarstedt (2016) maintain that the use of substantial, moderate, and weak phrases could describe the figures **0.75**, **0.50** and **0.25**, respectively, following the R^2's structural model's independent constructs. At the same time, Henseler, Ringle and Sarstedt (2015) encourages the labelling of R^2 measures such as **0.67, 0.33** and **0.19** to represent the independent latent constructs with an in-depth path to the descriptive considerable, fair, and weak, respectively. Research experts also advise investigators to approximate path coefficients in consideration of the significance of their P-values (Kock, 2017).

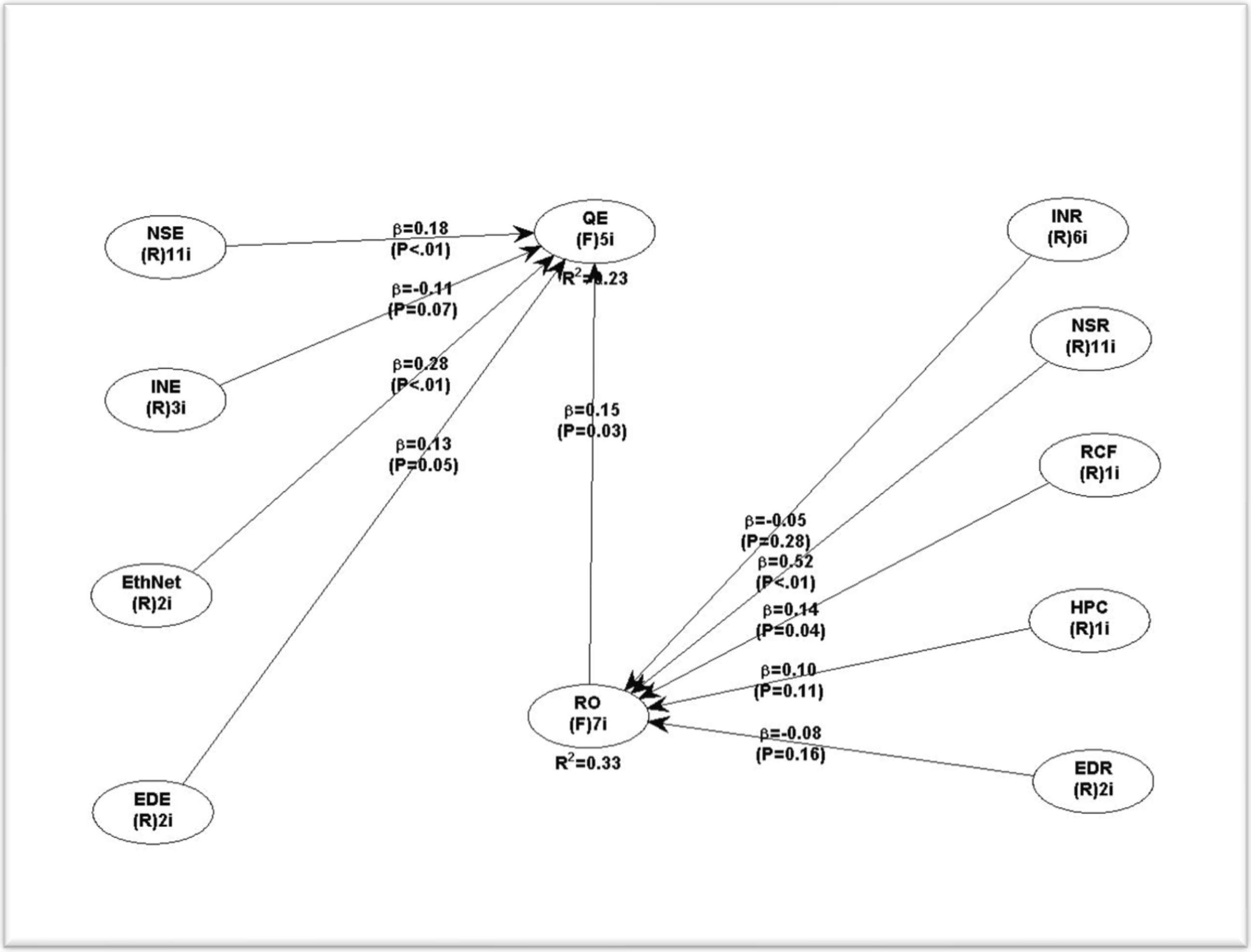

Figure 5. 54: SEM Model as-is from WarpPLS

Evaluating the R^2 measures further changes in the R^2, also referred to as the effect size test, can be explored to examine the substantive impact of each independent construct on the dependent construct. The power of the substantive effect of an independent construct is Effect Size $f^2 = (R^2\text{included} – R^2\text{excluded}) / (1-R^2\text{included})$ (Henseler, Ringle and Sarstedt, 2015).

The values **0.02, 0.15,** and **0.35** are an indication of the low, moderate, and high nature of the independent latent variables on the structural level (Henseler, Ringle and Sarstedt, 2015). Any value below **0.02** demonstrates that its effects remain too small to be treated relevant from a practical point of view, even when the corresponding P-values are statistically significant; this situation may occur with large sample sizes. Table 5. 19 is a summary of the results of the **Effect**

Size (**ES**). The statistics captured in the table reveal that all values remain above **0.02** apart from NSE**_11** (**0.002**), whose effects are too marginal to consider relevant from a practical viewpoint, even though the P-values maintain their statistical significance.

Figure 5. 52, Figure 5. 53 and Figure 5. 54 and Table 5. 18 and Table 5. 19, contain the findings of the SEM analysis. Examining the explanatory power requires the evaluation of the R-squared values (**$R^{2)}$**, as well as the exploration of the effect sizes (**f^2**) of the latent variables of the model. Therefore, the discussion that follows should address the R^2 and the f^2 in full. **Even though the Effect Size (f^2) is too small, it dramatically influences the analysis and evaluation of the outcomes. Effect Size of below 0.02 demonstrates that its effects remain too small to be treated relevant.**

The section is divided into two parts:

1) The relationships from NREN Service for Education (NSE), Institutional Network for Education (INE), EthERNet for Education (EthNet), Electronic Devices for Education (EDE) and Research Output (RO) to Quality of Education (QE).
2) The relationships from Institutional network for Research (INR), NREN Service for Research (NSR), Electronic Devices for Research (EDR), High-Performance Computing (HPC) and Remote Computing Facilities (RCF) to Research Output (RO).

5.5.2.1. The Relationships from NSE, INE, EthNet, EDE and RO to QE

This section is concerned with assessing the previously proposed ten hypotheses. The first five hypotheses deal with the impact of NREN service for education, institutional network, EthERNet, electronic device and research output on quality of education in Ethiopian higher education institutions. The analysis of the data collected shows that the research variables; NREN service for education, EthERNet, electronic device and research output have a significant positive impact on Quality of Education (QE) to different degrees. Within this regard, EthERNet has the highest positive impact on quality of education (standardised estimate = 0.28, P< 0.01), followed by NREN service for education (standardised estimate = 0.18, P< 0.01), then the research output (standardised estimate = 0.15, P< 0.03) and Electronic device for education (standardised estimate = 0.13, P=0.05). However, institutional networks for education (standardised estimate = 0.11, P= 0.07) had the least effect. Accordingly, EthERNet and NREN services for education are the most important variables affecting Quality of Education (QE) positively, as shown in Figure 5. 55 for a depiction of these positive and significant relationships).

The analysis of the data collected shows that the institutional network has a weak relationship with quality of education (standardised estimate = 0.11, P= 0.07) and that the existing institutional network at Ethiopian higher education is not good enough to support the teaching and learning activities. The analysis of the data collected shows that the NREN service for education has a substantial impact on the quality of education (standardised estimate = 0.18, P< 0.01) and that the NREN service for education is one of the main factors affecting the quality of education in Ethiopian higher education institutions by providing the required service for lecturers and students. As fourth EthERNet variable, the analysis of the data collected also shows that the EthERNet and the services provided for its member institutions had the highest positive impact on the quality of education (standardised estimate = 0.28, P< 0.01). The quantitative findings show that the relationship between the institutional network and quality of education is weak (standardised estimate = 0.11, P=0.07).

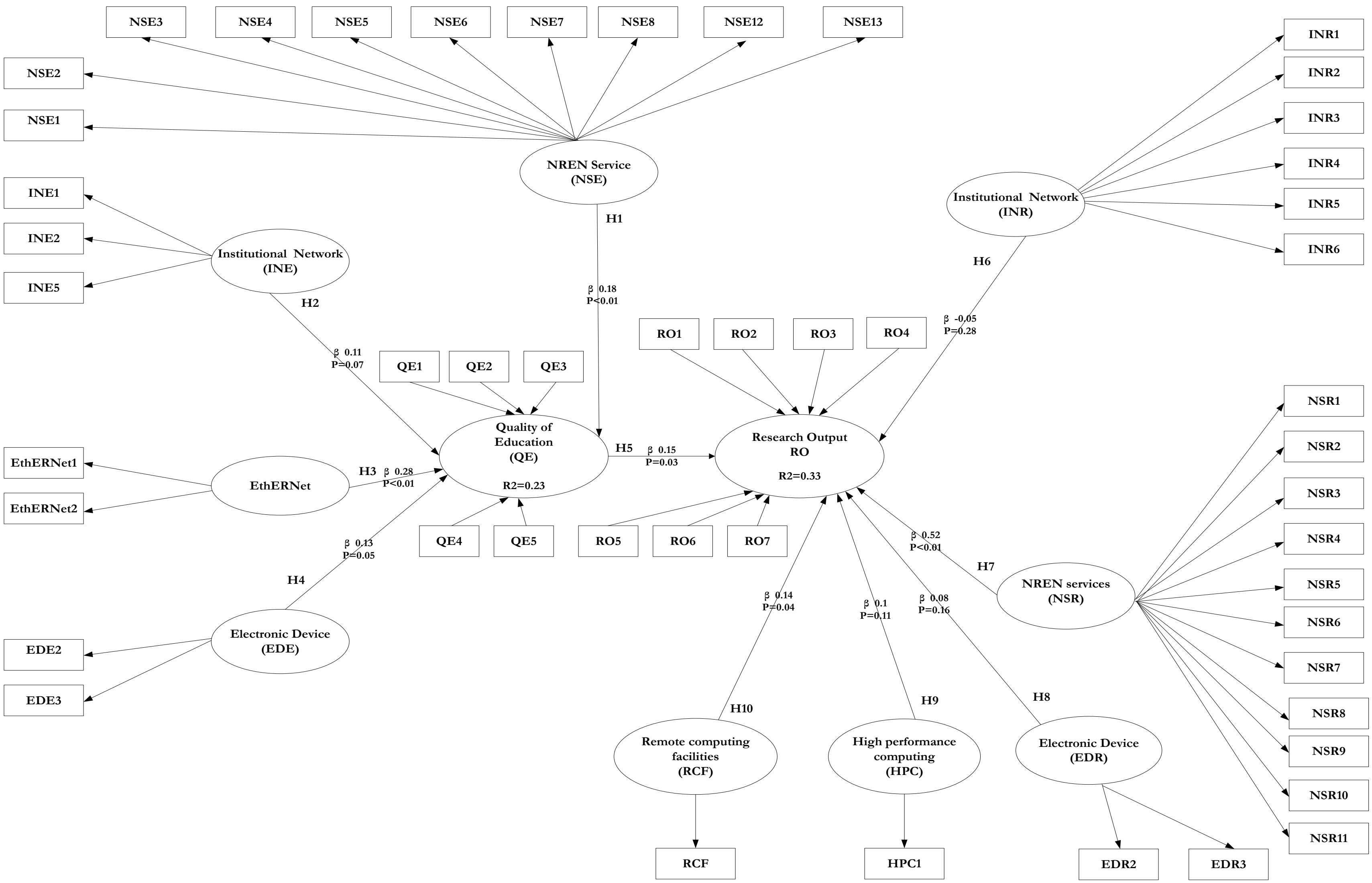

Figure 5. 55: The Path Model Results

Table 5. 18: The Hypothesis Results using Different Direct Tests

Independent Variables	β	P. Values	H	Supported/Not Supported
NREN service → Quality of education	0.18	<0.01	H1	**Supported**
Institutional Network → Quality of education	**-0.11**	=0.07	H2	***Not Supported**
EthERNet → Quality of education	0.28	<0.01	H3	**Supported**
Electronic Device → Quality of education	0.13	=0.05	H4	**Supported**
Research output → Quality of education	0.15	=0.03	H5	**Supported**
Institutional network → Research output	**-0.05**	=0.28	H6	****Not Supported**
NREN service → Research output	0.52	<0.01	H7	**Supported**
Electronic device → Research output	0.08	=0.16	H8	**Not Supported**
High performance computing → Research output	0.1	=0.11	H9	*****Supported**
Remote computing facilities → Research output	0.14	=0.04	H10	**Supported**

R-squared Coefficient for Dependent Variables

Dependent Latent Variables	**R-squared Coefficient**	**Assessment**
Quality of Education (QE)	$R^2 = 0.23$	Small Effect
Research Output (RO)	$R^2 = 0.33$	Medium Effect

***H2 is not supported. That means the existing institutional network is not up to the required standard to support the quality of education.**

****H6 is not supported. That means the existing institutional network is not up to the required standard to support the research output.**

*****H9 is supported considering the Effect sizes for path coefficients.**

	NSE	INE	EthNet	EDE	RO	INR	NSR	RCF	HPC	EDR	QE
R-squared					0.326						0.231
Adj. R-squared					0.303						0.205
Composite reliab.	0.900	0.848	0.924	0.761	0.909	0.919	0.870	1.000	1.000	0.753	0.892
Cronbach's alpha	0.874	0.729	0.836	0.373	0.884	0.893	0.834	1.000	1.000	0.344	0.848
Avg. var. extrac.	0.479	0.653	0.859	0.614	0.589	0.659	0.382	1.000	1.000	0.604	0.623
Full collin. VIF	1.337	1.118	1.176	1.158	1.481	1.132	1.516	4.585	4.395	1.308	1.213
Q-squared					0.357						0.226
Min	-0.914	-2.645	-0.972	-0.786	-1.295	-2.816	-1.747	-0.656	-0.622	-0.854	-0.904
Max	5.817	1.640	3.265	4.729	2.505	1.726	3.538	5.854	5.749	2.323	4.058
Median	-0.229	0.350	0.059	-0.000	0.000	0.002	-0.000	-0.656	-0.622	0.043	-0.350
Mode	-0.914	0.642	-0.972	-0.786	-1.295	-0.000	-0.000	-0.656	-0.622	-0.854	-0.904
Skewness	2.629	-0.662	0.506	2.256	0.219	-0.537	0.311	2.635	3.011	0.982	1.077
Exc. kurtosis	9.853	-0.510	-0.539	6.209	-0.944	-0.111	1.038	9.824	12.909	0.107	0.831
Unimodal-RS	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Unimodal-KMV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Normal-JB	No	No	No	No	No	No	No	No	No	No	No
Normal-RJB	No	No	No	No	Yes	No	No	No	No	No	No
Histogram	View	View	View	View	View	View	View	View	View	View	View

Notes: Unimodal-RS = Rohatgi-Székely test of unimodality; Unimodal-KMV = Klaassen-Mokveld-van Es test of unimodality; Normal-JB = Jarque-Bera test of normality; Normal-RJB = robust Jarque-Bera test of normality; click on "View" cell to see corresponding histogram.

Figure 5. 59: Latent variable coefficients as-is from WarpPLS

Besides, an examination of the data gathered demonstrates that the effect size of the NREN service, EthERNet, electronic device and research output has a small effect on the quality of education. The effect size of the path coefficient from institutional network to quality of education has **no effect** (f^2=0.018), which means the existing institutional network at Ethiopian higher education is weak in support of the quality of education as shown in Table 5. 19. These three independent variables, NREN service, EthERNet and electronic device, and one dependent variable (RO), explain their moderate impact on the quality of education, with an R^2=0.23. This means that the services required by end-users that can be provided by EthERNet have positive impacts in improving the quality of education at Ethiopian higher education institutions. Accordingly, the four hypotheses (**H1, H3, H4 and H5**) are supported.

5.5.2.2. The Relationships from INR, NSR, EDR, HPC and RCF to RO

The second five hypotheses deal with the impact of the Institutional Network for Research (INR), NREN Service for Research (NSR), Electronic Devices for Research (EDR), High-Performance Computing (HPC) and Remote Computing Facilities (RCF) to improve the Research Output (RO) at Ethiopian higher education institutions. The examination of the data gathered demonstrates that the research variables; NREN service for research, high-performance computing, and remote computing facilities have a significant positive impact on Research Output (RO) to different degrees.

In greater detail, the NREN service for researchers had the highest positive impact on research output (standardised estimate = 0.52, $P< 0.01$), followed by remote computing facilities (standardised estimate = 0.14, $P= 0.04$) and high-performance computing (standardised estimate = 0.10, $P= 0.11$. However, institutional network for research (standardised estimate = 0.11, $P= 0.07$) and electronic device for research (standardised estimate = -0.08, $P= 0.16$) have the least and negative effect, respectively, on research output as shown in Figure 5. 54 for a depiction of these positive and significant relationships).

The path coefficient from the institutional network to research output was found to be non-significant ($\beta=-0.05$, $P=0.28$). The institutional network has no effect on the research output ($f^2=0.007$). This means that the institutional network at Ethiopian higher education does not support the research activities of the researcher. **Accordingly, hypothesis H6 is not supported**.

The path coefficient from NREN service to research output was found to be positive and significant ($\beta=0.52$, $P<0.01$). The effect size of this path is medium ($f^2=0.281$). This means that the NREN service for research provides the necessary service for the researcher and assists in improving the research output. **Accordingly, hypothesis H7 is supported**.

The path coefficient from Electronic device to research output was found to be non-significant ($\beta=0.08$, $P=0.16$). The Electronic device has no effect on the research output ($f^2=0.014$). This means that the Electronic device alone does not have much impact on the research output. **Accordingly, hypothesis H8 is not supported**.

The path coefficient from High-performance computing to research output was found to be slightly positive and slightly significant (β=0.10, P=0.11). The effect size of this path is small (f^2=0.021). This means combining both effects, High-performance computing supports the researcher and improves the research output. **Accordingly, hypothesis H9 is supported**.

The path coefficient from Remote computing facilities to research output was found to be positive and significant (β=0.14, P=0.04). The effect size of this path is small (f^2=0.031). This means that Remote computing facilities support the research activities that are currently impossible and improve the research output. **Accordingly, hypothesis H10 is supported**. These three independent variables, NREN service, High-performance computing, Remote computing facilities, moderately explain the impact on research output, with an R^2=0.33.

Table 5. 19: Path Coefficients Effect Sizes

Independent Variables	**f^2**	***Effect Size Assessment**
NREN service → Quality of education	0.055	Small
Institutional Network → Quality of education	0.018	**No effect**
EthERNet → Quality of education	0.099	Small
Electronic Device → Quality of education	0.023	Small
Research output → Quality of education	0.035	Small
Institutional network → Research output	0.007	**No Effect**
NREN service → Research output	0.281	Medium
Electronic device → Research output	0.014	**No Effect**
High-performance computing → Research output	0.021	Small
Remote computing facilities → Research output	0.031	Small

***It is recommended that all indicator effect sizes be equal to or greater than 0.02, for both formative and reflective latent variables (Kock, 2014a).**

5.5.2.3. *Predictive Validity (relevance)*

Apart from the consideration of the previous methodology, it is also vital to evaluate the predictive importance of the independent latent variable-squared coefficients, otherwise referred to as Stone-Geisser Q-squared coefficients (Kock, 2015d; Kock and Gaskins, 2014) as illustrated in Table 5.21. Hair, Hult, Ringle and Sarstedt (2016) shows that a Q-squared value of above 0 denotes predictive relevance of a model while that below 0 is an implication of its absence.

Table 5. 20: Dependent Constructs - Predictive Relevance

Q-squared Coefficient for dependent Latent Variables		
Dependent Latent Variables	**Q-squared Coefficient**	**Valuation**
Quality of Education (QE)	0.226	Small Effect
Research Output (RO)	0.357	Moderate Effect

According to Table 5. 20, a figure more than zero exhibits predictive relevance of the Q-squared coefficients to their latent variable block, as well as the dependent latent variables. Figure 5. 54, Table 5. 18, Table 5. 19, Table 5. 20 and Table 5. 21 provide the summarised results.

Table 5. 21: Summary of Results

Number of Hypothesis	Hypothesis	Supported/Not Supported
H1	NREN services have positive impacts on educational quality at most institutions of higher learning.	**Supported**
H2	The existing institutional networks at Ethiopian higher education institutions have positively affected the educational quality.	**Not Supported**
H3	The EthERNet has positively impacted on the educational quality at most of the Ethiopian higher learning institutions.	**Supported**
H4	Electronic devices have positively impacted on the quality of education at most institutions of higher learning.	**Supported**
H5	There is a positive correlation between research output and quality of education at most institutions of higher learning.	**Supported**
H6	The existing institutional networks at Ethiopian higher education institutions have positively affected the research output.	**Not Supported**
H7	NREN services have positively impacted on the research outputs at most institutions of higher learning.	**Supported**
H8	Electronic devices have positively impacted on the research output at most institutions of higher learning.	**Not Supported**
H9	Access to high-performance computing has a positive influence on the research output at most institutions of higher learning.	**Supported**
H10	Access to remote computing facilities has a positive influence on the research outputs at most institutions of higher learning.	**Supported**

5.5.2.4. GoF of the Model

Besides the model indices used in this study, PLS-SEM also possesses another measure of fitness, as described by Tenenhaus in Henseler, Hubona and Ray (2016) as the measure of Global Fit (GoF). The measure accounts for the geometric mean of the averaged variance extracted and R-squared as per the endogenous variables (Yusr, Mokhtar and Othman, 2014). The calculation of the GoF follows the formula:

GoF= square root of; (average AVE) × (average R-squared).

For this (research) study, Tenenhaus GoF = 0.434.

In the methodology set out by Richter, Cepeda, Roldán and Ringle (2015), the 0.434 result is a demonstration of **the proposed theoretical framework model's fitness** not only in measure but also its adequacy and validity for the global PLS model. Richter, Cepeda, Roldán and Ringle (2015) suggested the use of 0.1 for small, 0.25 for medium, and 0.36 for large when it came to the standardisation of the GoF.

5.6. Summary

The questionaries' used to evaluate the NREN services required by end users at EthERNet member institutions. The analyses of the data gathered from questionnaires and the results of the in-depth analysis are presented in this chapter. The data analysis focuses on the questionnaire perceptions of the NREN services required by end-users. Besides, the analysis looked at what services can be provided for Ethiopian public higher education institutions to improve the quality of education and research output, as well as the main challenges faced by these institutions with regards to establishing an NREN service portfolio and roadmap.

Besides, this chapter explains the responses of the study's participants concerning the role of the NREN service, institutional network, and EthERNet in improving the quality of education and research output at Ethiopian public higher education institutions, the factors, both positive and negative, persuading the relationships between the latent variable of quality of education and research output actor-networks involved in providing the required service for the researcher and educators. The PLS-SEM statistical analysis validated the study's theoretical model, and it is found that most of the NREN services have a significant role to play in improving the quality of education and research output at Ethiopian higher education institutions. The model of the study was verified using the PLS-SEM, and it is found to be valid for clarifying the factors, both positive and negative, impacting the roles, relationships and formation of quality of education and research output actor-networks involved in providing the required services for end-users at Ethiopian higher education institutions.

Chapter 6: Data Analysis and Discussions

This Chapter discusses the main data analysis findings of the study.

6.1. Introduction

This section presents the findings of each sub-research question, which addressed the NREN services required, the challenges faced by Ethiopian higher education institutions, the impact of NREN/EthERNet on the quality of education and research output, and analyses the factors influencing actor-network relationships that impact on the quality of education and research output. These factors were then used to design an NREN service portfolio and roadmap for improving the quality of education and research output at Ethiopian institutions of higher learning.

The main aim of this study has been to investigate the NREN services required by end-users and to provide the service and develop a service portfolio and roadmap for EthERNet, which will assist in improving the quality of education and research output at Ethiopian higher education institutions. Moreover, the research has identified the association between NREN services and the influence of these associations on the role they play and the results of their work. This is despite the fact that most of the results were affected by the small effect of the factors as measured by Cohen's $f2$. However, the research could not establish the actual role played by NREN services as this was merely based on users' perceptions of NREN services.

The research study has established and outlined the critical thrust, which has been influential in the quality of research and learning offered (i.e. NREN service, institutional network, EthERNet, HPC and RCF) and demonstrated their impact on Ethiopian higher education institutions. However, results indicated that the existing institutional networks in Ethiopian higher education institutions do not improve on the quality of education and research output. In contrast, electronic device did not affect the research output. This is based on the results obtained after evaluating H2 and H6 for education and H8 for research, respectively.

The chapter also reviews the outcome of the research study (as **presented in Chapter 5).** It also analyses key findings from the research to create and design a more accurate picture of the impact of reliable networks on the quality of learning and research, NREN services and ANT. More importantly, the research findings related to the appropriate literature review in the study fields. The chapter also focuses on the applicability of ANT to depict NREN Service Implementation Requirements in Ethiopian higher education institutions.

The chapter also created and designed a more accurate picture of the impact of reliable networks on the quality of learning and research, NREN services and ANT concerning the results obtained in the literature review. The applicability of ANT in depicting NREN Service Implementation Requirements in Ethiopian higher education institutions played a crucial role.

Thus, this chapter integrates the statistical data analysis result done by using SPSS and WarpPLS structural equation modelling. SPSS helped in explaining the **WarpPLS** results. On this foundation following the study objectives, it explains the impact of NREN services in improving the quality of education and research output. It addresses how the end-user expressed dissatisfactions; these negative factors can be used to design the required NREN service. It looks at the factors influencing the use of EthERNet, the formation of NREN related actor-networks, the factors affecting their construction and how they function, the expected challenges and lastly the value of ANT's theoretical structure.

To encapsulate, the objectives of the study included, the need to investigate the services required by researchers and educators, to find out the main challenges faced by Ethiopian higher education institutions with regards to their network. Furthermore, the objectives also stipulated the need to assess the factors that illuminate the impact of EthERNet/reliable network. Also, Actor-Network Theory (ANT) concepts will be covered in the following sections, and the ANT theory is validating the proposed theoretical framework by identifying and evaluating the variables in the framework. Which is more emphasized on the strong link among the actors identified earlier. Moreover, the sixth objective will be addressed in chapter 7.

6.2. Services

This subsection covers the first study objective, namely, to investigate the service required by researchers and educators within Ethiopian higher education to enhance the research and education quality. The aim here is to gain a deeper understanding of the required services at Ethiopian higher education institutions by both educators and researchers, to assist them in improving the research and education quality. The quantitative findings using SPSS were used to analyse the data. The findings showed that for both the educator and researchers, the institutional network caused them problems when they are trying to access network-related services. Security related with network, system and data are judged necessary by the research participants. Besides, limited bandwidth, intermittent power outage and absence standard campus network considered a problem for the respondents.

6.2.1. NREN Service for Education Issues

The below issues related with NREN Services for Education were identified.

Academics and students need frequently access of resources online and need to distribute materials.

As indicated in Figure 5. 3, 92.21% of academics would like to have an online access to resources regularly to assist the teaching and learning process. Varity of online resources were required, including journals both subscribed and open access archives, local Learning Management Systems and MOOCs to access online academic materials. As shown in Figure 5. 5, (72%) the professors would like to provide supporting educational materials online including, assignments and reference materials, laboratory materials and experiments manuals. Compared to academicians, students have less frequent access to online materials. As depicted in Figure 5. 7, 59.09% of the academic staff know that their students' needs to have supporting educational materials online. The most common type of materials their students want to accesses are e-learning materials, open education resources, presentations, lab manuals, lecture related references, articles, journals, E-books, dissertations and theses, Learning Management System (LMS) platform, mainly Moodle, Microsoft 365 mainly for email purpose and educational reference materials such as YouTube.

Lecturers and students required regular and occasional access to a wide variety of online software.

According to Figure 5. 9, 55.79% of academics would like to have frequent access to online software. The most popular software includes SPSS, Plagiarism Checker, applications that support educational systems and ArcGIS. (42.1%) students want to have gain access to software online as indicated in Figure 5. 11. Additionally, a need for lecture notes and reference materials, Massive Open Online Courses (MOCCs), Learning Management System (LMS), modelling–/Statistical software and search engines.

Regarding education-related services use and usefulness, the below conclusions can be drawn:

As indicated in Figure 5. 13, all services used to assist education are required by end users and useful to support end users. Institutional email service, online library resources and ResearchGate were almost used by everyone and easily available for the users. The required services but currently are not provided by the institutions are, massive open online courseware, the capability to use their credentials to log in at another institute, recording tools to use in lectures, collaboration tools, video or web conferencing and online (Web-based) teaching and learning resources. The lowest ranked were the ability to login to another institution and MOOCs. ResearchGate and LinkedIn were the most used in teaching among social media platforms. Cloud Computing and File transfer were the required applications together with other applications

Using EthERNet there is a big potential to provide Distance Learning Programmes:

As indicated in Figure 5. 14 and Figure 5. 15, 87.02% of the participants agreed that using EthERNet there is a big potential to provide Distance Learning Programmes in Ethiopia and 83.12% of the participants agreed that, using EthERNet there is a possibility to provide distance learning programmes for global students.

Besides, the number of potential students to accommodate distance learning programme that might be reached locally or globally are shown in Figure 5. 16 and Figure 5. 17. Accordingly, it is easy to reach up to 1500 students locally and up to 1050 globally if they are using EthERNet

Most of the electronic devices are were deemed useful for teaching and learning purposes. Among them, laptops are very common devices compered to PCs, followed by mobile devices. Tablets and Virtual Desktop Environment (VDI) or Thin Client is also important as an alternative electronic device that can be used by mass on in the computer laboratory

6.2.2. NREN Services Issues Identified for Research

The below points are identified related with the services provided by NREN for Research activities.

A strong desire is there for researchers towards transfer large files while collaborating with other researchers:

As indicated in Figure 5. 24 and Figure 5. 25, 69.77% of researchers want to collaborate with their project partners, which involve large file transfers over a data communication network and 37.78 % researchers want to transfer a file of more than 1GB.

Researcher would like to collaborate and work together with their local and global counterpart:

According to Figure 5. 24 and Figure 5. 25, 31.78% of the research participants frequently work in partnership with another researcher locally. Just 43.41% frequently collaborate internationally. Most of the respondents collaborate nationally at some time. Most international research collaboration is with the USA, Sweden, Germany, Netherlands India, and South Africa

Researchers would like to have connectivity access to get resources online used to support their research work:

As indicated in Figure 5. 28, 91.47 % of researchers are using reputable journals, articles and online conferencing in order to support their research work. The most famous search engines for researchers includes Google and Google Scholar. A wide variety of (53.49%) datasets are accessed online regularly, as shown in Figure 5. 33. 62.79% of researchers publish open access research/data work, as shown in Figure 5. 35.

Researchers need a wide variety of software:

As indicated in Figure 5. 37, statistical, forecasting and modelling tools such as SPSS and R are the most desired applications needed by researchers. As shown in Figure 5. 40, a small percentage (10.23%) of respondents wish to publish frequently online, but most researchers were not interested in creating and publishing their software.

As indicated in Figure 5. 37, R and SPSS are the most desired applications needed by researchers. As shown in Figure 5. 40, 10.23% of research participants want to develop and distribute software's online, but the majority of researchers do not do it.

A few researchers would like to have remote sensors access online:

As indicated in Figure 5. 42, 10% of the respondents need to access online sensors frequently. 29% of them wish to do this occasionally; however, many of them are not accessing remote sensors online. The most desired are the remote sensors used for communication related issues

Regarding the research-related services use and usefulness, the below points can be reached:

As indicated in Figure 5. 45, institutional email services, online library resources, and video or web conferencing services were the mainly provided services by the institutions. The most desired but currently unavailable services; are login into other organizations using the local credentials or single sign-on, access to storage space, Web-based portals or remote access to institutional resources including, but not limited; to, teaching, learning materials, research materials, computing resources and sensor services to support the community and collaboration and communication tools.

Some of the social media like ResearchGate is also used for educational purposes, among others. Other than the above-mentioned services, licensed software, accessing other universities/research centre resources (library and laboratory and access to journals and articles which are also required by researchers.

All electronic devices were deemed useful. As indicated in Figure 5. 46, 100% of the users labelled laptops as a useful electronic device , while desktop PC and smart mobile devices, drawing 96.1% an 80.47% respondent, respectively. Other devices used for research work including but not limited to tablets and VDI (Virtual Desktop Environment) would be another choice due to energy efficiency, portability, and cost-effectiveness

6.2.3. List of Services Identified

For education and research purposes, the below list of services is identified:

1. S1: Digital Library Platform and Services
2. S2: Learning Management System (LMS) Platform (e.g. Moodle)
3. S3: Massively Open Online Courses (MOOCs) services
4. S4: Open access repository services (National/Institutional)
5. S5: The provision of online learning resources (such as the class notes, supporting materials and videos)
6. S6: Institutional Email Services
7. S7: Online access to software and applications (e.g. SPSS, R, Plagiarism Checker and ArcGIS) used for education and research
8. S8: Video or web-conferencing platform and services
9. S9: National negotiation and procurement of software licenses and online subscriptions (eJournals and eBooks) for use in educational and research institutions
10. S10: Collaboration tools (e.g. wikis, event calendars and instant messaging).
11. S11: Large file transfer service
12. S12: Service to have remote sensors access
13. S13: Remote login using the identity provided
14. S14: The services to remote (non-local) computing services
15. S15: The services which help the end users to login into other remote institutions by using local identity
16. S16: Data storage services
17. S17: Local computing facilities (e.g. computer labs and VDI)
18. S18: Access to high performance computing facilities
19. S19: Online software development platform
20. S20: Training and capacity building available to users to improve digital literacy

6.3. Challenges

This section covers the second objective of the study that is to find out the main challenges faced by Ethiopian higher education institutions with regards to their network and in using EthERNet to enhance the quality of education and research output. The aim here is to gain a deeper understanding of the main problems and shortcomings of the existing institutional network for education and research at Ethiopian higher education institutions and the main barriers in using EthERNet and other issues to be considered at the campus level. The quantitative findings using **SPSS** were used to analyse the data. The study showed that most of the services related to network for researcher and educators showed that the existing institutional network connectivity affected them. The main concern for educators and researchers is found to be unavailability of reliability network is a big concern. Security related issues for both network and data are also a concern for both researcher and educators. In addition to the above-mentioned problems, frequent power outage, small internet bandwidth and unavailability of standard campus network are also a problem raised for the users. Besides, the main barriers to using EthERNet and their internal campus network are identified in the subsections below.

6.3.1. Main Problems with the Existing Network for Education

As indicated in Figure 5. 3, 55.19% of the academics have a problem with their institutional network~~,~~ when they are trying to access online materials and/or data. As indicated in Figure 5. 6, 60% of the academics expressed that the institutions network has a big problem to give online related materials and data used for educational purposes for students and 65.79% of the academics said that there is still a big problem with connectivity for the students to use it for their educational purposes. As indicated in Figure 5. 10, 62.33% academics cannot easily access software related resources used for educational purposes because of the poor network connectivity. According to Figure 5. 12, 69.72% of academics confirmed that their institutional connectivity inhibits the students from accessing resources available online.

As illustrated in Figure 5. 19, the main problems, which accounted for more than 68% for academics with the institutional network in their teaching and learning process are unreliability of the network. Students are unable to connect easily to the network, students are unable to gain access to devices such as computers or smart mobiles quickly, academics cannot easily connect to the network, academics cannot guarantee data privacy and network security is not ensured. Hence, most academics agreed that the problems mentioned above harm their teaching and learning processes while using the network. The most common problems are related to the reliability and connectivity of the network. Getting access to electronic devices followed. Security related issues including network and information were also reflected very important for the end user at the institutions as per the survey.

Other network-related problems, which should be improved upon including frequent power outages and power supply concerns, insufficient Internet bandwidth, limited technical support from ICT staff, lack of standard campus-wide network and limited Wi-Fi hotspot coverage, filtering/proxy from both the Internet Service Provider (ISP) and campus network.

Overall, these results indicate that the majority of educators need reliable and adequate bandwidth in addition to access to devices for the students. Providing Wi-Fi hotspots and securing the network must also be considered. While issues such as frequent power outages, limited technical support and content filtering problems are essential, in summery the under noted are required.

- Avoid unnecessary filtering /proxy from the ISP and campus network
- Provide (a) standard campus network including access to Wi-Fi
- Provide adequate Internet bandwidth
- Provide data and application security
- Provide Reliable and secure network for users (student and academics)
- Provide a reliable power supply
- Provide sufficient access to devices such as computers or smart mobiles for students
- Provide technical support from ISP and the campus network for end-users

6.3.2. Existing Network Issues for Research Purpose

As indicated in Chapter 5, Figure 5. 29, 61.11% of researchers confirmed that the network is not reliable when they are searching for an online conference, and journal articles and as per indicated in section 5.3.10 and Figure 5. 32, a significant proportion of researchers (61.72%) indicated that their network causes access problems and the same is true for access to online data sets and publishing open access research/data.

Among researchers who are trying to access data sets, 58% of the researcher concern is the network reliability and 57.25% of the researcher think the network is not reliable when they are trying to publish open access research/data. Moreover, 60.46% of researchers indicated that their network causes problems when they are trying to access software online used for their research work.

Intermittent institutional network connection made it difficult for 79.89 % of researchers to take part in international conferences and 74.22 % of researchers to participate in International Conference Programme Committees. Connectivity and internet speed are the main concern to participate on the editorial board for almost 67.97% of researchers.

As indicated in Figure 5. 27, 71.43% of researchers agreed that their network is unreliable when they collaborate with other scholars internationally. Also, the network hinders them: when wanting access to virtual labs and facilities like HPC; when transferring large files; when working on shared resources; when collaborating via video/web conferencing, chatting, having online discussions, webinar; and when sending emails, participating forums or courses conducted online, collaborative joint research development, access their library, uploading data, analysing real-time data, etc. These are some of the inherent limitations that the network is endowed with.

As indicated in Figure 5. 45, 64.85 % of researchers agreed that the local computing facilities supported their research activities, while the reset researcher says that the support required was not enough. In contrast, 91.48% of researchers stated that unavailability of the required research infrastructure such as HPC and remote access computing facilities are the main problems to conduct their research activities. The majority of researchers (60.47%) do not have adequate storage to put their data which is an obstacle to do their research activities, though 89.92% of them agreed that having more access storage to put their research related data assist them to do more research which is not currently possible. Regarding the capability of sharing data for research purposes, 90.62% researchers is required to share research related data with their counterpart from wherever they are, and 86.72% of researchers agreed that by sharing their data online~~,~~ they would be able to do more research which may not be possible to do right now

Most of the researchers also stated that getting an experience by paying a visit physically with other research institutions and participating in global meeting and conference would enable them to improve their research activities. Moreover, 91.47% of researchers agreed that using the local credentials to log in at another institution to access their resources would enhance their research work.

Other barriers, including intermittent network connection, make it difficult for 79.89% of researchers to take part in international conferences and International Conference Programme Committees. Network speed is also an issue for 67.97% of researchers when participating on scientific editorial boards, even though 96.9% of researchers agreed that participating in international academic communities and collaborating with them is useful for future path. Some of the researcher request to participation in international conferences, access to subscribed journals and articles, access to licensed software and Remote Access Services (RAS). As indicated in Figure 5. 48, the main problems currently being experienced with the network in supporting the research activities of researcher are as follows: difficulty connecting to the network quickly, the unreliability of the network, difficulty in granting network security and data privacy. Other problems include low/insufficient Internet bandwidth, intermittent Internet connection, power supply issues, poor support and maintenance and availability and affordability of off-campus accessibility, which are the most repeated concerns in supporting the research activities.

6.3.3. Main Barriers in Using Ethernet: Views of ICT Directors and EthERNet Staff

As illustrated in Figure 5. 51 (i), the main barriers to the use of EthERNet and provision of ICT services for academicians and researchers in Ethiopian public higher education institutions are lack of Institutional ICT Policy, to which 80% of the ICT directors agreed. Some of them have drafted a policy, which has not yet been approved by the concerned body or implemented. Lack of getting skilled ICT staff~~s~~ and retention mechanism for those currently working are also identified barriers. Also, more than half of the ICT directors agreed that lack of a standard Data Centre, lack of a standard campus network, lack of network and data security, insufficient Internet bandwidth, insufficient support from the network provider (Ethio Telecom), lack of support and commitment from top level management, lack of last-mile connectivity for remote campuses, lack of institutional ICT strategy, lack of alignment for institutional ICT strategy with the corporate strategy, difficulty in ICT strategy implementation and lack of sufficient budget for ICT are also indicated as barriers for non-utilization of the EthERNet network to provide the required ICT services by end-users.

In addition to the above, lack of capacity building for ICT staff, lack of coordination and collaboration amongst public universities in respect to shared ICT activities, lack of commitment by ICT staff, lack of application provided by EthERNet other than connectivity, frequent power outages and lack of awareness of the National ICT policy by both ICT staff and higher officials are among the barriers mentioned by participants to be considered.

As indicated in Section 5.4.3, the main barriers to getting EthERNet to provide cloud services are security, privacy, reliability of ~~l~~ocation, availability and technical support from the cable provider, Ethio-Telecom. Currently, the main challenges/barriers for EthERNet to provide ICT services used for research and education purposes are insufficient Internet bandwidth, reliability of the network, insufficient support from the cable provider /ISP, unavailability of national ICT policy and strategy, lack of sufficient budget allocated, lack of skilled ICT staff and lack of retention mechanisms for staff.

6.4. Impact

This section covers the third objective of the study, which is to assess the impact of EthERNet in providing a reliable network to assist in improving the quality of education and research output at Ethiopian higher education institutions. The aim here is to gain a deeper understanding of the impact of a reliable network on education and research in assisting the educators and researchers, and the impact of a reliable network and low-cost Internet connectivity for universities to assist in establishing standard campus networks. The quantitative findings, using **SPSS,** to analyse the data showed that the impact of a reliable network on teaching delivery and student education, as well as on research has a significant impact at both national and international level. It is therefore imperative for ICT Directors to reflect on the priority interests concerning networked services and application management, which are elaborated in the subsections below.

6.4.1. Impact of a Reliable Network on Education

Nearly all the respondents agreed that an effective NREN is likely to improve, to a great extent, the learning experience, as well as enabling students to enrol in online courses. As indicated in Figure 5. 20, virtually all respondents (more than 90%) agreed that a reliable network would have a significant impact on teaching delivery and student education. Additionally, it gives a chance for learners to attend classes online, which will be as effective as the interaction between learners and instructors through web-based video conferencing.

Overall, these figures show that by making EthERNet an effective NREN, would provide a reliable network for the higher education institutions and this would have a significant impact on teaching delivery and student education, as well as enabling students to attend University through distance learning. However, this is heavily dependent on the reliability of institutional networks, which were highlighted as a major obstacle by educators and lecturers.

6.4.2. Impact of a Reliable Network on Research

Over 90% of respondents agreed that there was a significant impact of a reliable network on research at the national and international level, as indicated in Figure 5. 49. This enables the research to make a substantial effect both locally and globally enabling the establishment of new partnerships and collaboration with their counterparts around the globe.

Virtually almost all respondents agreed that an effective NREN could provide a reliable network to the member institutions and it would have a significant impact on research at both national and international levels. Furthermore, it will enable the facilitation of various research collaborations. However, it is heavily dependent on the reliability of institutional networks, which seemed to be a significant obstacle for researchers and lecturers.

6.4.3. Impact of a Reliable Network and Low-cost Internet Connectivity: Views of ICT Directors

As indicated in Figure 5.53, ICT Directors explained their requirements to assist the researcher and educators needs. The major task for the shall be to implement standard campus network and provide reliable network for the end users as indicated by more than 95% of the respondents. Other main task that should be provided rated over 77% agreement, which includes providing both network and application security, providing Web-based teaching and learning resources, providing unified communication tools (video- or web-conferencing), providing collaboration tools and implementing voice over IP services. Besides, there is a plan to provide other network technologies or applications, which include–among other things, the following identified services: Video Surveillance System /CCTV, Digital Signage, Virtual Desktop Infrastructure, Integrated University Management System (one card system), Fleet Management System, IPTV (IP Television), setting up ICT Incubation Centre and providing Webhosting services for the nearest communities.

In summary, sections 6.2- 6.4, reported on the survey results, analysis, and discussions, which will form the basis for further analysis while proposing a NREN service portfolio.

6.5. Factors

This part covers the fourth aim of the research. It is analysing the factors both negative and positive that affects the linkage amongst active networks in enhancing the quality of research and learning in Ethiopian higher learning institutions. It also analyses the fitness of the developed structural model and hypothesised research.

The quantitative analysis of the data using WarpPLS in this study revealed that the study variables (NREN service for education, EthERNet, electronic device and research output) have a significant and positive impact on Quality of Education (QE) to differing degrees. EthERNet was found to have the highest impact, followed by NREN service, research output and electronic devices, respectively. Accordingly, EthERNet and NREN services are shown to be the most important variables affecting the chances of success in improving the Quality of Education (QE). However, the analysis of the data collected also shows that institutional networking has a weak relationship with the quality of education, which means the existing institutional network or campus network infrastructure at Ethiopian higher education causes problems when students and instructors try to access resources available online to assist the teaching and learning activities. The study's findings showed that weak EthERNet as opposed to strong NREN service, which is not available to the user at Ethiopian higher education institutions, makes it challenging to deliver distance learning programmes both internationally and nationally. In turn, this negatively impacts on access to education. Besides, students and lecturers could not get potential networked services that might be useful in the teaching and learning process, which adversely affects the quality of education.

For the research output also, the data analysed using WarpPLS revealed that the study variables (NREN service for research, high-performance computing, and remote computing facilities) have a significant and positive impact on Research Output (RO) to differing degrees. In this regard, the NREN service for researchers had the highest positive impact on research output, followed by remote computing facilities and high-performance computing.

Accordingly, NREN service for researchers', RCF and HPC infrastructure and services are indicated to be the most crucial variables affecting the chances of being successful in enhancing the Research Output (RO). However, the analysis of the data collected also shows that institutional network and electronic devices have a weak relationship with research output, which means the existing institutional network or campus network infrastructure at Ethiopian higher education causes problems when researchers try to work with other researchers internationally, search for an online conference and journal articles, access data sets and publish open access research to support their research activities.

In looking at the overall picture, the lack of the critical factors in the study have negatively impacted the research and education quality. The descriptive analysis from SPSS results are like the Structural Equation Model results from WarpPLS. **The quantitative findings using WarpPLS and SPSS analysis are explained jointly in sections 6.5.1-6.5.6.**

6.5.1. EthERNet and its Relationships with Quality of Education

The analysis of the data collected for this study in Section 5.5.2.1 showed that EthERNet is found to be one of the main factors positively affecting the quality of education in this regard. **This is also supported by the findings of the analysis using SPSS**. From the data analysis in section 6.2.1 respondents indicated that they would reach potentially more national and international students if they are using EthERNet to provide distance learning programmes, which will increase access and quality to higher education.

These findings are consistent with Esmat, Adrian, Mischa and Maria (2017). They have all confirmed the impact of NREN in improving distance learning program using tele-teaching and tele mentoring for manual training and skill development as they are dedicated backbone that can reliably network connectivity for the education sector. NREN is also active in hosting open education resources and provides a platform for OER to improve the quality of distance education.

6.5.2. NREN Services and its Relationships with Quality of Education

The analysis of the data in Section 5.5.2.1 showed that unavailability of the required NREN service leads to a negative impact in supporting the teaching and learning process at Ethiopian higher education institutions and that, NREN service is one of the main factors affecting the quality of education.

As indicated in Table 5. 6, some services are presented as follows, subjecting them to the process of Confirmatory Factor Analysis (CFA) and redundancy using WarpPLS analysis.

The below services are not removed.

- Video- or web-conferencing
- Unified communication and collaboration platforms
- Classroom recording during live lecture
- Freely available and accessible online resources
- Online resources used for educational purposes
- Teaching and learning platforms
- Remote login at other institute with local credentials
- LinkedIn and
- Massively Open Online Courseware
- ResearchGate

However, the below services are removed

- Institutional Email service (NSE_9)
- Facebook (NSE_10) and
- Twitter (NSE_11)

This is supported by the findings of the SPSS analysis too. As indicated in Section 5.2.7 and Figure 5. 13, more than 83%+ of the respondents agreed that all technologies used to assist the teaching and learning activities are highly required by the study participants to improve the quality of education.

Also, in terms of the usefulness of social media, the SPSS analysis showed that Facebook (30.37%) and Twitter (33.33%) **are not that much useful to support the quality of education,** which is confirmed by both the SPSS and WarpPLS analysis.

The results are in line with many researchers, such as Kashefi *et al.* (2018) indicated that NREN service like video conferencing services and some collaboration tools are useful for remote lecturing that helps to share skilled human resources amongst NREN member institutes, ultimately improving the quality of education. Foley (2016) and Kunda and Khunga (2015) all found that

NREN services including, but not limited to, MOOCs, OER and collaboration tools have a positive impact on improving the quality of education. NREN can assist the teaching and learning processes by providing platforms to share and create traditional and online (such as MOOCs) course development.

6.5.3. Institutional Network and its Relationships with Quality of Education

The analysis of the data as discussed in Section 5.5.2.1 showed that, an institutional network has a weak relationship with the quality of education and that the existing institutional networks at Ethiopian higher education institutions are not good enough to support the teaching and learning activities. This means that the campus network at each university is too weak to support the need of the user communities within the university. **This is supported by the findings of the SPSS analysis too. As explained in detail in Section 6.3.1, most of** the academic staffs and students have a problem with their existing institutional network, when accessing resources available online.

These findings are consistent with Herold (2017) and ECAR (2016), who found that the availability of functional network connectivity has a positive impact on educational quality. Vala (2014) also stated the importance of a WiFi network for students for them to be able to study effectively. Their institutions should provide this as part of the campus network. This means that poor institutional network harms the quality of education.

Overall, taking the analysis of SPSS and WarpPLS together, it can be concluded that the existing institutional network is not good enough to support the end-user at Ethiopian higher education institutions.

6.5.4. Institutional Network and its Relationships with Research Output

The quantitative findings discussed in Section 5.5.2.2 showed that the institutional network at Ethiopian higher education institutions does not support the research activities of the researcher.

This is in line with the analysis done by using SPSS. As explained in detail in Section 6.3.2, the current institutional network causes problems when researchers want to work with other researchers internationally, search for the online conference and journal articles, access online conference and journal articles, access data sets, publish open access research work or data online and access software online.

These findings are consistent with Matthew, Joro and Manasseh (2015), who stated that an institutional network is vital for the researcher to communicate and collaborate with his/her peers both locally and around the globe, which ultimately has an impact on the research output. However, many developing nations' campus networks are still not providing reliable connectivity at the campus level due to various reason, including the cost of bandwidth, poor network infrastructure and skilled ICT staff.

6.5.5. NREN Service and its Relationships with Research Output

The analysis of the data in Section 5.5.2.2 showed that the NREN service for research, which can provide the necessary service for researcher and assist in improving the research output at Ethiopian higher education institutions is one of the main factors affecting the research output.

This is supported by the findings of the SPSS analysis too. As indicated in Section 5.3.17 and Figure 5. 45, the most used available services for researchers were "institutional email services" (83.72%), "online library resources" (77.52%) and "Video or web conferencing services" (33.33%). Besides, researchers believe that those services are essential to assist the research output, which includes "Login into other organizations using the local credentials or single sign-on" (72.87%), "Access to a storage space" (70.54%), "Web-based portals or remote access to provide access to institutional resources including but not limited to teaching and learning materials, research materials, computing resources and sensor services to support the community" (67.19%) and "collaboration and communication tools" (65.63%).

Generally, taking the analysis of SPSS and WarpPLS together, it can be concluded that all the services were identified as being highly useful and those NREN services are useful in assisting in improving research output. These results are in line with Ogunmakin (2018) who found NREN services are considered a vital tool to improve research output as they can provide a cost-effective platform for the researcher to share resources and applications. Critical examples provided by Ogunmakin related the NREN services that can be used by researchers include web-based information retrieval and the electronic materials that can improve the quality of research. Other researchers such as Mtebe (2015) and Warugaba *et al.* (2016) agree that the primary mission of higher education should also be research in addition to education and NREN assisted service improves the quality of research and higher education. Moreover, researchers Bornman (2018) notes that NREN services and networked services such as AAI, storage, hosting, video conferencing, eScience infrastructure services, grid computing, storage and others are used by researchers to collaborate and work together to improve the research output.

6.5.6. HPC and RCF and its Relationships with Research Output

The analysis of the data in Section 5.5.2.2 shows that, the availability of High-Performance Computing (HPC) and access to RCF enables researchers to conduct computing power intensive research and support researchers in improving their research output. **This is supported by the findings of the SPSS analysis too.** As indicated in Section 5.3.16 and Figure 5. 44 (b and c), access to RCF (91.48 %) and HPC services (91.48%) would assist the researcher in doing research activities that are currently impossible, which indicates that the lack of both facilities was both identified as potential inhibitors to research accessibility and enablement. Overall, taking the analysis of SPSS and WarpPLS together, it can be concluded that both access to RCF and access to HPC was identified as being highly useful for researchers in assisting to improve the research output.

These results are in line with Ezell and Atkinson (2016), Don Johnston (2014) and Apon *et al.* (2015) who explained the use, applicability, and necessity of HPC and RCF to improve the quality of research in various sectors including higher education. As mentioned earlier, higher education in developing countries lacks those advanced infrastructures to conduct research, which has an ultimate impact on the output of intellectual property and research from these countries.

Thus, having addressed the key factors and their impact on the quality of education and research output, it is now essential to delve into the consequences of Ethiopian higher education institutions.

Mainly, the effect of these critical factors on the formation of NREN actors in improving the quality of education and research output considering the case of EthERNet will be looked at.

6.6. Actor-Network Theory to depict NREN service implementation requirement in higher education

This section covers the fifth objective of the study, which is to assess how Actor-Network Theory (ANT) concepts can be used to understand NREN service requirement within Ethiopian higher education institutions and to trace and explain actors influencing the required NREN service, their relative importance and their relationships. The section also investigates the role of NREN actors in improving the quality of education and research output considering the case of EthERNet, in Ethiopia by providing the required NREN service. The actors, through their extended network and aligned interest, improve the efficiencies of Ethiopian higher education, which in turn assist in the development of socioeconomic of the country. Nevertheless, only a few types of research have been carried out in trying to understand the role of NREN in improving the quality of research and education in developing countries.

The objective of this section, therefore, is to address this knowledge gap by analysing the study conducted using the quantitative method discussed in chapter 4 at Ethiopian higher education institutions. In this study, we explored the EthERNet project introduced by the Ethiopian government investment to connect 36 public higher institutions in its first phase and examine how the member institutions can fully utilise it. The formation and extension of EthERNet went through various projects, through different stages of identifying the various negotiations, roles, actors, and their interest alignment. In understanding the various phases, Actor-Network Theory (ANT) is used to explore how the EthERNet project can assist researchers and educators at Ethiopian institutions of higher learning. Additionally, actors in the network were identified and enrolled to create a network of aligned interest. The study also identified several challenges such as lack of reliable network service from EthERNet, lack of ICT policies and strategies, lack of required NREN services from EthERNet and poor campus network infrastructure that may impede the network building process. Furthermore, we learn from this study that a strong NREN has a significant impact in supporting research and education activities of one country.

This section addresses how different NREN actors and networks improve the quality of education and research output. Online surveys illustrated in Chapter 4 were used to explore the role of NREN in improving the quality of education and research output at higher education institutions. The research relied on the use of the actor-network approach in understanding the development and extension process of EthERNet and validating the proposed theoretical framework in the study. Despite the existence of numerous challenges, it was noted that NREN could positively impact on teaching, learning quality and research output.

The identification of ANT's actors involved the use of feedback from four study groups: researchers, lecturers, EthERNet staff members, and ICT directors, who participated in the survey. The study elaborated on how the ANT actors affect each other while at the same time maintaining the implementation of the NREN services. It is critical to note that the stabilisation and construction of the naturally dynamic ANT actors aim at the achievement of validating the proposed theoretical framework in Figure 3. 2 and identifying the actors affecting the use of NREN services in Ethiopia's institutions of higher education.

The study evaluates critical information that makes it a source of referenced analytical processes that future NREN services can use as a guide in the implementation of studies, with the help of the proposed theoretical framework and the study results. Once the actors are identified, their participation in the project and the extent to which they are aligned in terms of the attributes can be used to assess the implementation requirement of both the NREN and member institution to use the NREN services. Theoretically, this paper provides evidence that sociological theories such as ANT can be used to complement traditional technology implementation requirement, adoption, and use models.

6.6.1. Proposed Concept of Actor-Network Theory (ANT)

In this section, the use of ANT assumes the role of an auxiliary theoretical framework. Generalised symmetry, which accounts for both human and non-human actors, forms the basis for ANT's philosophy.

In the study of the impact of NREN on education, research studies have to focus on both interests of human elements such as readiness, as well as non-human attributes. As a result, the impact of NREN relies on a complicated network that includes interrelated actors, a component that calls for the full use of comprehensive analysis in the study. The separation of technical and human participants into groups of disconnected camps relies on the assumption that the two elements remain mutually inclusive in nature and unidirectional (Sánchez, 2016).

Alternatively, in this section, the impact of NREN is viewed as a social and technical network that includes many actors working together with heterogeneity. As such, it becomes critical to employ a presumption that does not oblige the adoption of a prior philosophical approach on the actors, to enable the researcher to maintain objectivity and openness to the ideology of interactions among the actors. This enabled the investigator to comprehend the actors and their influence on EthERNet, as well as the improvement of the quality of research and education output provided and in adherence to the higher education institutions of Ethiopia.

This study adopted the three ANT concepts; problematization, inscription and Obligatory Passage Point (OPP) as illustrated in Figure 6. 1. The visual representation of the ANT concepts shows the research model as used in studies.

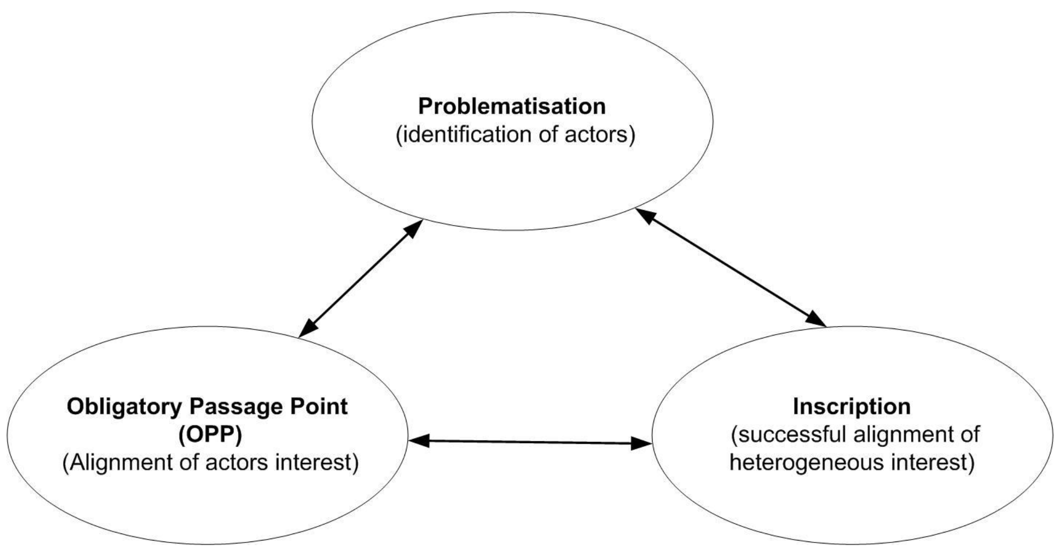

Figure 6. 1: Research Model

The section below is a discussion of the proposed ANT concepts and discusses problematization as a component of the translation process.

6.6.1.1. Translation

Translation refers to, on the one hand, the steps involved in the identification and alignment of interests of various actors, including the principal actor and those of less influence. On the other hand, research experts can also define translation as the process involving the creation of a network that supports its actors (Páscoa and Tribolet, 2016).

Translation denotes the procedure that the actors participate in to enhance their understanding and adaptation of the conduct of the remaining actors, as well as how they interact with each other (Alasuutari, 2015). Four main components constitute translation; interessement, mobilisation, problematisation and enrolment (Gunawong and Gao, 2017; Thapa, Budhathoki and Munkvold, 2017; Trotter, 2014). This section of the research study is unified only to the concept of problematisation, citing its importance in the achievement of the NREN services. Therefore, the remaining three components: enrolment, interessement and mobilisation, do not feature in this section.

Problematisation denotes the route taken by the main actor towards the definition of interests and then allows the minor actors to identify their intentions too, before aligning the two (Mwenya and Brown, 2017). The declaration of interests' process ensures that the principal actor remains motivated in the definition and solving of the problems as set out in the network proposal (Gunawong and Gao, 2017). In other words, problematisation defines agreements and association of a system as shared among actors (Alasuutari, 2015). During the process of problematisation, actors may or may not choose to behave in an alternate manner, one that does not enhance research (Bilodeau and Potvin, 2016). As a result, it is vital to ensure the alignment of interests of all actors in the network (Avgerou and McGrath, 2017). Although some actors may opt-out of the research, those that remain should be willing to participate fully (Gunawong and Gao, 2017). It is the variation in the behaviour of actors that forces researchers to follow the concept of problematisation (Bilodeau and Potvin, 2016).

6.6.1.2. Obligatory Passage Point (OPP)

Various sources define OPP as the procedure involved in the engagement of actors within a network to ensure the satisfaction of their interests (Alasuutari, 2015; Iyamu, Hamunyela and Mkhomazi, 2014; Alexander and Silvis, 2014). The functionality of OPP enables the component to pave the way for the alignment of actor interests within an informal network. However, OPP bases its work on the satisfaction of the actor (Boelens and de Roo, 2016). In other words, OPP has to ensure that all actors remain convinced of their interests and for the interest to remain a priority (Shrafat, Alrawabdeh and Ababneh, 2016). According to Mwenya and Brown (2017), it is only through the adoption and implementation of OPP that the interests of all actors can be met. Additionally, Paledi and Alexander (2017) maintained that the human and non-human factors considered in the interest translation process hold so much power, so much so that it becomes the pivotal network. There is an implication that the absence of the actor would lead to the existence of a vacuum within the network, avoid that could stall not only the NREN impact but also result in faulty analyses.

6.6.1.3. Inscription

Inscription materialises in an environment where the stability of the network is assured (Paledi and Alexander, 2017; Latour, 2017; Shrafat, Alrawabdeh and Ababneh, 2016). In other words, inscription denotes the process that invokes the engraving of knowledge, ideas, values, and beliefs for the design and implementation of new artefacts that guarantee the protection of the interests of the actors. Therefore, the inscription of artefacts should not be a blinded affair. Instead, researchers should remain in line with the beliefs, ideas, assumptions, and knowledge of the innovations (Shimizu, 2017). To achieve successful inscription, proper alignment of the different interest is a compulsory observation (Chen *et al.,* 2009). The application of the concept of the inscription in recent studies involving information systems suggests that some considerations of the process include the actor's patterns, the role of the users, the technological functionality, all who work in unison with the technological availability (Shimizu, 2017; Rydin and Tate, 2016; Eze, Dean and Chin, 2014). For instance, the actors could decide to compile new designs and policies of the NREN services in a process often subjected to the inheritance of the use of technological patterns, expectations, and organisational beliefs over the functionality of the innovation. Therefore, this study views inscription as a path towards the evaluation of the strength of the interactions of the actors.

6.6.2. Scope

In this study, inscription aims at suggesting the appropriate NREN services required in higher learning institutions. Not only does the assessment involve planning but also incorporates the preparation of data that will come in handy in the project's advanced stage. ANT's assumption of problematisation enables the investigators to identify and elaborate on how actors influence NREN services and the comparative value of their correlation. As indicated earlier, the limits of this thesis circles around the process of problematisation because it requires preliminary assessments of NREN services and its gains to the end-user.

6.6.3. Methodology and participants

The analysis of this study adopted the quantitative research methodology, as described in chapter 4. The study aims at investigating the impact of NREN services following the requirements of the end-users at the higher education institutions in Ethiopia. The employment and adoption of this research approach in the examination of NREN services are selected to understand the participants' perception. This is opposed to the qualitative approach, which emphasises on a participant's lived experience regarding how the services they can obtain from the use of NREN services. The data used in this study were from both human and non-human actors to provide more insights on NREN services and to validate the proposed theoretical framework.

The data collection and analysis had to occur within the locality, to ensure that the information analysed in the study reflected the real situation on the ground and not mere heresy or assumptions. To examine the impact of NREN services among the participants, the study relied on the use of purposive sampling, as explained in Section 4.6.

6.6.4. Result

Since the study used the ANT as a methodological lens, the presentation of this project study's findings maintained the format used in the categorisation of ANT concepts as shown in Figure 6.1, which involve problematisation, inscription and Obligatory Passage Point (OPP), as discussed below.

6.6.4.1. Problematisation

The identification of both internal and external actors that work towards the success of NREN services resulted from the data provided by researchers, educators, and ICT directors, through the questionnaires they answered. All three categories of respondents participated in the identification of actors and the validation of the proposed theoretical framework. Below are three perspectives provided by the participants regarding NREN services actors and their interaction with each other.

1. Educators' /Lecturers Perspective

The term Lecturer is used for all the academic staff involved in teaching. The tutors' responses provide evidence of a strong connection between them and the other actors, including learners within the network. The first relationship that was noted was between Lecturer and online materials. As indicated in Section 5.2.2, most of the responses on the frequency of accessing online materials and/or data to support the teaching learning process revealed that academics in Ethiopia (92.21%) need to access online materials.

A further relationship was noted between lecturers and students. As indicated in Section 5.2.3, most of the academic staff (72%) want to provide materials online regularly to support their students. Thus, there is evidence that the teachers enrol students into the actor-network. The other connection observed between the campus and the network provider on the campus.

As indicated in Section 5.2.7, most of the academic staff require several education-related networked technologies and services, which are useful for their teaching learning purposes. The lecturers indicated that the technologies identified and used to provide technology assisted teaching and learning is very useful service required by educators (83% +), and the university should provide the required networked services. In this case, there is proof that there is an indirect association between the actors. The tutors are responding to the needs and importance of an actor that they are not directly linked. In this case, there is proof that the actors may influence the associations of other actors to which they are indirectly related. The teachers, in this case, may account for issues that they observe to actors over which they do not have control. Also, some of the above-mentioned required services such as Massive Open Online Courseware, the capability to use their credentials to log in at another institute and video or web conferencing services can be provided centrally as a private cloud service from EthERNet for the universities. Therefore, EthERNet can provide the required NREN service for member institutions in an organised and reliable manner.

From the analysis of the lectures' questionnaires, actors such as PCs, laptop, tablets and VDI solutions are embedded within the university actor, which are called electronic devices. However, these are one of the key actors from the lecturers' perspective as they indicated that there is a need for these end user PC devices for students to enable them to access digital contents online. Due to their invaluable use, the university needs to avail themselves of these electronic devices as this will give them access to the online educational resources to assist the teaching and learning process.

Lastly, there is a relationship between universities and reliable institutional network/campus network. The educators' responses are evidence of a strong relationship between the university and the ICT infrastructure, mainly the standard campus network. As indicated in Section 5.2.10, approximately 68% and 80% of the study participants agreed that their campus connectivity service would have an impact on the educational delivery. Network reliability is the main issues highly ranked by the respondents. Accordingly, it is the responsibility of the university to avail itself of a standard and reliable institutional/campus network to make ICT infrastructure available to the lecturers and students.

Table 6. 1 summarises the relationships between the actors from the lecturers' perspective.

Table 6. 1: Actors' Relationships – Lecturers’ perspective

Actor 1	Relationship	Actor 2
Lecturers	Access	Online materials
Lecturers	Provide online materials	Students
University	Provide	Networked Services
EthERNet	Provide	NREN services
University	Avail	Electronic device
University	Avail	Reliable institutional network/campus network

Figure 6. 2 gives an overview of the actors’ relationship from the lecturers’ perspectives, which is also similar to the actors/constructs used to develop the theoretical framework in Figure 3. 2.

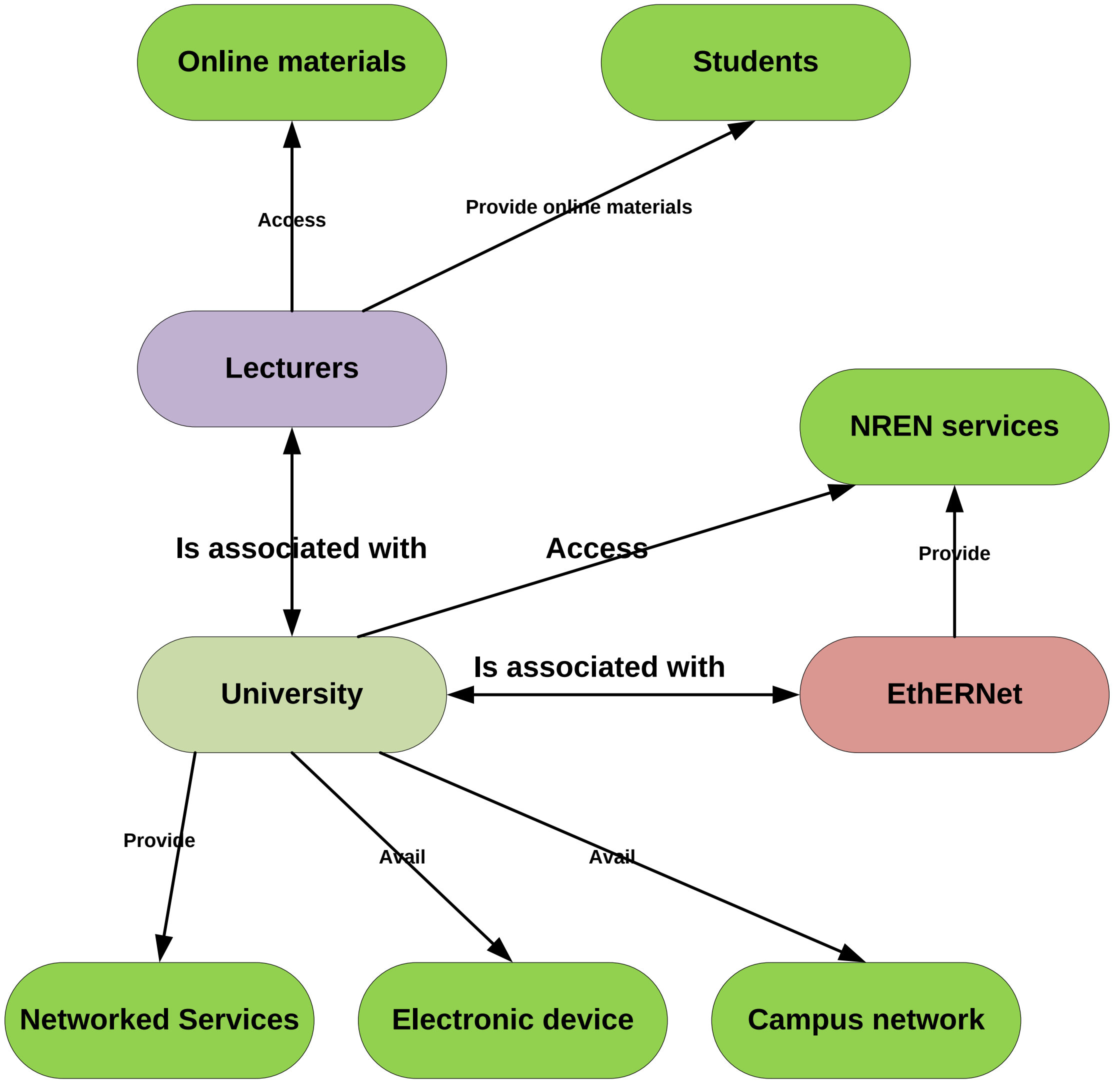

Figure 6. 2: Actors' relationships – Lecturers' perspective

2. Researcher Perspective

As per the responses from researchers, there is an association between them and other actors identified in the network, which will assist in determining the required service for the researcher to improve their research output. This encompasses the development of a detailed requirement plan on how the required NREN service and other infrastructure will be implemented. From the analysis of the researchers' questionnaires in section 5.3.4, the latter wants to collaborate with other researchers both nationally and internationally.

The other relationship that was noted was between researchers and online materials. As indicated in Section 5.3.8 -15, in respect of the frequency of accessing online materials/journals/conference materials/data set/sensors to support their research process researchers revealed that a significant number of researchers in Ethiopia need to access those mentioned online materials.

A further relationship was noted between the university and local computing facilities. As indicated in Section 5.3.16, majority of them require the local computing facilities to support their research work. Also, researchers require access to HPC infrastructure facilities which will be used to assist their research activities required intensive computing resources. Hence, EthERNet should provide HPC infrastructure, which requires huge investment, but provides the necessary service for the universities.

Like the lecturers' responses, the researchers indicated that the university should provide a networked service used for research activities. As explained in detail in Section 5.3.17, most researchers (minimum 92.25%), responses show that all the networked research services are all required by the respondents. Besides, some of the mentioned networked services for research such as Video or web conferencing services, login into other organizations using the local credentials or single sign-on, access to storage space, collaboration and communication tools and large file transfer applications can be provided centrally as a private cloud service from EthERNet for the universities. Therefore, EthERNet can provide the required NREN service for member institutions in an organised and reliable manner. In this case, there is proof that an indirect relationship lies between the actors. Researchers are making comments on the importance of an actor with which they are not directly associated. Therefore, there exists proof that those actors can influence the relationship of other actors to which they are not directly related. The researchers in this scenario may report the required networked service for research, which can be provided by both universities and EthERNet to the actors that control it.

Like the lecturers' questionnaires analysis, actors such as PCs, laptops, tablets and VDI solutions are embedded within the university actor, referred to as electronic devices. Nevertheless, these are identified as one of the key actors from the researchers' point of view show that there is a need for these electronic devices to have online access for the research work and research services.

Accordingly, the university should avail themselves of these electronic devices for researchers to assist in their research activities.

Finally, there is a relationship between a university and a reliable institutional network/campus network. The researchers' comments are proof of a strong connection between the ICT infrastructure, standard campus network and the university. As indicated in Section 5.3.19, 74.42% of the respondents agreed that four problems concerning the network they use for research would have an impact on their research activities. The top-ranked issues were related to network reliability, security, and privacy. Accordingly, it is the responsibility of the university to provide standard and reliable institutional/campus network and make ICT the infrastructure available for researchers. Also, over 90% of respondents agreed with the significant impact of a reliable network on research at a national and international level, which will also enable the establishment of new partnerships and collaboration with their counterparts around the globe. Accordingly, reliable, and EthERNet should give sufficient Internet bandwidth to the universities.

Table 6. 2 summaries the relationships between the actors from the researchers' perspective.

Table 6. 2: Actors' Relationships – Researcher' perspective

Actor 1	Relationship	Actor 2
Researchers	Collaborate	Other researchers (national and international)
Researchers	Access	Online resources
University	Avail	Local computing facilities
EthERNet	Provide	HPC
University	Provide	Networked Services
EthERNet	Provide	NREN service
University	Avail	Electronic Devices
University	Avail	Reliable institutional network/Campus network
EthERNet	Provide	Sufficient Internet bandwidth

Figure 6.3 gives an overview of the actors' relationships from the researchers' perspectives. Similarly, this figure also validates the actors/constructs used to develop the theoretical framework in Figure 3. 2.

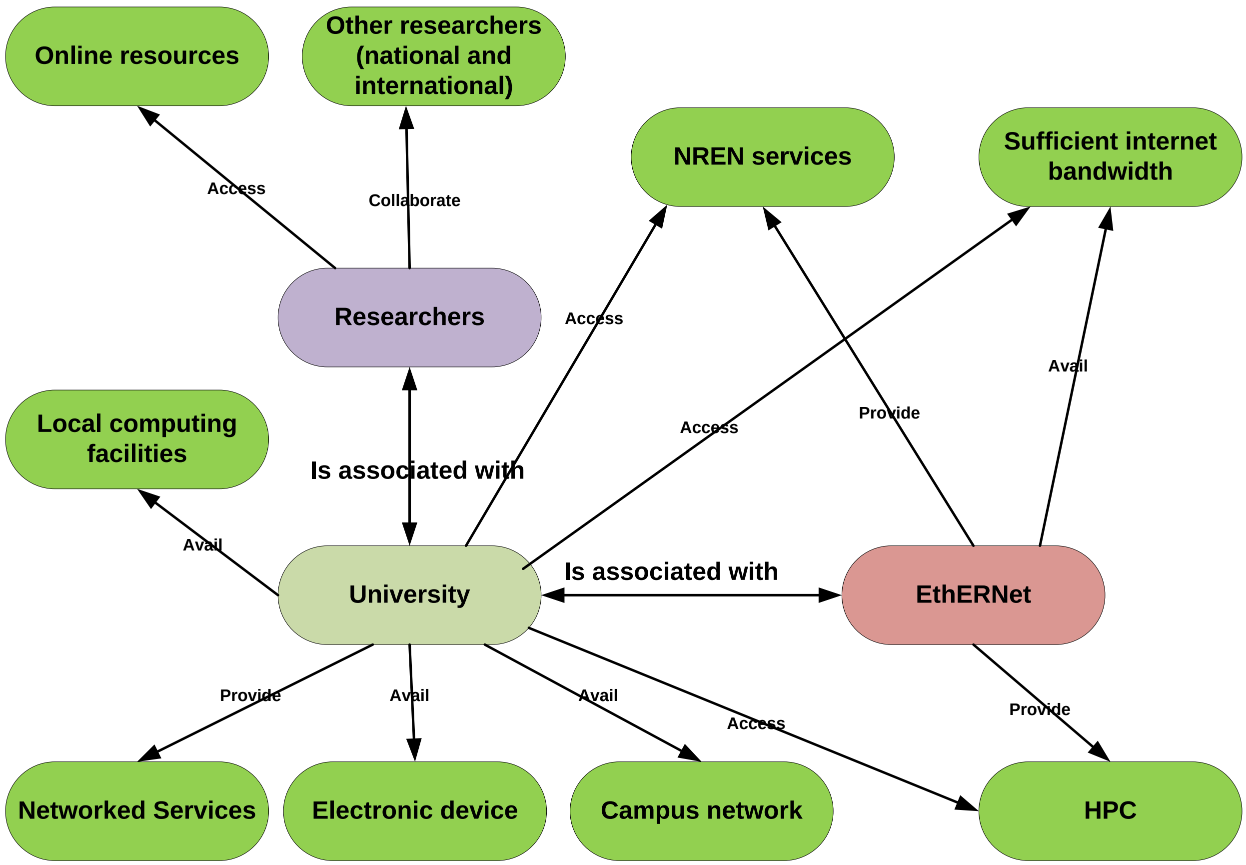

Figure 6. 3: Actors' relationships – Researchers' perspective

3. ICT Directors and EthERNet Perspective

The empirical data collected from the ICT Directors of the universities introduced additional actors such as Institutional ICT Policy, retention mechanism for ICT staff, skilled ICT staff, sufficient Internet bandwidth, support and maintenance, ICT Directorate, ICT strategy and sufficient budgets for ICT to assist in the network. The ICT Directors department indicated that there is a strong connection between actors identified.

The ICT directors believe that the university should implement ICT Policy and strategy because, without the policy and strategy, it might be difficult for the university to allocate the required budget for the implementation of the required ICT infrastructure and services. Therefore, it is critical to obtain such implementation.

The ICT Directors responses are evidence of a strong relationship between the university and the availability of a reliable institutional network/campus network. As indicated in Section 4.4.2, most of the respondents (95%) are interested in improving the institute's network infrastructure/-campus network considering that they can easily access secure and reliable network. Hence, it is the responsibility of the university to make the institutional ICT infrastructure available to the university communities (students, educators, and researchers). Besides, there are required services from the end-user, which can be provided by EthERNet as a private educational cloud service for the universities including but not limited to, video conferencing services, collaboration tools, online learning environment (LMS), MOOCS and digital library amongst others. Therefore, EthERNet should provide those NREN services to the universities. Moreover, EthERNet should implement ICT Policy and strategy, used for both EthERNet and universities. Still, without these policies and strategy, it is difficult to get continuous funding and support from the Government to provide the required NREN services and ICT infrastructure for the member institutions.

The respondents also provided evidence of a strong association between the campus and ICT policy and strategies. As indicated in Section 4.4.3, among the main challenges/barriers in using EthERNet to provide ICT services used for research and education purposes were unavailability of Institutional ICT Policy (80%), Institutional ICT Policy not being implemented (80%), unavailability of Institutional ICT strategy (60%), Institutional ICT strategy not being aligned to the corporate strategy (52%) and difficulty of ICT strategy implementation (64%). Therefore, for the university to implement the required ICT infrastructure and services, there should be an ICT strategy, which should be aligned with the corporate strategy of the university to get top management's attention and budget allocation from the university. Also, there should be an institutional ICT policy to manage the ICT infrastructure and service in an efficient way.

The other relationship noted is that between the university, retention mechanism for ICT staff and Skilled ICT staff. As indicated in Section 5.4.3, among the main challenges/barriers in using EthERNet to provide ICT services used for research and education purposes is lack of retention mechanism for ICT staff (80%) and lack of skilled ICT staff~~s~~ (76%). Hence, the ICT directorate should set up a strategy on how to retain ICT staff and recruit skilled ICT staff and make proposals to the university top management for approval and implementation.

There is evidence that without proper Internet connectivity, providing the required services for the users in the university, the strategy will not be successful. Besides, a distant relationship was noted between EthERNet and support and maintenance. As indicated in Section 5.4.3, majority of the ICT directors (64%) in the university claim there is insufficient support from the network provider. Accordingly, EthERNet should provide reliable support and maintenance for its member institutions.

The other relationship identified was between the top-level management of the university actor and support for ICT directorate and the allocation of sufficient budget for ICT actors. As indicated in Section 5.4.3, the main challenges/barriers for the majority of the ICT directors in using EthERNet to provide ICT services used for research and education purposes were lack of support and commitment from top level management (52%) and lack of sufficient budget allocated for ICT (64%). Therefore, the top-level management of the university should be committed to providing the necessary support and attention for the ICT directorate and assign sufficient budget for the intuitional ICT infrastructure implementation.

Table 6. 3 summarises the relationships between the actors from the researchers' perspective.

Table 6. 3: Actors' Relationships – ICT Directors perspective

Actor 1	Relationship	Actor 2
University	Avail	Reliable institutional network/Campus network
EthERNet	Provide	NREN service
EthERNet	Implement	ICT Policy and Strategy
University	Implement	Institutional ICT Policy
University	Implement	ICT strategy
University	Set strategy for	Retention mechanism for ICT staff
University	Recruit	Skilled ICT staffs
EthERNet	Provide	Sufficient Internet bandwidth
EthERNet	Provide	Support and Maintenance
Top-level management	Support	ICT Directorate
Top-level management	Allocate	Enough budget for ICT

Depicted in Figure 6.4 are the visualised actors' relationships from ICT Director's perspective.

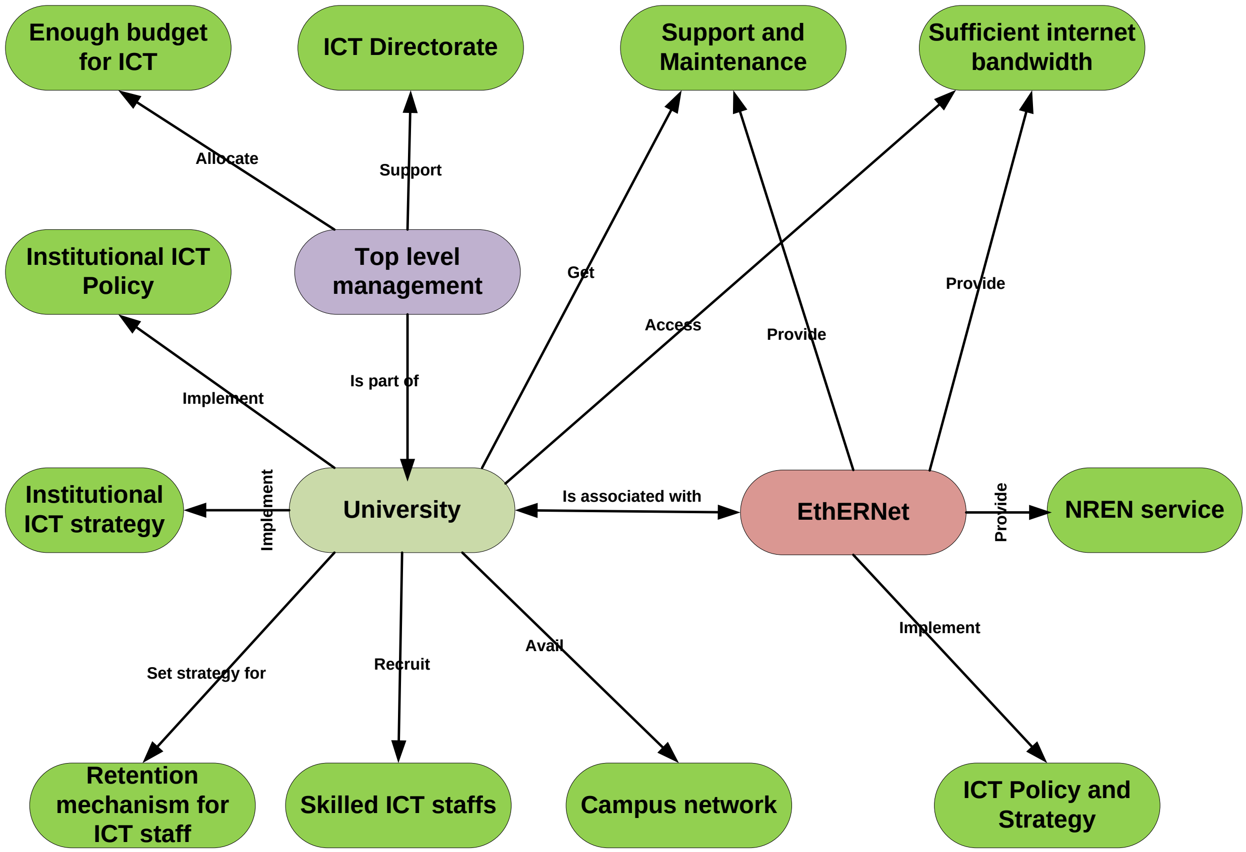

Figure 6. 4: Actors' relationships – ICT Directors and EthERNet perspective

6.6.4.2. Obligatory Passage Point (OPP)

From the discussion in section 6.2.2, the institution of an Obligatory Passage Point is indicated as a crucial facet of the ANT. OPP is depicted as a scenario, which occurs among the actors in the satisfaction of interest given to them by the principal actor (Alexander and Silvis, 2014). In this research, there is adequate evidence that OPP changes in the future as the network stabilises. For example, to implement and provide the required NREN service for end-users, as discussed in Section 5.1.3, there should be an ICT policy and strategy from EthERNet where the actors agree on how NREN service and required ICT infrastructure should be provided. Therefore, the implementation of the ICT policy and strategy by EthERNet is the OPP of the network. Thus, when there is an alignment of actors to an OPP actor at this phase, it is expected that to a certain extent, the interests of the principal actor shall be brought to them, and this prepares them in responding appropriately. For example, “NREN service is to help in understanding what is expected”.

The second OPP that was proposed in this study is the campus network/ reliable institutional network. There is evidence that without a proper and standard campus network infrastructure, end-users will not get the required NREN service from EthERNet. The campus network infrastructure must be available, maintained, and accessible by all stakeholders in the universities. Thus, for learners, tutors, and researchers to participate in the use of NREN service issued by EthERNet, there is a need to have a reliable network connection on the campus.

Figure 6.5 shows an example of actors aligning themselves to the OPP.

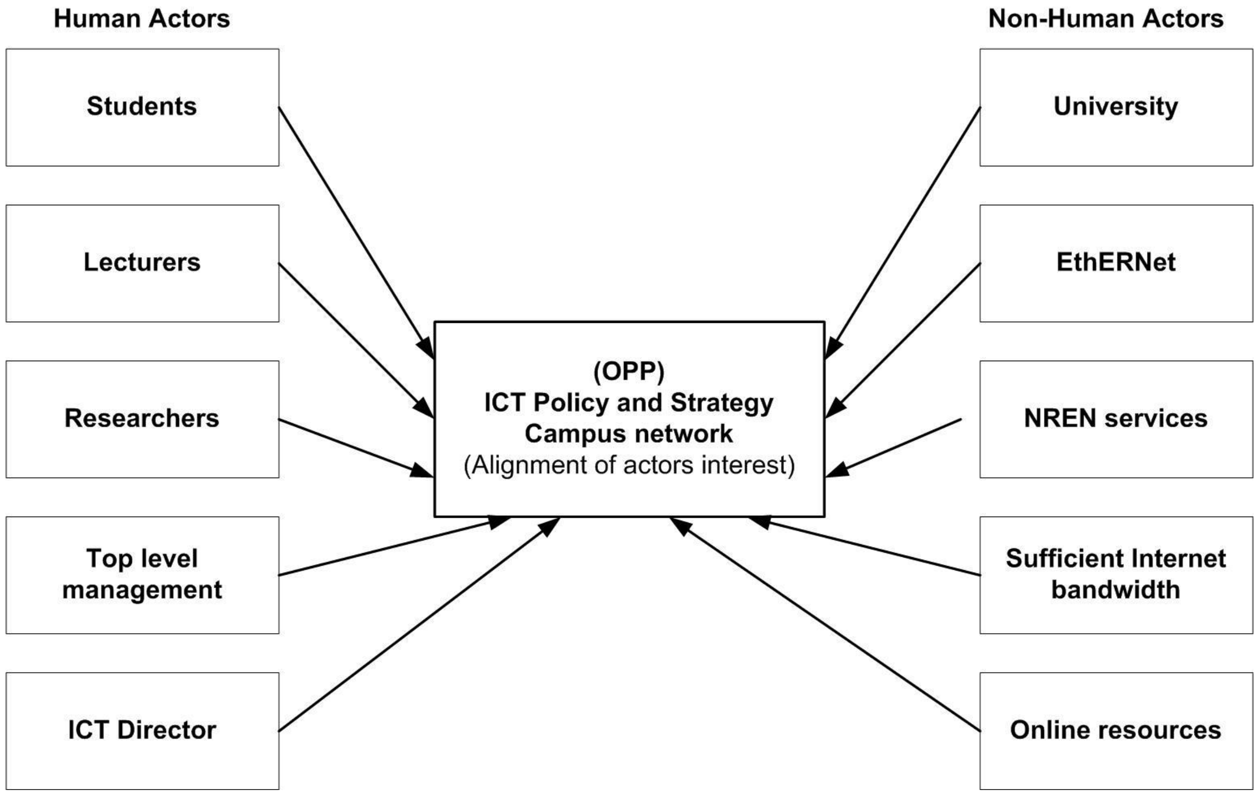

Figure 6. 5: Alignment of Actors to OPP

Figure 6.5 shows how ICT policy and strategy actors and the university actor (OPP) align the interest of the principal actor with the other actors. Nevertheless, the actors can decide not to be included in the network if interests are not clearly defined and aligned.

6.6.4.3. Inscription

The previous discussion shows that an inscription is obtained in the identification of the latent variables, which assists in the successful alignment of the different interests. Because of an enormous number of quotations in the information and limitation of the work, only references and attributes to the cases that support the empirical data are presented. Table 6.5 shows possible attributes that can support learning in the actor-network, which includes training, awareness creation, understanding user requirements, budget, power supply, off-campus accessibility, collaboration and resource sharing, last mile connectivity and commitment of ICT staffs. These attributes were observed in the participants' comments, which are outlined as the means in stabilising NREN. Some of these attributes are addressed in the subsequent sections.

Table 6. 4: The Attributes for facilitating and stabilising of Actor-Network

Attributes	Supporting Cases
Capacity building/training	Section 5.2.11, 5,3,2, 5.3.20, 5.4.3
Awareness creation	Section 5.3.2, 5.4.3
Understand user requirement	Section 5.2.7, 5.2.10, 5.3.17, 5.3.19
Budget	Section 5.4.3
Power supply	Section 5.2.10, 5.3.2, 5.3.19, 5.4.3
Off-campus accessibility	Section 5.3.19
Collaboration and resource sharing	Section 5.2.11, 5.4.3
Last-mile connectivity	Section 5.4.3
A commitment to ICT staff	Section 5.4.3

The above nine attributes are from the participants' comments, which are outlined as the means in stabilising NREN.

6.6.5. Findings

6.6.5.1. Problematisation

According to the research findings, the enrolment of human actors such as learners, tutors and researchers have been identified as evidence that these actors are the key actors in the network. Nevertheless, the collected information shows the need for the enrolment of more human actors. These include management and ICT Directors, and the data also confirms the importance of non-human actors, which are NREN, EthERNet and the University Campus.

As stated, without having reliable Internet connectivity and ICT infrastructure end-users at the universities could not access the NREN service provided by EthERNet. This study indicates that for the university to access the NREN service provided by EthERNet, it must find ways to facilitate the end user's access to the resources and learning the material through electronic devices inside the campus.

6.6.5.2. Obligatory Passage Point (OPP)

From the finding of the study, it can be deduced that it is crucial to establish OPP to enhance alignment of the interest of the actors to those of the principal actor. Therefore, OPP is not static and is expected to keep changing as the network stabilises. The implication is that at NREN stage implementation, new OPP emerges.

6.6.5.3. Inscription

For the actor-network to stabilise, it was noted that there must be a successful alignment of the actors' heterogeneous interest. Vaughan, Buja, Kruczkiewicz and Goddard (2016) and Emdon, Elder, Petrazzini and Fuchs (2014) established that several attributes could influence the alignment of heterogeneous interests such as capacity building, enhanced training, awareness creation, understanding user requirements, budget, power supply, off-campus accessibility, collaboration and resource sharing, last mile connectivity and commitment of ICT staffs. For instance, capacity building ensured that there was a high level of commitment in the development of reliable networks that could support the quality of education and research output (Emdon, Elder, Petrazzini and Fuchs, 2014). These could provide insights on how the NREN could be used to improve the quality of education and research output.

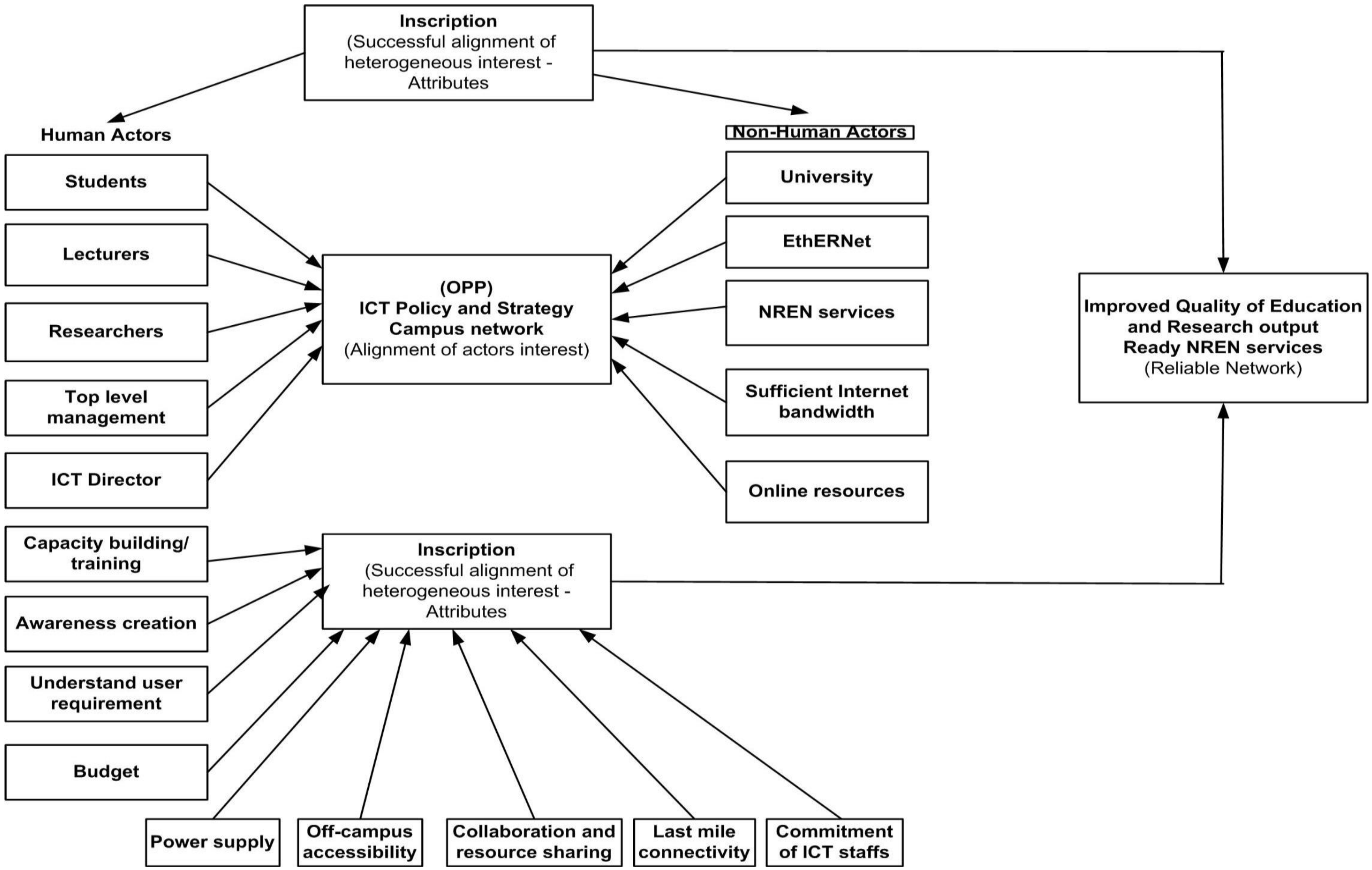

Figure 6. 6: The Proposed ANT Model

Figure 6. 6 depicts the proposed ANT model. Generally, the proposed ANT model and Figures 6. 2- 6. 6 identifies more actors that should be involved to develop the NREN service portfolio and roadmap. Additionally, those Figures and the ANT model confirm the result. Theoretically, they validate the proposed theoretical framework in Figure 3. 2. Most of the identified constructs of the proposed framework are valuable for the development of the NREN service portfolios and roadmap for EthERNet.

This section contributes to literature in two different ways, namely; (i) proposition of an analytical procedure that could be used in guiding the future NREN service needs in enhancing improvements in the quality of learning and research and (ii) supplements the traditional adoption of technology as a method of assessing technology end-user requirements. This is opposed to theories such as ANT, which complement different views by providing a perspective of the NREN services.

Overall, the outcome of the research shows a broad-variety requirement for many technologies and services used for education and research activities which are not yet provided by EthERNet. EthERNet should also emphasis on providing technologies and services used to enhance the educational quality and output of research to achieve the required target, that assist in improving the quality of education and increasing the research output at Ethiopian public higher education institutions.

6.7. Summary

The research findings of Chapter 5 were analysed, discussed, and presented in this chapter concerning the three research questions and objectives posed. The chapter also discussed the quantitative findings of the study, according to the objectives. It integrated the analysis of the findings by both SPSS and WarpPLS and linked them to previous studies. It also covered the critical issues including the challenges faced by Ethiopian higher education institutions, the impact of capable NREN/EthERNet to improve quality of education and research output and analysed the factors influencing the relationships amongst actor-networks in improving the quality of education and research output at Ethiopian higher education institutions. The descriptive analysis from SPSS results is like the structural equation model results from WarpPLS. This confirms the reliability of these findings and the effects of the critical success factors in improving the quality of education and research output.

The chapter also illustrates how ANT theory and SWOT analysis inform the user requirements and challenges affecting the need for NREN service in Ethiopian institutions of higher learning. A SWOT analysis was used to group the services needed by the end-users into two categories, namely short-term and long-term factors, which can be used to create a roadmap. On the other hand, the main actors in the study were identified from the respondent's comments as the key players in NREN service requirements within the context of university learning. The chapter also deals with three major concepts relating to ANT, namely OPPs recognition, the problematisation and inscription process. The thesis focused only on NREN actors that are found in the university, which are ICT directors, researchers, learners, and educators.

Chapter 7: Proposed NRENs Service Portfolio and Roadmap for EthERNet

This chapter introduces the overlay of the proposed NREN service portfolio and roadmap for EthERNet. It further discusses the details of the services in the proposed portfolio, their requirements and uses cases. The proposed roadmap enhances service delivery and sets the standard for EthERNet and other NREN within a similar context in the developing world. Each section of this chapter answers the research questions, objectives and acknowledges the Literature Review explained in Section 2.14.

The study develops a theoretical framework that identifies and deals with the required NREN services that have an impact on improving the higher education quality and research output in Ethiopia. To justify the developed theoretical framework, the principles a 3-step design science approach is used. The development of the theoretical framework is guided through in understanding the difference between the existing model in literature and the empirical model developed via this study. Face validation is done by using the ANT technique that further enabled the ease of the research since it acts as the platform that harnessed different actors and participants of the entire research process by taking the case of Ethiopian public universities and EthERNet. The theoretical framework is used as a base to develop the service portfolio and roadmap conceived to design the required NREN service for EthERNet. Additionally, Roadmapping and Service portfolio are good examples of IT artefacts, similarly, a well-created and applicable design science would produce a functional roadmap and portfolio for the research (Hevner *et al.,* 2019) as explained in Section 2.14.3.

Moreover, to establish the ability of the proposed theoretical framework in identifying the required NREN services to improve the quality of education and research output, it is examined by surveying one hundred and seventy-two (172) participants drawn from twenty-nine (29) Ethiopian Public Universities. The study further validates the conformity of the proposed theoretical model with the result of the research by applying the PLS-SEM analysis to the collected data. The outcomes reveal that based on the major findings of this study as shown in Figure 5.3 and Figure 5. 28, 92.21% of academics would like to utilise online materials and/or data frequently to facilitate the teaching and learning process and 91.47 % of respondent require to hunt materials online regularly and access a variety of resources online to support their research. Besides, respondents indicated that 83.46% of researchers are not using EthERNet network, as shown in Figure 5.22. Also, the challenges and the reasons for not using EthERNet network are explained in detail in Section 5.3.2 and Figure 5.54.

Additionally, as per indicated in Section 2.14, service portfolio and roadmap are the best way to provide the required NREN services (Comerio *et al.,* 2015 and Hussain, Tapinos and Knight, 2017). All these stresses the need for proposing NREN service portfolio and roadmap to provide the required services for the end-user at Ethiopian public higher education institutions to enhance the quality of research and education output. This is not devoid of the fact that there are other possibilities, which can be used to enhance the research output and the quality of teaching and learning in higher education institutions.

Furthermore, this study emphasizes on the information provided in the literature review on the existing services and the benefits, which NRENs could provide. Through the questionnaire, the outcomes of the analyses also identified the recommendations and means which is used to identify the twenty services requested by the end-users as per explained in Chapter 6. Thus, those services that have been retrieved from end-users' requirements, which have been identified in the questionnaires' responses used for this study is used as a base to design service portfolios integrated with the use cases and a roadmap for EthERNet. Accordingly, the study proposes a detailed service portfolio and use cases for EthERNet to implement those services and provide for member institutions to ensure the quality of education and research output. The primary aim of this endeavour is to allow LDCs (including Ethiopia) to benefit from the NREN paradigm, as these countries currently face insurmountable handicap due to excessive bandwidth pricing and poor network infrastructure, among other challenges, as things stand today. Through the identification and provision of viable recommendations to be implemented in the future, this chapter proposes substantial solutions for implementation.

7.1. Service Portfolio

This identifies the means and gives recommendations that will hopefully be implemented in the future. The primary findings of this thesis were outlined, and services presented in Chapter 6 on Data analysis and Discussions. Thus, this Chapter 7 provides service portfolio development for future implementation and a roadmap for EthERNet that will be implemented in the future application of essential NREN services in Ethiopia, considering into account for the recommendations provided in this study. The previous chapter aims to help EthERNet in identifying and describing packages of primary and critical services essential in supporting Ethiopian educators and researchers in working with colleagues around the globe and contributing to international projects. An emphasis is placed on identifying the services needed by the end-users and the challenges they are facing using NRENs based on the ANT model. In this case, the ANT model is intended to provide a clear roadmap on how the different actors relate to each other.

For this study, the waterfall approach as per indicated in Section 2.14.1.1 and Figure 2. 10 is chosen for portfolios development workflow and design the services as designing of strategic service groups, and service categories become apparent after the first batch of services are provided but would characterise pure presumption if begun parallel to the service design effort (Justin, 2018). The selected approach was to focus on the readily available NREN services, therefore for each of the services that were identified in the study, this chapter has provided an explanation and service deployment plan. Furthermore, in making the portfolio accessible for the EthERNet society, this section finished the exercise by making recommendations of mandatory connectivity services in addition to the deliverable. The connectivity services are technical requirements to provide end-user services. Fundamentally, the services can be administered on the EthERNet level or institutional level, and most of them may be (or already are) mutualised and delivered at the EthERNet level.

Concluding from the research results and findings, this part describes services, which can be input into the proposed roadmap. The services can be categorised in two classifications, which will be addressed in the next part of the document. In ensuring connectivity, the links that are integrated into the differing network pieces should be established and operational, including the EthERNet network and higher education campus network. Single point of failure affects the functionality of the entire network system. Thus, it is crucial to have back-up and redundant links that support different network router or core network and transmission device redundancy.

Preliminary suggestions previously ahead of the implementation of EthERNet high-level services is the sharing of data and checking the level of maturity for each leading network service provider at every point:

- EthERNet must establish the capacity to provide end to end services and connectivity for end users whenever required.
- The information and communication support and services in each higher education must collaborate with EthERNet to have a standard campus network connectivity. EthERNet should help with the technical assessment of these needs.

The above recommendations for EthERNet are to provide a reliable network and cheaper Internet connectivity. Indeed, the higher the capacity in Gbit/s or Mbit/s required when connecting every member institution bandwidth requirement, the lesser the prices on hand. Most of the Ethiopian higher education institutions are generally "younger" institutions and networks. Therefore, EthERNet can help them to access connectivity in a reliable way and at fair prices by allowing hosting on its backbone.

There is a need for every connectivity layer to be operational to implement high-level services. Nevertheless, deployment of the high-level service needs to start immediately to serve users who have requested for the network, so that it works as a teaser for the ones that are not yet ready. The availability of advanced services acts as a lever on the set of connections and thus helps in sharing devices on the national grid. Security is a critical issue in ensuring that the network is operational. EthERNet needs to build a team that ensures best practices are carried out and are relying on various security contacts in every campus or higher learning institutions. Member institutions and EthERNet must put up their CSIRTs per the level of infrastructure and services provided. With the reasoning that various levels of service implementation start from the laptop of end-users, both at equipment and software level, this part gives implementation solutions for every service zone:

- User level: deals with what is required to be implemented for the user to utilise the service.
- NREN level: deals with the global services at EthERNet level.
- Institution level: solutions that need to be implemented by higher education and research institutions level.

It is also essential to take into consideration that the security should back the services provided and monitored by an ICT team.

7.1.1. Network Connectivity Services

The main aim of the NREN is to give all the required education and research services to the communities. Nevertheless, some of the services, such as IT services, are requisites for other services. A reliable network connection is fundamental in supporting other service layers hosted

The study uses an NREN model adopted from Europe as indicated in Figure 2. 1; accordingly, this section proposes the education and research networks connectivity by dividing it into three layers:

- National level connection
- Campus level connection
- International level connection

While proposing the connectivity services, end to end services is aimed at hosting the three layers. It is crucial to focus on the IP before finding solutions to the issues emanating from there. The Internet network operates under Autonomous Numbers AS and IP addresses (IPv4/v6). Hence, the networks have Public IP addresses provided to them:

- At the regional level, it is provided by one of the five RIRs that issue IPs to registered LIRs.
- The LIR then issues IP addresses to each unique client.

Because the AS number is essential to groups of various networks that belong to one business (NREN ought to possess its individual AS), the AS is utilised for BGP protocol routing. The arrangement enables the business holding to be autonomous. Therefore, the owner can initiate various connections with diverse operators without being forced to alter the architecture of the network. In such cases having the ability to own its provider independently referred to in short as “IP”. The IP address is a pre-requisite in the designing of a controlled network.

7.1.1.1. Proposed Campus Network

The initial stage in the provision of connection services to the end-users is connecting their PCs and peripherals. To do this, there should be a network connection that is established on campus and in the research centre. The networks connected should be able to be accessed from any building in the school. Therefore, there should be adequate links and loops created such that each room would have network connectivity through cable or wireless for easy access. All the connections should have one point of control, which is the technical room or data centre. The data centre acts as an intermediary or interface between NREN, the service provider and the internal network.

To ensure that the connection can be used, it is also essential to employ IT services such as firewall security and (DNS, DHCP, IP address plans) and there is a need for on IT engineer to keep monitoring and to resolve any network problems.

1. **Support member institutions**

Currently, all the universities do not benefit from EthERNet as they do not have a standard campus network infrastructure. Hence, member institutions must have a standard campus network to use the service provided by EthERNet and to service their communities on the campus.

The campus networks form the base of any efforts geared towards the development of regional and national education and research networks. The campus network, therefore, needs to be framed in such a manner that it supports research, teaching, learning and administration. The tasks that are involved in accessing content and Internet in general, for example, data management, data protection, managing and reserving bandwidth, training, applications, help desk service, authentication and security should be administered at campus connectivity level.

To benefit from the investment made by EthERNet, member institutions needed to have their standard campus network to be connected to other institutions through EthERNet. The proposed campus should follow all the campus network standards, as depicted in Figure 7. 1.

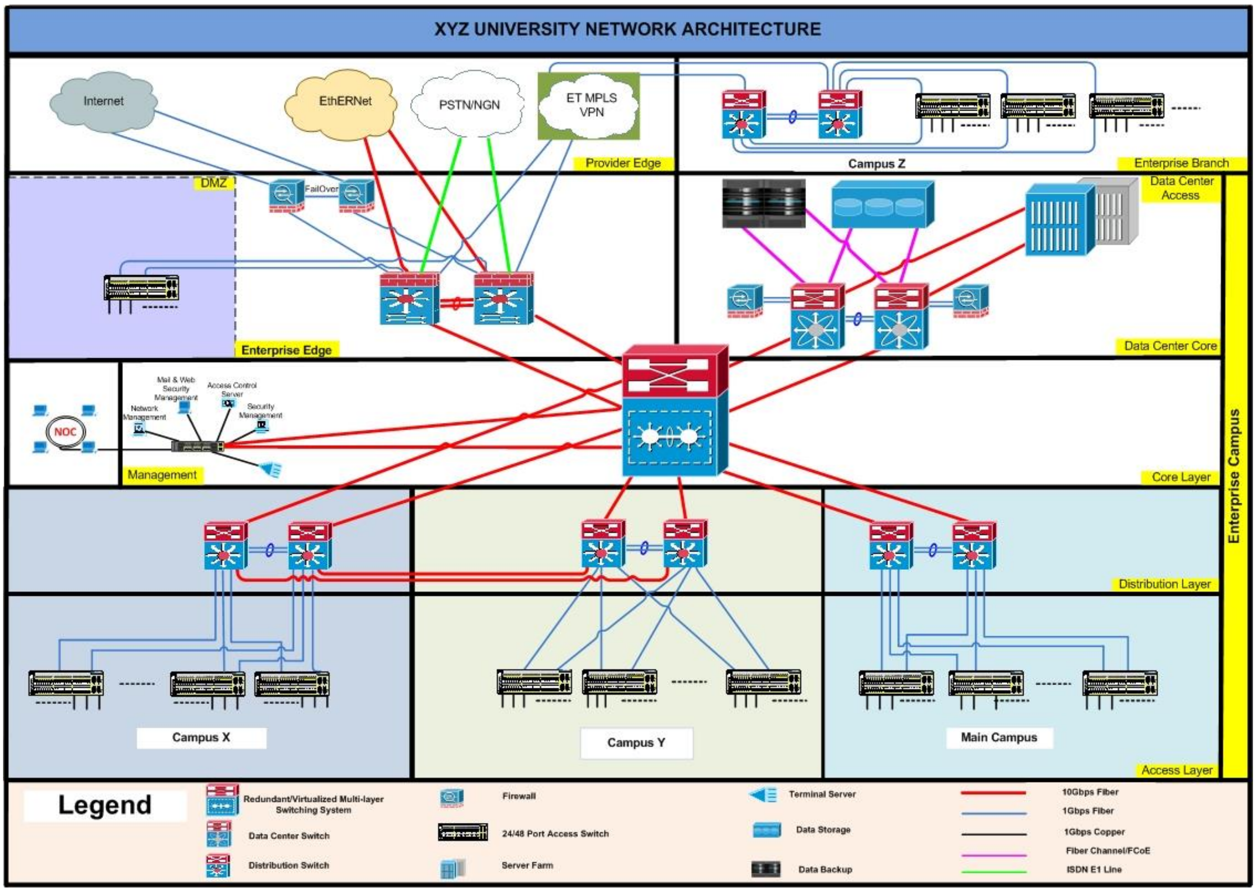

Figure 7. 1: Recommended Standard Campus Network Architecture

7.1.1.2. Proposed National Connectivity

National education and research institutions must be linked to a national grid, which is a role that is performed by NREN. NREN builds a private network among all the research centres and universities. Having such a connection, learning institutions can send and receive scientific and educational data. It is crucial that NREN does implement an Acceptable Use Policy and therefore operates under research and education use.

Because of increasing demand by the end-users to work internationally, NREN must interconnect with RREN at different points. This interconnection provided interaction of all learning and research institutions in the world. To have access to information that is being hosted by commercial networks, NREN should also relate to the commercial networks.

Consequently, an NREN can purchase data from a commercial provider and link it up with its network. It means that NREN has a bilateral peer arrangement that empowers NREN to exchange traffic.

Regarding the management and monitoring of the network connectivity, 24/7 scrutiny of the networks is required to identify faults, outages, abnormalities, and critical events on the connection. NREN, in collaboration with CSIRT, can, therefore, enhance connection security.

1. Making the EthERNet network available and reliable

As depicted in Figure 2. 3, the existing EthERNet transmission network is a single point of failure design and has a ring topology only on the aggregate network. So, the transmission network should be upgraded to a full Meshed network, and the ring topology should increase from 2 to 5 Rings to make the network more reliable, strengthen service availability and avoid a single point of failure. Figure 7. 2 is the proposed and recommended full mesh topology for EthERNet optical network.

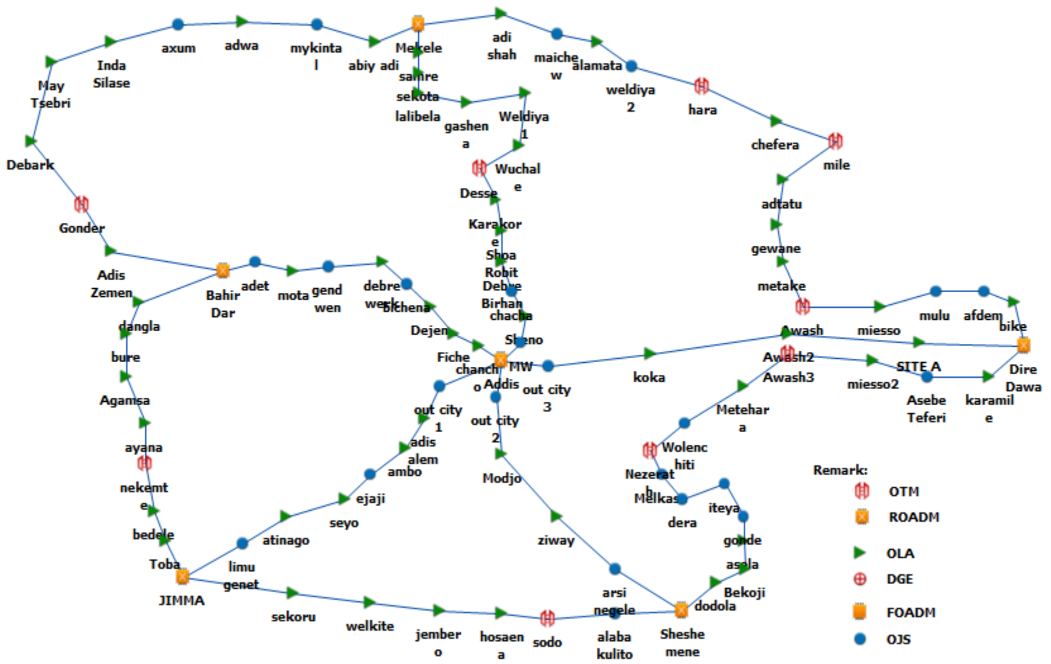

Figure 7. 2: Recommended Full Mesh Topology for EthERNet Optical Network.

As depicted in Figure 2. 2, there is no redundancy for the existing aggregate routers. Here, redundancy should be considered on the aggregate level. Hence, one more aggregate router should be added for each aggregate site. The existing edge router at each university is a Single Point of Failure. Hence, there should be a redundant edge router, or it should be stocked to make it readily available in case of failure.

Figure 7. 3 is proposed and recommended Redundant aggregate Topology for EthERNet IP Backbone.

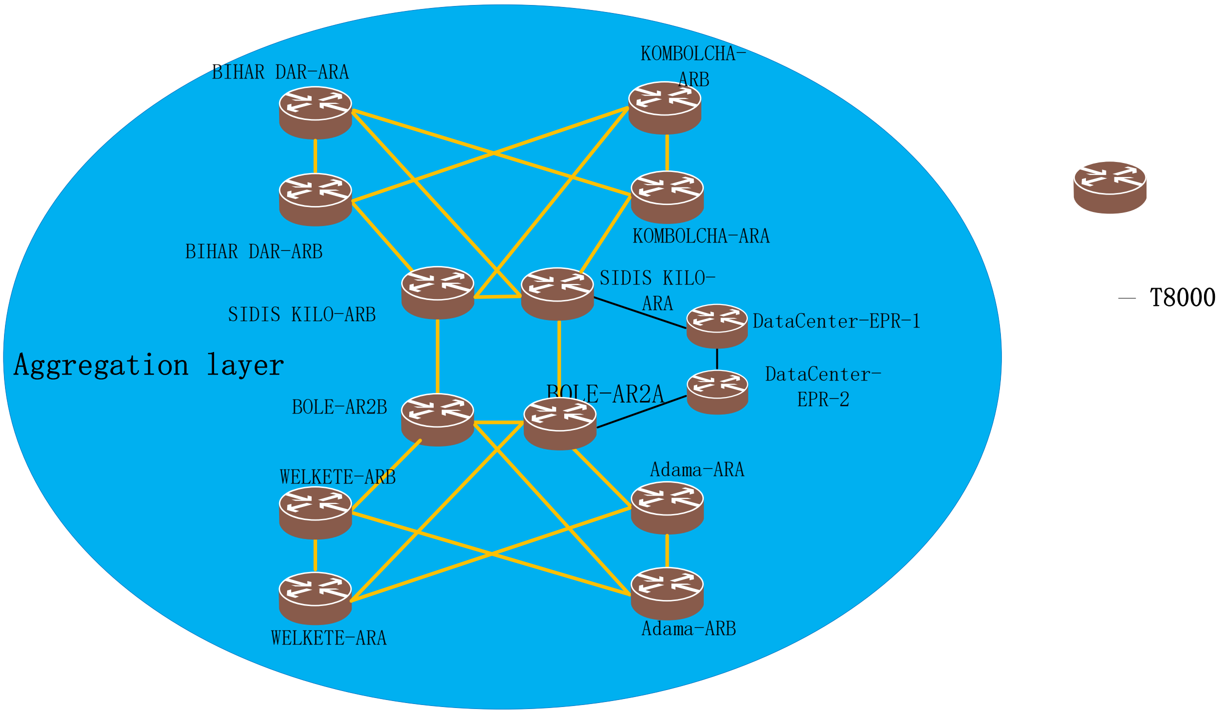

Figure 7. 3: Recommended Redundant Aggregate Topology for EthERNet IP Backbone

7.1.1.3. Proposed International Connectivity

NREN provides Internet connection at the national and regional level. NREN should also link to RREN. The various RRENs from many parts of the world are interconnecting to form the world R and E connectivity.

- Currently, the EthERNet network is an island and is not yet connected to the global research and education network. All member institutions are getting Internet services from a commercial service provider. Hence, the EthERNet network should be connected to global research and education networks like other African NRENs.

Figure 7. 4 is the proposed and recommended International Connectivity to the UbuntuNet router in London.

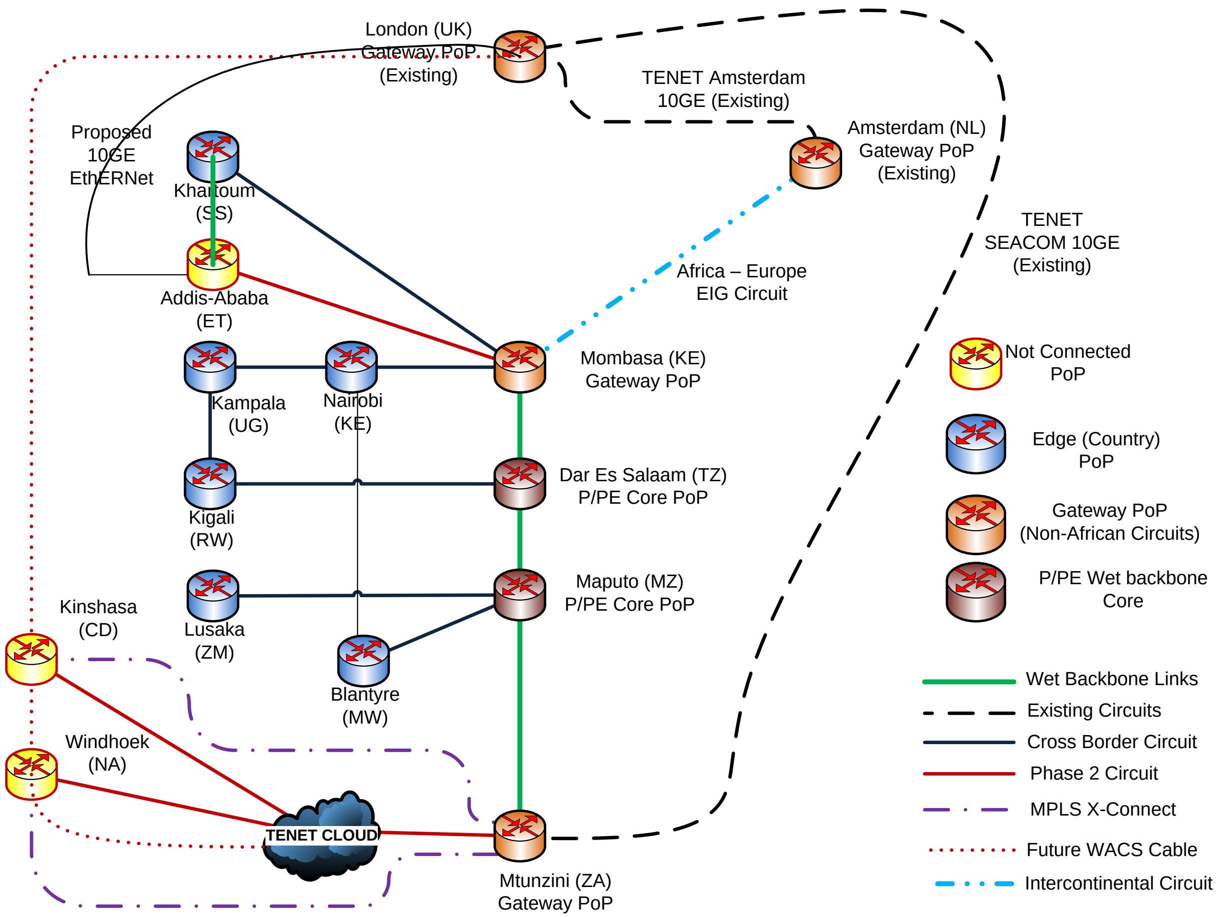

Figure 7. 4: Recommended International Connectivity to the UbuntuNet router in London

As explained in Sections 2.8, the EthERNet does not have international connectivity to the Internet yet and other global NRENs. So, there should be an international gateway link connection of at least 10Gbps bandwidth for its member institutions like other UbuntuNet alliance member NRENs, which has similar context with EthERNet.

Hence, to implement capacity of 1*10Gbps for EthERNet, existing links from Diredawa to Dewelle (Ethio -Djibouti Border) with line 1+1 OP should be used by the Ethio telecom DWDM site with an addition of cards at selected terminal stations. From Diredawa to Addis Ababa, the 1+1 OP protection will be adopted to cut fibre risk. From Addis to Adama, the working and protection path can be used on the EthERNet OTN network. From Adama to

Diredawa, the working path can be used on the OTN network, and the protection path can be used by the DWDM network, as shown in Figure 7. 5.

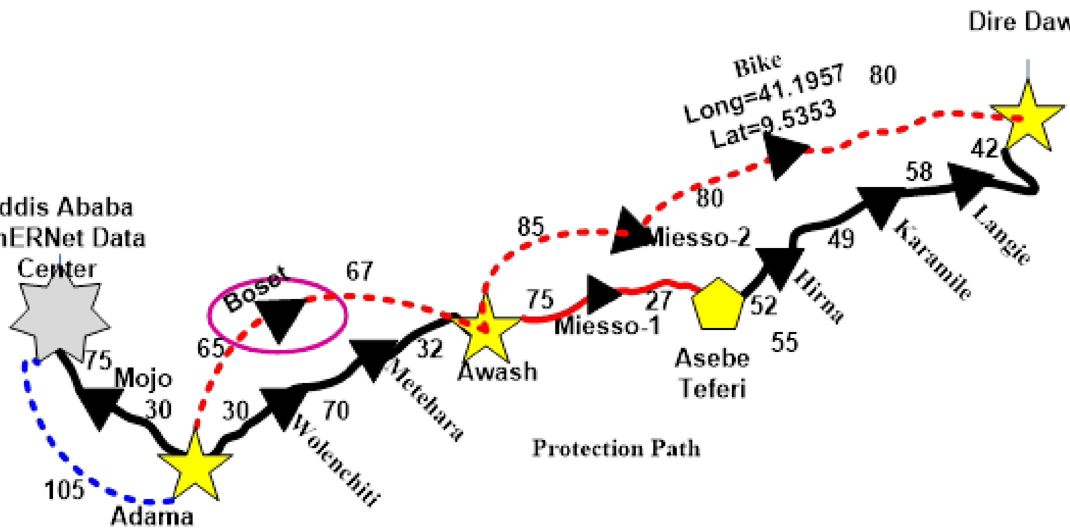

Figure 7. 5: Proposed transmission path for EthERNet international connectivity

Figure 7. 6 depicts the high-level design of the 1*10G proposed link from Dewelle to Sidist Killo: At Dewelle, a Terminal 10G card is used to drop the service at the site for further transmission to Djibouti. On the way from Dewelle to Addis Ababa, the service needs to be regenerated to compensate for the loss in transmission. Thus, it is proposed that Dire Dawa and Nazereth are used as regenerator stations so that two 10G cards will be installed at these sites with the appropriate lambdas to be used in the link.

After the service reaches Addis Ababa (Sidis kilo), it needs to install a terminal 10G card at Sidis kilo. From there the EthERNet data centre can use the existing fibre link already installed to receive/transmit the service to a data centre.

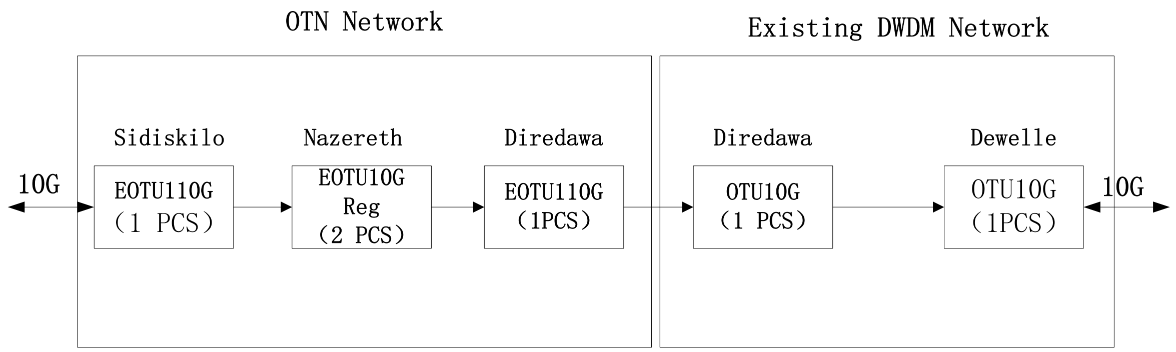

Figure 7. 6: A proposed high-level design for EthERNet international connectivity

7.1.2. Identified Service Expected by end-user

7.1.2.1. Providing Education Materials Online (S1)

Freely available learning materials online (S1 service) in different services can be rejected, and therefore, cases are used.

The uses of each service with their implementation and requirements are discussed below.

1. **Online Teaching Resources**
   I. **Use**

While using ICT to improve training and education systems, online learning is one of the key initiatives. It means reducing teachers because of less physical presence and reducing older teachers that are not ICT savvy. Online learning, therefore, fundamentally prepares the learners for the likely challenges in the new digital era. Therefore, online teaching increases the effectiveness of learning by impacting positively on society. The online platform has tools to help in navigating and customising the learning experience and improving on resources usage.

The primary features of online learning environs include editing and recording tutorials and lectures, making use of interactive materials, allowing checking modules before starting class, personalising the learning experience, testing, and evaluating learners’ ability and so forth.

In an environment with tutor deficiency, both in quality and quantity, online learning in Ethiopian higher learning institutions will be an essential factor in enhancing the sharing of materials and collaboration amongst the teaching community in respect to higher learning. For example, in every learning institution, the teacher will be flexible in interacting with the students online even after the stipulated teaching durations. The online platform also enhances teacher to student, teacher to teacher and student to student communication. It offers pedagogical innovation, which teachers and students can experience and use various online tools to communicate and receive feedback immediately as in face to face environment.

In the increasing need for the use of libraries in Ethiopian higher learning institutions, producing and availing themselves of relevant cheaper learning materials has been challenging in bid to improve the quality of learning. Thus, to start initiating collaborative "fabric" of Open Educational Resources (OER), there are some key advantages that can be relied on which come with the online resource centres that include:

- Availability of quality control and testing materials.
- Extensive usage of OER.
- Creation of resource metadata.
- For ODEL, provide compliance teaching materials.
- Have management tools useful for editing and authoring.
- Resource metadata creation.

II. Implementation

User-level Requirements:

- Internet and Network access
- Mobile Device/ Computer
- Tutor training

The initial step is that teachers and other staff involved must make learning materials available to the learners.

The learners will be able to access the materials through the PCs, and therefore each system should be interconnected.

Institution level Requirements:

- Network-Infrastructure
- Pedagogical and system administrators
- Students and faculty end user's assistance desk
- Thematic for local online learning groups

EthERNet (Service Providers) level Requirements:

In the provision of online learning environs: SaaS at the national level:

- Back up for national grid
- Help desk for institutions
- Pedagogical and system administrator
- Various infrastructures such as servers, network, backup, and storage clouds

2. Virtual learning environment

I. Uses

A Virtual Learning Environment (VLE) is a learning program that is set up to improve on the learners' educational experience. The primary aspects of the VLE package include a roadmap for the curriculum, tracking students, online communication, online support for students and tutors and linkage to external materials through the Internet. The tutors and the students share the same materials and platform. Still, the tutors have additional user and administrative rights in creating and modifying the content and in tracking and evaluating the student performance.

The key advantages of VLE are:

- Availability of different communication tools
- Enabling submission of work online - the students will not have to hand in work physically
- The content is embedded
- There are adequate storage spaces for resources for the teachers and students, which are secure
- There is linkage to external contents

II. Implementation

User-level Requirements:

- Mobile Device/ Computer
- Internet and Network access

The end-user must not carry out the installation or configuration of his/ her working station. The VLA can be available from any browser as long it is Internet-connected. The user can be able to access their messages and emails from any working station that has Internet connectivity.

Institution level Requirements:

In the provision of online learning environment services:

- Administrators for the system
- End user's assistance desk
- Network infrastructure

NREN level Requirements:

In the provision of online learning environment services (SaaS):

- Administrators for the system
- Infrastructure such as backup, storage, server, and network clouds.
- Institution assistance desk

7.1.2.2. Software accessible online for Education and Research Purposes (S2)

Different tools are available which be able to greet this condition. On this regard, bargaining among institutions and NREN will support the institutions attain the finest available software at fair pricing. The thesis proposes a list of "open" tools, that do not require licensing which are already in use in European NRENs. The list is given below.

1. **Large files transfer**

From the analysis carried out, the survey identified this service as a high priority for researchers.

I. **Use**

The service enables files to be uploaded securely onto the site where they are available to users who can easily download the files through the URL issued to them. It is a means of indirectly receiving files that exceed the email size limits and those which need to be transferred.

The service enables the person uploading the materials to safely do so and generate a unique URL which the recipient will use in accessing the files uploaded. The downloading can be via email or message to the recipient who clicks on it to access the materials. There are other features available such as sending links through the dashboard for materials uploads, time to time email notifications and invitations when files are uploaded.

II. **Implementation**

User-level Requirements:

- Mobile Device/ Computer that has an updated browser
- Connectivity Services

No need of installation required from the client PC. The files can be available from any browser as long it is Internet-connected. The user can access uploads from any working station that has Internet connectivity. To get access to the files, there should be a need for one to have authorisation by the depositor of the files, and therefore a password is given to secure the files. The depositor and recipient must have login details for identification for the institution site.

Institution level Requirements:

- Identity Federation /depository account
- Infrastructure: Network
- System Administrator
- The end-user helpdesk

EthERNet level Requirements:

- The administrator of the system
- Helpdesk in learning institutions
- Identity Federation / depositor account
- Network infrastructure

2. Scheduling tools

The survey analysis also has depicted the requirement of this service for both educators and researchers.

I. Use

It allows smooth coordination of meetings, services, courses, and diaries. The service enables the users to simplify appointments scheduling.

II. Implementation

User-level Requirements:

- Computer
- Network or Internet access

Institution level Requirements:

- Administrator of systems
- Network infrastructure
- Software Engineer
- The end-user helpdesk

NREN level Requirements:

- The administrator of the system
- Helpdesk in learning institutions
- Identity Federation / depositor account
- Network infrastructure

7.1.2.3. Service that Enables Users to login to Different Educational and Research Institutions using their Local Credentials (S6)

1. **Identity Provider /Identity Federation**

The survey analysis also underlined this service as a high priority. The service is helpful to the end-users in developing one of the services required, which is, making it accessible to the global research and education community. Additionally, Ethiopia does not have an identity federations operator, as indicated in Figure 2. 5; hence, EthERNet should provide the services for its member institutions.

I. Use

The services enable the users to carry out one authentication and gain multiple services access. Therefore, it improves the user's experience by reducing the costs and complexity involved in the issuance and management of credentials while ensuring user privacy and accountability.

II. Implementation

User-level Requirements:

- Computer and Network or Internet access

Institution level Requirements:

- End users help desk
- Infrastructure: network
- System administrators

EthERNet level Requirements:

To make use of Identity Federation and Identity Provider and to integrate it with the international services provided by eduGAIN.

- Administrator of systems
- An engineer in software
- Federations identity
- Network infrastructure
- The end-user helpdesk

1. Eduroam

The analysis of the survey indicated the requirement of this service with priority for end-users.

I. Use

Fast and reliable Wi-Fi accessibility for learning and carrying out research. Eduroam (education roaming) is a safe world-wide roaming access service that was created for international learning and research community. The Wi-Fi enables learners, researchers, and tutors to access Internet connectivity seamlessly within the campus perimeter. Eduroam helps in saving time and facilities. It is useful for collaboration amongst institutions and countries while still benefiting IT departments in the learning institutions.

As shown in Figure 2. 4, there is no Eduroam service in Ethiopia, and there is a need to set up the service as it is one of the required services for the end-user.

II. Implementation

User-level Requirements:

- Device with WiFi

Institution level Requirements:

Type: Eduroam register

- End users help desk
- Infrastructure: network
- System administrators

EthERNet level Requirements:

Category: Software as a service for the Eduroam registered nationally

- Infrastructure: Network and cloud-based server, storage, backup solution
- Institutions help desk
- System administrators

7.1.2.4. Collaboration Service (S4)

The questionnaire evaluation of the study indicated the requirement of this service with priority for end-users.

I. Use

Video conferencing enables voice, video, chat, and data online communication between two or more persons. Various devices can be connected, such as a PC, Smartphone, and Tablet. The advanced features available create better interaction amongst the users. With such features, it becomes possible to send or receive files, screenshots or use an online whiteboard. The services are facilitated using WebRTC technologies or Multi-Conference Unit (MCU) Services.

Figure 7. 7 depicts the recommended high-level design for the EthERNet to implement the service for its end-user.

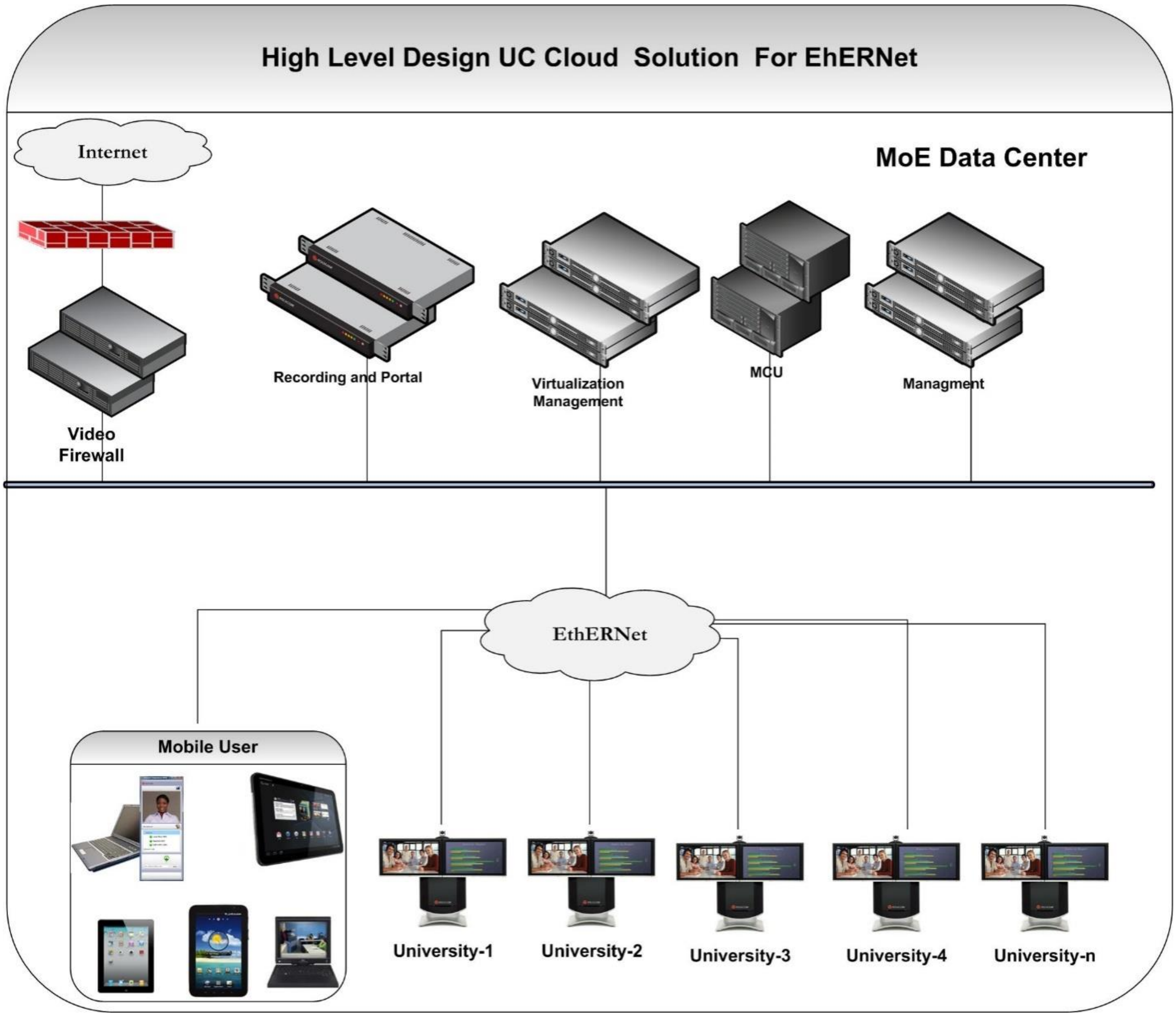

Figure 7. 7: Recommended HLD UC Cloud solutions for EthERNet

II. Implementation

User-level Requirements:

- Computer / Smartphone / Tablet / Phone /
- Network or Internet access

Institution level Requirements:

- End users help desk
- Infrastructure: network
- Meeting rooms equipped with video conferencing systems.
- Network administrator
- Peripheral devices: webcam, headphones, tablets, and smartphones

EthERNet level Requirements:

Category 1: Centrally hosted MCU – Enables to connect to various VC end devices:

- Infrastructure: Cloud-based video conferencing infrastructure (MCU, management server, video firewall, recording and streaming server)
- Institutions help desk
- Software engineer
- System administrators

7.1.2.5. Massively Open Online Courseware (MOOCs) (S9)

The questionaries' assessment the study indicated the requirement for this service with priority for end-users.

I. Use

The service facilitates the creation of online courses by tutors and researchers and shares the same with academic communities online and enables the learners to use the materials remotely. Tutors create courses that are tailored to remote learning, which are based on thematic modules. Each of the modules has various contents such as videos, references, additional texts, knowledge tests and exercises.

The course includes the final academic award by issuing an official degree as the instructors can monitor, administer, and grade students and map performances and engagement in the course.

There is also provision for various collaboration and communication tools that the users, tutors, and learners, can utilise. Because of the advancement in technology, learners can simultaneously access modules at their own pace. Access to resources can be restricted or made free to all users.

II. Implementation

Student Side Requirements:

- Computer / Smartphone / Tablet / Phone /
- Connectivity Services

Content Development Side Requirements:

- There is a need for an audio-visual production chain
- Guidance in creating and deploying the online course material

Institution Level Requirements:

- Administrators for the system
- Directory for student user accounts
- End users help desk
- Network infrastructure

EthERNet level Requirements:

Category: Computing resources to implement MOOC:

- Administrators for the system
- Directory for student user accounts
- End users help desk
- Network infrastructure

7.1.2.6. Mail Service

Analysis of the survey indicated that the Ethiopian higher education institutions researcher and educators asked particularly for institutional email accounts on the domain name of the university for their communication with others.

I. Use

Most of the students studying on online campuses have an institutional email address, which is required, but some use them regularly. The service aims at providing each member of the university with an email address to give the user credibility. The email filtering is managed from the service or through other activities. The best services to use are Google and O.365 because they are offered free to learning institutions by the vendor.

II. Implementation

User-level Requirements:

- Computer / Smartphone / Tablet / Phone /
- Connectivity Services

PC is required from end user side. The service can be available from any browser as long it is Internet-connected. The user can access their messages and emails from any working station that has Internet connectivity.

Institution level Requirements:

- Administrators for the system
- End users help desk
- Network infrastructure

NREN level Requirements:

- Administrators for the system
- Institutions help desk
- Software engineer
- The support team from institutions

7.1.2.7. Domain Name

I. Use

The primary use of the service is offering registration services for institutions' domain names. Besides, the value of the service is in proposal pooling. Over and-above the final aspects and technical benefits, it helps in reinforcing the institution's identity.

II. Implementation

EthERNet level Requirements:

Type: National domain name registration for education and research or service provider (with subcontractor). Register and manage domain names.

- Help desk Institutions

7.1.2.8. Security Certificate

I. Use

The first use of the service is offering a confidential certificated service for research and education institutions. Also, the value of the service is in proposal pooling. To enhance and provide excellent ICT services, security certificates is essential at all level. Since the number of issued certificates for learning and research in a country can be many, it is recommendable to purchase a bundle at the regional or national level.

II. Implementation

Institution Level Requirements:

- Advanced security engineers and administrators

EthERNet Side Requirements:

Category: Service Provider contactors with Certification Authorities:

- An agreement with the certificate provider
- Provide all the required support for end users
- Strong security Engineers and administrators

7.1.2.9. ICT Security

I. Use

The intention of ICT related security is to avail reliable support and services required for the network, system, and applications. The security team should talk to each other for information exchange and take all the required measures.

II. Implementation

Institution Level Requirements:

Type: ICT Security Service:

- Certified security engineers and administrators
- End user Support
- All the required security administrations team

EthERNet Side Requirements:

Categories: ICT Security support and callability:

- Help desk
- ICT security team (CSIRT)

7.1.2.10. Data repository services readily available (S15)

The institutional or national repository services gives access to thesis, dissertation, and digital contents. Those repositories can be utilized by researcher and educators for search, examination, and services like content mining. The Sci-Gaia initiatives project by EU (joint effort venture) is the best reference, that has created and conveyed a standard-based Open Science Platform that supports combined verification.

7.1.2.11. Universal Collaborative Projects Support (S7)

Collaboration platforms and services required for the researcher and educators must be incorporated into the recommend services (S1), in particular the arrangement of online instructive materials. Numerous instruments exist for the usage of those web-based services. They can be coordinated impassively by the institutions or by the EthERNet. At the point when these platforms are structured, they ought to be coordinated into the single sign on services for ease of use and secure access. (Service S6).

7.1.2.12. Educational Services and Platforms Provided Online (S8)

Those services which we call it learning and training management system was likewise distinguished in the study and required by the Ethiopian higher education institutions. It very well may be gathered with the other digital multimedia contents recently portrayed in S1 arrangement of online instructive materials.

7.1.2.13. Remote login that allows users to remotely use Institutional infrastructure and services (S10)

Services that are required to be access remotely by researcher and educators, enable them to get to applications ordinarily got to on their premises in any event when they are moving from their institution's premises. Right now, a significant number of these applications do not exist on EthERNet. For this situation, it will be simpler to legitimately plan applications to be gotten to through the EthERNet as a Private Cloud services.

7.1.2.14. Remote Sensors Access Service (S12)

Some research project requires access to remote sensors mainly outside of the institution's premises. They will challenge mutualise. EthERNet may team up with other project related to those research and with these necessities to offer the required network bandwidth.

7.1.2.15. Remote Computing Facilities Access (S13)

I. Use

The RCF service enables researcher and educators to associate with their remote campus so as to get to applications and records that are not open from the outside except if explicitly approved and with secure access.

II. Implementation

User-level Requirements:

- Internet access or network
- Mobile Device/ Computer
- VPN Software

Institutions level Requirements:

- End-user help desk
- Network infrastructure
- Software engineer
- System administrators

7.1.2.16. High-Performance Computing Facilities (S14)

I. Use

The absence of HPC offices was recognized by 91.48% of Ethiopian public higher education researchers as an obstruction to their research work. This infrastructure and services intend to give the researcher to conduct research that needs high computing processes which can’t be done using normal computers.

The HPC service must accommodate broad information stockpiling to store essential information and modeling results. The measure of information used to run the model requires reliable and affordable network and computing infrastructure.

II. Implementation

User Level Requirements:

- Electronic Devices
- Connectivity Services

The end-client must not complete establishments nor design his/her working station. The service can be accessible from any program as long as it is Internet-associated and can present the work. Contingent upon the size of the information expected to run the model, he/she may require a magnificent system association with adequate internet connection.

Requirements at Institutional level:

- Administrator of systems
- Network infrastructure
- Software engineer
- End-user Support

Requirements at EthERNet level:

Type: High performance computing infrastructure:

- Administrator of systems
- Learning institutions help desk
- Network infrastructure
- Software engineer

7.1.2.17. Data Storage Services (S15)

I. Use

This service has three uses:

- Secure storage space can be offered for end-users
- Data can be gotten to from all over the place and from any gadgets
- Data can be effectively imparted to different clients

However, information privacy is fundamental in research and educational activities. It is required that the information put away is just gotten to by the verified and approved individual and that every one of the rights, including copyright, are regarded. A few apparatuses enable organizations to set up such a help. The area of the information is an issue that should be registered before entering with an agreement with such provider offering the services.

II. Implementation

User-level Requirements:

- Electronic Devices
- Connectivity Services

Requirements at Institution Level:

- Administrator of systems
- Network infrastructure
- Software engineer
- The end-user helpdesk

EthERNet level Requirements:

- Administrators for the system
- Learning institutions help desk
- Software engineer
- The support team from the institutions

The EthERNet-ET venture will assist EthERNet with building a system that will give great services to end-clients effectively. In accomplishing that, this proposition proposed a lot of services that are as of now accessible in most research and higher education instruction institutions around the globe and were additionally recognized by end-clients during the study.

As the execution of these services will require some serious energy and cash, it is exceptionally suggested that these services are actualized on EthERNet as a private cloud offering. In setting up its roadmap, EthERNet should concentrate on administrations that can be executed autonomously from member institutions, thus:

- Network Connectivity Improvement: by connecting EthERNet to the international connectivity (10Gbps) GÉANT network, which will also make it easier to connect to other NREN in the world.
- Implementation and hosting of the services expected by end-clients: to start with, EthERNet should be centred around the services that won't require a lot of association with education and research institutions, and which can begin rapidly to make a decent copying and give results

While preparing the roadmap, the above recommendations are considered.

7.2. Infrastructure and Service Roadmap

As per the result of the study, once the service portfolio is developed, a roadmap for EthERNet is proposed to enhance service delivery and sets the standard for EthERNet and other NREN within a similar context in the developing world. To develop the roadmap, the technology road-mapping framework as per indicated in Figure 2. 11, that has the flexibility and personalization to adjust the timeframes and layers that are specific to the client requirements is used. Also, to outline the road-mapping process, a function-based sectoral roadmap that can encompass various activities at different levels of the organizations is used as per indicated in Figure 2. 12. Accordingly, the below sections discuss the details of the recommended infrastructure and service roadmap.

7.2.1. Infrastructure Roadmap

The EthERNet network infrastructure is composed of a backbone that has a capacity of a multiple of 10 Gbps and access links to connect to the Ethiopian public higher education institutions.

International connectivity for Ethiopia, which does not have access to undersea cables, is generally designated as a land-locked country. Therefore connectivity is through the available terrestrial fibre infrastructure from Djibouti, Sudan, Kenya, and Somalia as an option.

It is planned that there will be a connection to GÉANT POPs in the UK (London). UbuntuNet Alliance has already a POP presence in London and can align with GÉANT as soon as the link is ready from Addis Abba to London. This is because construction work is underway to connect the two locations using the GÉANT. However, a possible alternative which can be used includes Mombasa (Kenya) and Mtunzini (South Africa).

Figure 7. 8 depicts the EthERNet proposed road map for connectivity.

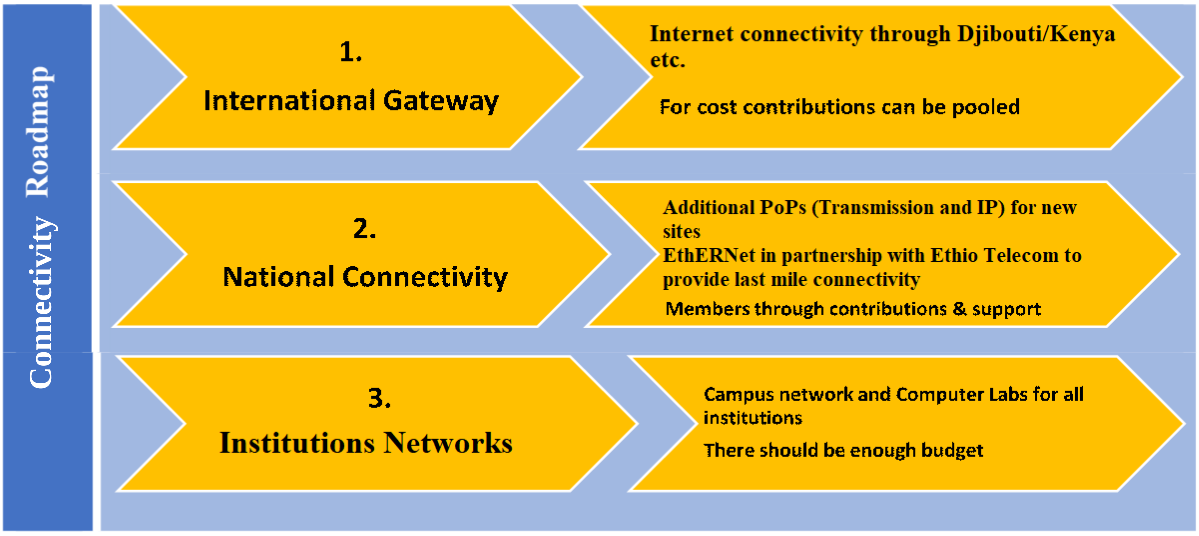

Figure 7. 8:Proposed Roadmap for Connectivity

7.2.2. Service Roadmap

As explained in Section 2.13 and Figure 2. 9 of the SWOT analysis matrix diagrams, it showed that weakness marked the lowest value compared to strengths, opportunities, and threats of NREN services in the Ethiopian higher education. It proves that the educator, researcher, and ICT directors at Ethiopian higher education institutions believe that NREN services are essential to improve the quality of education and research output. As explained in Section 4.5, the study adopted a descriptive survey design with the support of online surveys that were administered to research participants. The online survey was designed to allow the research to gather relevant data from the research participants regarding the available and required NREN services, which could then be used to assess the Strengths, Weaknesses, Opportunities and Threats (SWOT).

A SWOT analysis was used to assess the required services. The findings of this study will undoubtedly help EthERNet and the universities to implement those services in a short -term or long-term roadmap, eventually pave the way towards providing better and improved NREN services for their end-user to enhance the quality of education and research output. Therefore, before starting the elaboration of this roadmap, this section assessed the required services in terms of SWOT analysis. The results of this analysis are presented in the section below.

7.2.2.1. Analysis of the Services

As explained in detail in Section 2.13, SWOT is an acronym representing the Strengths (S), Weaknesses (W), Opportunities (O) and Threats (T). Strengths and weaknesses are internal, while opportunities and threats are external.

Tables 7.1 - 7.8 presents the SWOT analysis of various resources required by NREN.

Table 7. 1: IaaS

Strengths	**Weaknesses**
• EthERNet team technical capacity • Offer currently deployed at EthERNet • Pooling resources leading to a decrease in costs	• Need to quantify user needs and to elaborate a business model for this service • Service could be unknown to users
Opportunities	**Threats**
• Almost all the public higher education institutions cannot offer this type of service at their level. Then EthERNet could offer it at the national level. • EthERNet network with higher education is reliable and has high bandwidth	• Lack of continuous budget on this service leading to a possible cessation of its procurement to users • Wrong business model • Wrong choices on the cloud service catalogue • Wrong description of the service

Implementing a data centre is not recorded in the service portfolio suggestions. In any case, the ICT equipment is important to actualize the necessary services required from end user. This is the motivation behind why offering IaaS at the national level comes into the primary stage on the roadmap.

Table 7. 2: AAI

Strengths	**Weaknesses**
• Facilitate access to resources • Facilitate the sharing of resources and services • Promote collaboration • Strengthen security	• The complexity of the technology • Dependency on local provisioning of identity registries • Trust depends on local provisioning of identity registry
Opportunities	**Threats**
• Early adoption for online services • No existing federation so that to use the latecomer advantage of the latest technology • Possibility to join eduGAIN • Possibility to secure and restrict access to Wi-Fi	• Scarcity of the needed skills • Unknown quality of the identity registries

Online services expect verification to restrict access to the scholastic clients however empowering the utilization of neighbourhood accreditations to confirm one of the suggestions in the service portfolio of eduroam to ensure Wi-Fi network and to character, organization to secure web applications' entrance subsequently showing up in the present moment roadmap.

Table 7. 3: Mail

Strengths	Weaknesses
• Institutions gaining invisibility of Internet • Possibility of pooling resources • Service which can bring EthERNet visibility to institutions and politicians	• High investment to provide in- house mail service for higher education communities • Correctly manage mail account life cycle is challenging • Potential user's knowledge of this service • Service operational costs compared to free email service available online
Opportunities	**Threats**
• Ability to guaranty seamless service availability if EthERNet operates the service as a negotiation with the free provider (O.365 and Gmail) can be done on behalf of the member institutions • African institutions' need for service independent from the big providers • Many institutions failing in delivering this type of service • Service can be given from Microsoft and Gmail free of charge for educational institutions	• Lack of long-term investments leading to a cessation of the service • The free provider may ask for a fee at some point in time • Users' support quality • Wrong business model (not easy to define) • Wrong description of the service

Giving an institutional email service to each end-client is suggested in the service portfolio. Encouraging the execution of institutional email administration comes in the present moment roadmap for all the open advanced education organizations as a portion of the colleges are very much experienced in utilizing O.365 and Gmail as an institutional email service.

Table 7. 4: MOOC – Online Courses

Strengths	Weaknesses
• Pooling resources leading to economies of scale and a broader e-learning catalogue • Provide value to local skills	• Specific know-how needed to prepare a MOOC • Need to commit teachers and people with the knowledge to set up online courses (recognition/political or financial incentives) • Technical resources and skills to commit to this service
Opportunities	**Threats**
• Possible collaboration with other international institutions having a similar experience • Specific training needs to cover. • Use of EthERNet private cloud platform	• Difficulty to access to MOOC realisation tools and support for teachers • Need for long term budgeting • Potential users lack knowledge about this service

Table 7. 5: Open Education Resources

Strengths	**Weaknesses**
• Pooling resources leading to added value • Resource needs increasing progressively • Standards and tools not requiring high technical skills • Active user needs from Ethiopian higher education institutions	• Classification to be defined • No business model for this service • The validation process to organise
Opportunities	**Threats**
• Current resources to highlight • Possible use of Sci-Gaia platform to deliver this service • Use of EthERNet IaaS platform	• Lack of visibility for this type of service • Risk of increasing budget if the service is successful

The requirement for digital content for education is underlined in the service portfolio and spreads a lot of apparatuses. A few instruments like MOOC, intelligent assets or digital content encouraging conditions are not feasible in the extent of the present moment roadmap, however the availability to open record stages can be performed rapidly.

Table 7. 6: Generic Top-level domains (gTLDs) – Domain Name Registration

Strengths	**Weaknesses**
• Pooling resources leading to a decrease in costs (if many gTLDs register) • Simplification of the processes, institutions not having to select among several registrars	• Possible difficulty to define the process and registrations delegations to each institution and to maintain them
Opportunities	**Threats**
• Development of African domain names • Outreach in respect of the possibility to register domain names in the scientific (and academic) communities	• Difficulty in obtaining and maintaining the budget collectively funded to deliver this domain name registration service • The quality level of the user's support • Risk of weakening Country Code (ccTLDs)

Provide central domain name services for the institutions is listed in the service portfolio recommendations. It should be developed in EthERNet service roadmap since it is a national service.

Table 7. 7: Software licence distribution

Strengths	Weakness
• The limited budget needed to deploy the service • Pooling resources leading to added value	• Business model to find for this service • License distribution process to organise
Opportunities	**Threats**
• A potential market for editors • The real expectation by academic librarians	• Difficulties in controlling licenses distribution process and efficiency • Lack of information about this service to potential users

Bulk license mediation of software does not require huge scale responsibilities and can be performed promptly with brisk advantages.

Table 7. 8: Video Conferencing

Strengths	Weaknesses
• Previous experience with EthERNet • Reduces travelling • Reinforces collaboration • Ubiquity	• The complexity of the technology • Cost of the equipment
Opportunities	**Threats**
• Large areas and poor travel infrastructures • Maturity and inter-operability of the solutions	• Lack of devices (room-based VC) • The popularity of free services like Skype

The implementation of a videoconference facilities and services are likewise suggested in the service portfolio proposal. It ought to be considered in a present moment with regards to accessible VC facilities and services and reliably network infrastructure.

7.2.2.2. Fundamental Services

As per Figure 7. 9, these fundamental services exemplify those that EthERNet needs to implement and host at its data centre ahead of any other services. It may be helpful to review that this deliverable spotlights on a roadmap for EthERNet.

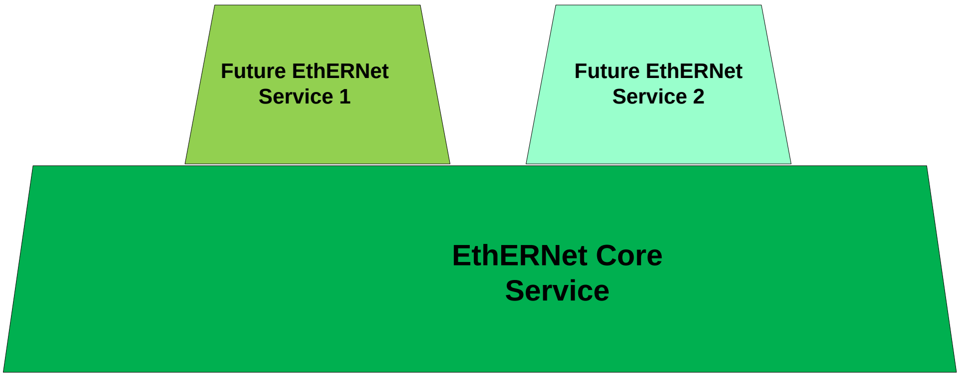

Figure 7. 9: Hierarchal Model for Services

Without a doubt, there are conditions among services. A few services are featured as need with respect to these conditions. Services, for example, private cloud or security facilities are the first to be sent to empower appropriate quality execution of different services over the cloud framework. Services, for example, NOC and CSIRT are additionally expected to guarantee accessibility and security. A few administrations prescribed in the administration portfolio, for example, MOOC and elite registering, need immense ventures and astounding human aptitudes. Despite the fact that end-clients exceptionally anticipate these administrations, they ought to be considered in the long-haul guide.

The bulk licence arrangement in a specific help is profoundly expected by end-clients and requires no hardware or software facilities. The expense is low; however, the advantage can be tremendous as far as cash and terms of perceivability for EthERNet. EthERNet can implement and host those services required by end uses and mentioned in the roadmap.

The recommended rundown of required services for the present moment guide are:

1. Network Operation Centre (NOCaaS)
2. Authentication and Authorisation Infrastructure
3. Infrastructure as a Service (IaaS datacentre)
4. Security Team both engineers and administrators
5. Gateway for the science related issues
6. Open Document (OADR)
7. Institutional /Corporate Email
8. Mass common use Licence procurement

7.2.2.2.1. Infrastructure as a Service to be hosted at the Datacentre

Computing Infrastructure (including server, storage, network, backup, etc) is expected to be implemented and hosted at the data centre. It is not just an issue of intensity and cooling limits or every minute of everyday services yet in addition an issue of versatility, security, and flexibility. This data centre obviously combined with another for a reinforcement ought to convey a virtual machine to give processing or capacity limit on request. A few data centres as of now exist in the member institutions, and specialist co-ops work others. EthERNet ought to depend without anyone else facilities. Past the sufficient needs of the foundations, the point is to assist the EthERNet with deploying a national IaaS infrastructure and services.

7.2.2.2.2. NOC Service

A NOC is a centre for network, system, and security administrators to administer, screen and keep up a media communication organize. It is typically staffed all day, every day with work force who persistently screen the system for blackouts, deficiencies, basic occasions, and variations from the norm. Building a NOC office involves a huge venture as well as satisfactory information and a lot of time and vitality. Providing a reliable service with nonstop help (every minute of every day) requires a sufficient measured group of prepared specialists. NOC as a help gives a significant cost sparing because of the pooling of assets, (for example, human and systems).

The proposed NOC will deal with the EthERNet system and its interconnections with the advanced education organizations arrange and different systems. At the point when the administration is completely operational at EthERNet level, EthERNet will offer this support of its part organizations which are not in a situation to fabricate a NOC office due to all necessities required (speculation, prepared work force and security) or this can be the initial step before building their NOC. All things considered, the NOC will regulate the institutions 's system from its interconnection with EthERNet and every one of its establishments associated with the system.

7.2.2.2.3. Computer Security Incident Response Team

Security is basic in Research and Education situations. In this manner, Acceptable Use Policies which EthERNet request that their clients sign all the time allude to security issues.

A CSIRT is a group devoted to cybersecurity. As EthERNet systems incorporate the data, EthERNet CSIRT is the best spot to watch, break down, treat, and handle the entirety of the parts of security for its member institutions. A basic perspective in the wake of setting up a CSIRT is to characterize its centre administrations as per the accessible interior assets, and for this situation, it relies upon the quantity of users from the institutions side. The centre CSIRT services provided can be gathered into three fundamental classifications: receptive, proactive and security quality administration benefits as depicted by European Union Agency for Network and Information Security (CSIRT services, 2018).

Receptive services, which comprise of post-episode/assault/occasions, are a prerequisite in a CSIRT. Proactive services can be sent after the beginning time and will be conveyed as far as group aptitudes. Its classification is made out of reviews, pentests, apparatuses advancement, interruption, or recognition. Security Quality Management administrations can be mentioned on-request and are not time subordinate. Services gave by EthERNet CSIRT can and should advance. CSIRT or CERT is a similar assistance/group, however "CERT" is an enrolled trademark claimed via Carnegie Mellon University. Thus, if EthERNet service needs to utilize the CERT abbreviation in his name, it must get authorization to receive from the CERT-CC for the privilege to utilize it. The service is given to the advanced education CSIRTs of the EthERNet people group that gives a CSIRT administration to the individuals from EthERNet. For this situation, targets are security contacts of part organizations.

7.2.2.2.4. Infrastructure Providing Authentication and Authorisation

Being certain that solitary a confirmed individual can approach a few information is crucial for Research and Education as it involves ensuring and verifying their insight. In this manner, having a unified verification system is the reason for having the option to implement the services at own platform. Numerous advanced assets on the institutions, for example, digital library, computing infrastructure, email, or LMS, expect clients to validate themselves (commonly with a username and password). Contingent upon their profile, verified clients can get authorization to get to or to oversee assets. Instead of oversee accreditations per application expecting clients to have separate certifications for every client, institutions can send AAI to offer a solitary computerized personality to clients to concede access to every one of the assets (regularly a solitary sign-on framework – SSO). Figure 7. 10 portray the suggested AAI model. Campuses can combine their AAI using identity federation t to enable clients to get to online assets from other institutions with some arrangements between them. Hence, clients' single identifications can be utilized over numerous institutions.

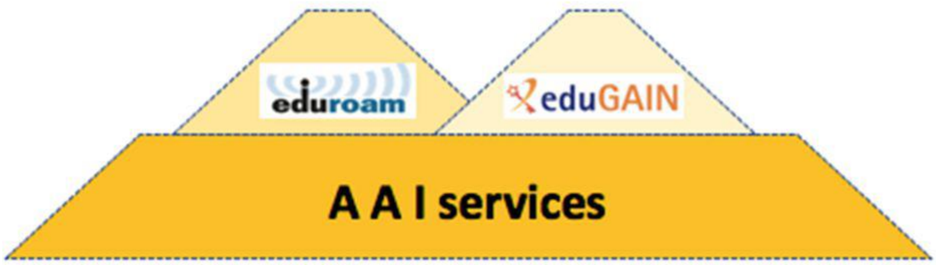

Figure 7. 10: AAI Model

In addition, joining eduGAIN, the worldwide Interfederation of scholastic alliances offers access to a more extensive scope of assets and joint efforts all around the globe. Eduroam is another segment of an AAI. It is a protected, overall wandering access for the education and research institutions. Eduroam enables clients to utilize their home association personality to access remote systems for places where Eduroam has been conveyed. Advantages come about because of abstaining from provisioning and de-provisioning visitor represents visiting understudies and scientists yet in addition from having the option to control who can utilize the available resources in the institutions to keep the available services open to permitted clients.

Additionally, Ethiopia is not shown on the eduGAIN Global Footprint as per shown in Figure 2. 6; hence, EthERNet should show up on the map by availing the services to its member institutions. The objectives of the AAI service are the associations which need to give a superior encounter to clients while getting to access services or institutional based resources on the web yet additionally EthERNet, which needs to unite the associations' character the executives frameworks to offer versatility with Eduroam and a far reaching scope of coordinated efforts by means of eduGAIN.

7.2.2.2.5. Institutional /Corporate Email Service

The objective of this is to give an institutional email services to Ethiopian education and research institution. The email address shall be provided using the specific domain name of each institutions to which the researcher and educators belongs.

Notwithstanding greater perceivability of the connection in the associations, trust is improved when individuals send messages from an institutional partnered email address. Moreover, the email address can likewise be bound to an identifier in the personality vault of the organizations besides utilized in the edge of verification processes. The most ideal approach to furnish the administration is to have with a merchant which give the administration uninhibitedly to research and training, for example, Microsoft and Google. This administration will upgrade the perceivability of Ethiopian scientists and instructors on the worldwide REN people group.

7.2.2.2.6. Electronic Research Infrastructures

Electronic research infrastructures are the basic piece of research and science activities as they enable researchers to get to different resource and information assets to help their work. It has been produced for quite a long time in Europe and all around to help the different interdisciplinary and multidisciplinary researchers that can be conducted virtually. Accordingly, it encourages admittance to a variety scope of computing facilities and infrastructures , in which a huge system of distributed computing infrastructure aggregated together. Vision 2020 is the e-frameworks that will empower worldwide researchers to attempt better research paying little mind to area and worldview.

The Catania Science Gateway Framework: comprises of an occupation motor that upgrades the researcher tasks on one hand and the other hand, is an information motor that aides in the development of information from the dispersed computing facilities, a server that can host e-Token, client following and checking record. The activity motor is answerable for dealing with the whole series of the task accomplishment. It implies requests can be facilitated via CSGF deprived of researchers expecting to consume high performance computing infrastructure.

The objective of the service is for any researcher or educator who wishes others to get to their application or information by means of the internet, etc. A few candidates can likewise utilize HPC if accessible. Accordingly, it shall be critical enthusiasm to higher education institutions, just as the NRENs who bolster them.

7.2.2.2.7. Data Repository Accessible Openly

Scholastics regularly yield a varied assortment of "dim writing" or grey literature they demand to brand transparently available, a critical establishment of openly available for science use. This incorporates unpublished material, for example, specialized accounts, information, syllabus, digital resources, and application softwars. This should be possible by utilizing Institutional Open Access Document and Data Repositories (OADR). An OADR is an application platform that can be facilitated by an organization (for example a college and research foundation) and enables clients to transfer their "dim writing" for overall spread.

OADRs are broadly utilized over the globe. The hosting institute's administration can oversee quality. Significantly, any institutions who required the services, can easily obtain a Digital Object Identifier (DOI) (www.doi.org) to make their document uniquely identifiable. This can be linked to a research registry service such as ORCID (orcid.org) that brings together a complete collection of a scientist's work in one conveniently accessible place. These services are essential in raising the international profile of a scientist, their university, their country and, ultimately, African research worldwide.

Furthermore, OADRs can be connected to Science Gateways to let researchers and even citizen scientists reproduce and reuse scientific data on distributed Grid and/or Cloud-based infrastructures. Some examples are provided at http://oar.scigaia. eu/record/77 and http://sgw.africa-grid.org/alice.

This is significant for EthERNet since EthERNet is obviously put to control the advancement of Ethiopian OADRs as a basic system administration for knowledge. EthERNet can take part in creating OADR in Ethiopia strategies and policies, spread the significance for Ethiopian science, train faculties and researchers in building up and possibly have OADRs nationally. The basic opinion is that EthERNet can give fundamental initiative in floating the universal profile of the country's researchers and make a noteworthy commitment in pulling in look into financing and advancing excellent worldwide research and coordinated effort.

The objective of the service is for any establishment that desires to store information and additionally reports that can be accessible may do as such. This incorporates Universities and research institutions.

7.2.2.2.8. Software Licence Distribution Service

This service plans to give required software licenses in batch for the educators used to improve the quality of education and research output in a sensible expense. By doing, EthERNet could consult by the leading software vendors or the sake of the entire Ethiopian research and education community. The non-benefit part of educating and the quantity of prospective end-clients may possibly initiate a decrease of the license’s charges.

Those services can be given in two different ways. Either EthERNet is the focal representatives for the license’s solicitations, or it can appoint the receipt taking care of to a specific specialist co-op, in Ethiopia, for example, the PPPDS (Public Procurement and Property Disposal Service). Contingent upon the required softwars or licenses and the editors, the two different ways could be consolidated.

Hence, the objective is all research and education institutions which ought to convey software for investigate in labs or lessons in classrooms or those which need to give software to their end-clients (educators, scientists and staffs) for their expert needs. These associations are not in a place of solidarity to arrange the expense with the overall editors; they therefore follow through on the list costs. The establishments will profit by the exchange made by the network and get a sensible receipt through the service. This action can be reached out to online science journals. EthERNet can likewise consult with editors.

7.2.2.2.9. Proposed Roadmap for EthERNet

The proposed roadmap shall be guide by quarter (Y1-Q1 = year 1/quarter 1). EthERNet shall pick the starting times of the administrations relying upon the accessible assets (HR, subsidizing) and the dependencies between services.

Every single field of the chart is part into "develop in house", "operate at EthERNet" and "open to the public organizations" (implying that the organizations will at that point be allowed to assume control over those services and convey them at the institutional level, under conditions set by EthERNet). The "develop" part compares to the setting up of the strategies, together with the agreements and assets. The "run EthERNet" part compares to the use of EthERNet itself.

The "open to public organizations" step compares to the spread and advancement of the services, the progressive incorporation of the services in the arrangement of the organizations and all the relating tuning errands which are tedious. Figure 7. 11 depicts the proposed service roadmap for EthERNet.

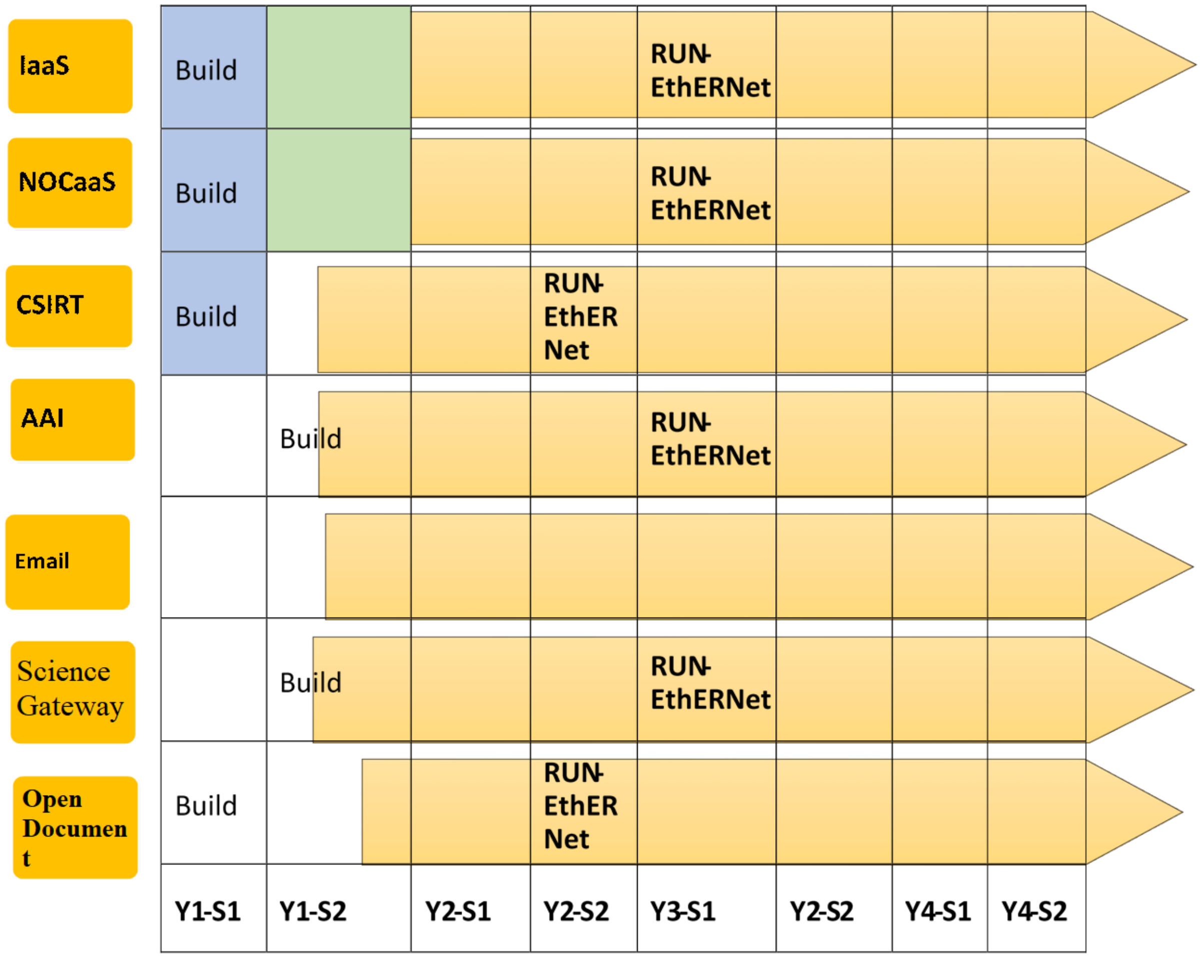

Figure 7. 11: EthERNet Service Roadmap

Long Term Roadmap

Currently, numerous services required by end users are not exist in the short-term roadmap because of their conditions (intensive capital requirements, personal talents, and reliable network and ICT infrastructures). High-performance computing, digital content and MOOC's are recommended to be implemented in long-term roadmap. The services required should be reassessed regularly to align with the upcoming technologies in the perspective of EthERNet future projects and initiatives.

Yet, those services required, like HPC, need rigorous analysis to find the appropriate situations within the existing environment. To this end, experience sharing could be explored with other global research and education institutions to share knowledge and contents.

7.3. Summary

This chapter proposes an NREN service portfolio and roadmap for EthERNet at a national level using the proposed theoretical framework as a base. Subsidiary principles apply, meaning that at a national level, institutions can build their strategy and decide whether to opt for EthERNet services. However, it is essential to state that looking at the universities infrastructure development in Ethiopia, is more than expected that universities will choose to take services offered by the national NREN, EthERNet, instead of developing them themselves, as few are adequately staffed, have dedicated budgets and have their roadmaps in place. Pooling resources into EthERNet will help them reach services that they might not be able to deliver individuals to their user constituencies.

From the higher education institutions point of view, outsourcing to EthERNet will provide benefits in terms of readiness of use, cost, and 24/7 operations. This will generate economies of scale. Time is indeed a severe factor that is needed to be kept in mind when preparing this EthERNet roadmap. If nothing is done at a national level to boost national development, the digital divide will remain and will increase and so will the scientific divide.

Regarding with the required network infrastructure, EthERNet is on the right track with its EthERNet-ET project to provide the required services for the institutions. This chapter also focuses on the required services by the NREN community, which will enable the development of service portfolio and roadmap for EthERNet. They are the basis for all required services by the education and research institutions. The responsibility of EthERNet is to assist higher education institutes to get access to the required NREN services, by designing and delivering the service from its cloud data centre. This roadmap sets up the EthERNet strategy.

Chapter 8: Conclusion and Contribution

This chapter presents the conclusions, contribution and recommendations based on the findings obtained from the study. A keen focus was placed on the theoretical, methodological, and practical contributions that impacted on the study. The recommendations are suggested to contribute to the improvement of the quality of learning and research output in Ethiopian higher education by providing the required NREN services.

8.1. Conclusion

A theoretical framework was proposed using a three-step design science approach by the study that is used as a foundation to develop a service portfolio and roadmap and to examine the relationships between higher education's research and educational activities and the formation of actor-networks impacted on the quality of education and research output. Two components that were examined using the theoretical framework were associated with quality of education and research output proposed in Figure 3. 2.

Examination of data provided by lecturers, researchers, ICT directors and EthERNet staff members during the quantitative phase relied on the use of descriptive statistical methods to identify and analyse~~s~~ the NREN services required by end-users, develop NREN service portfolio and road map for EthERNet. The findings of the study identified the necessary end-user requirements, impacts and challenges experienced by educators and researchers vis-à-vis the smooth operation of their professional activities as it relates to interconnected computing capability (both nationally and internationally). It then moves on to acknowledge the necessary and indispensable end-user requirements for improvement. It concludes that these challenges could aid in the development of the NREN service portfolio and the proposition to set up a roadmap for EthERNet. The study also evaluated various research hypotheses; whose outcomes are presented in Table 5. 19. The Structural Equation Modelling (SEM) was evaluated using the Partial Least Squares (PLS) in which the latent variables and indicators were identified.

The findings that were obtained from the study were guided by five sub-research questions that addressed services required, challenges faced by Ethiopian higher education institutions, the impact of capable NREN/EthERNet. In the first research question, the study attempted to identify the challenges faced by Ethiopian higher educational institutions with regards to their network and in using EthERNet. The various challenges that were identified included network unreliability, lack of access devices for students, data privacy and security issues, frequent power outages, insufficient Internet bandwidth, limited technical support lack of ICT policy and strategy, among others as shown in Figure 5. 48 and 5. 54 of Chapter 5.

The second research question aimed at ascertaining what impact a reliable network and EthERNet have on improving the quality of education and research output. The study found that an effective NREN would have a constructive contribution toward state-of-the-art teaching delivery and student education, as well as enabling researchers to have a significant impact at both national and international level. It would also empower the ICT Directorate of each university to improve on the institute's network infrastructure, as shown in Figure 5. 20, Figure 5. 49 and Figure 5. 50 of Chapter 5.

The third research question attempted to identify the positive and negative factors that influenced the actor-network relationship to assess the quality of education and research output, to evaluate the fitness of the hypothesised model, and develop a structural model. Through the hypothesised theoretical structural model as shown in Sections **6.5.1-6.5.6** of Chapter 6 and Section 5.1.2 of Chapter 5, the study identified various variable factors, which have a significant and positive impact on Quality of Education (QE) to differing degrees. However, the analysis of the data collected also shows that the institutional network has a weak relationship with the quality of education. Additionally, the study variables discovered that there was a significant and positive impact on Research Output (RO) to differing degrees. This was contrary to the weak relationship that existed between research output, institutional networks, and electronic devices.

The fourth research question intended to identify NREN services required by end-users at Ethiopian higher education institutions to develop a service portfolio and roadmap. The necessary services that were identified that contributed to the development of the NREN service portfolio and roadmap include, but are not limited to, connectivity services, IaaS, AAI, among others.

The fifth research question assessed how the concept of Actor-Network Theory (ANT) could be used to understand the NREN service requirements within Ethiopian higher education institutions. The study also examined the actors who influenced the required NREN service, their relative importance, and their relationships. In the study, the ANT model was proposed, and the ANT notion of problematisation was used to trace and explain actors influencing the required NREN service, their relative importance, and their relationships as shown in Figure 6. 6.

8.2. Implications of the Study

From a theoretical perspective, the research contributed to the existing literature by showing that there are alternative theories that can be used in assessing the adoption and usage of technology. The research explored the key factors, which influenced the success or failure of the formation and functioning of actors impacting on the quality of education and research output.

For example, the ANT theory was used to examine its role in enhancing knowledge and understanding of NREN related roles and responsibilities, their collaborative relationships and networks, and its influence on the quality of education and research output at Ethiopian higher education institutions. The outcome of the ANT has helped to identify the main factors affecting the success or failure of the formation and effectiveness of the NREN related actor-networks.

Methodologically, the study adopts the use of quantitative methods to accurately identify the strongest and weakest factors affecting the actor-network relationship, which in turn, affected their efficacy in quality of education and research output. Practically, the study contributes to the literature by demonstrating an analytical process, which could be used as a guide for future NREN service requirement studies to improve the quality of education and research output with the existing findings being used as a reference point. Moreover, finally, NREN service portfolio and roadmap for the effective use and implementation at EthERNet was proposed to assist EthERNet in providing those services needed to address the issues of quality of education and research output within Ethiopian higher education institutions.

8.3. Recommendations

The findings show that the end-users required many services at Ethiopian higher education institutions that could assist educators and researchers in improving the quality of education and research output. Service design should consider how fast and reliable access can be supported.

Many education-related networked services were rated as both highly desirable and useful such as collaboration tools, inter-university login capability, among others.

The study offers a proposal that includes a service portfolio for the NREN as well as a roadmap to guide EthERNet in its implementation. The service portfolio identifies, which new services can be implemented in the short term since they would need minimal input such as significant funds or newly trained staff, and which ones ought to be considered in the long term as those tasks would need a substantial injection of capital as well as the training and preparation of specialised staff. Also, the roadmap proposes a timeline for the implementation of the new proposed services. There is a strong desire to significantly revamp the national EthERNet that can avail all the required services for the potential student at a national and international access basis. Researchers need to search online frequently and to access a variety of online items to support their research. The survey indicated specific examples that fall within a computing or environmental research.

The study's findings also reveal that there are many challenges faced by Ethiopian higher education institutions with regards to their network and in using EthERNet to enhance the quality of education and research output. For both education and research, the biggest concern was their institution's network connectivity and reliability issues. There is also a need to collaborate nationally and internationally in research and that network issues present a barrier to effective collaboration.

8.4. Limitations of the Study

Despite the contribution to theory and practice, several limitations were encountered in the study. The researcher was only limited to the context of Ethiopian NREN and its member institutions because of the geographical proximity of the NRENs. Apart from the limited literature available in this area, one of the main challenges encountered in the study was the reluctance of the research participants to respond to the questionnaire on time. Other challenges encountered included logistical impediments in organising focus group discussions, restricted role, and limited financial capacity. On the design science methodology, to further enhance the validity of constructs and measures within the proposed theoretical framework, it was recommended that viewpoints using exploratory case studies from Ethiopian higher education end users to be reflected as a follow-up discussion on the proposed theoretical framework.

While examining the data, the researcher was faced with two main challenges associated with the use of the PLS-SEM approach namely the potential underestimation of path coefficients and the overestimation of factor loadings (Hussain, Fangwei, Siddiqi, Ali and Shabbir, 2018). Despite these limitations attributed to the PLS-SEM, the researcher still selected this approach. These limitations and others provided scope for further research, which may advance the understanding of NREN related services in improving the quality of education and research output at higher education institutions.

8.5. Future Research

The research explored the impact of NREN services on research output and quality of learning in higher institutions of learning and was able to identify the primary NREN services that are required by end-users, the challenges and the impact of the EthERNet. Additionally, this study developed an NREN service portfolio and roadmap for EthERNet that can inform the selection and implementation of reliable networks in other institutions of higher learning. However, there are several areas which can be considered as future directions of this research. Future research ought to consider the impact of free services provided by other global NREN and connecting EthERNet to the international gateway.

The study also came up with a proposed theoretical framework that was used to examine both positive and negative factors influencing the actor-network relationship to improve the quality of education and research output. To establish both positive and negative factors, the NREN context in the study was limited to a specific case. Even though the proposed theoretical framework is built upon validated ANT theory, it may not be entirely clear how well it works in practice. Consequently, future work should characterize contextual environments and real case studies that could evaluate the extent of the impact and improve the proposed theoretical framework's applicability by implementing a NREN having similar development contexts.

A critical component that can be considered in future research is the ability to provide a comparison of the context-sensitive actor-network relationships in different NRENs. The possibility that there are different actors and attributes for different NRENs need not be ignored. As a result, two future areas of research exist forthcoming studies can consider that. These future areas include the perception of the policymakers towards NREN related service, roles and outcomes in improving the quality of education and research output at higher education institutions and the consequences of NREN related services on the policymaker attitudes towards improving the quality of education and research output.

8.6. Summary

The initial investment made concerning the EthERNet to achieve its goals has helped to maximise the outcomes of the projects. The EthERNet has, in turn, strengthened the development of strong NREN in Ethiopia. This could make it possible for Ethiopian researchers and educators to work with their peers around the world and collaborate on international projects towards the socio-economic development of the country. Overall, by making EthERNet effective, it would have a significant and positive impact on teaching delivery, student education, distance learning, and research at both the national and international level. Furthermore, the theoretical model from this research can be used as a point of reference for future research.

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Appendix 1 - Ethical Clearance Certificate

UNISA university of south africa

UNISA COLLEGE OF SCIENCE, ENGINEERING AND TECHNOLOGY'S (CSET) RESEARCH AND ETHICS COMMITTEE

4 July 2017

Ref #: 088/ZAA/2016/CSET_SOC
Name: Zalalem Assefa Azene
Student #: 58529800

Dear Zalalem Assefa Azene

Decision: Ethics Approval for three years (Humans involved)

Researcher: Zalalem Assefa Azene
1367, Ministry of Education, Addis Ababa, Ethiopia
zalalem@ethernet.edu.et, +25 19 117 3183

RECEIVED
2017 -07- 27
Office of the Deputy Executive Dean
College of Science, Engineering & Technology

Supervisor (s): Prof F. Bankole
bankofo@unisa.ac.za, +27 11 670 9476

Proposal: The Impact of Ethiopian National Research and Education Network (EthERNet) on the Performance of Research and Education of Ethiopian Higher Education

Qualification: PhD in Computer Science

Thank you for the application for research ethics clearance by the Unisa College of Science, Engineering and Technology's (CSET) Research and Ethics Committee for the above mentioned research. Ethics approval is granted for a period of three years from 4 July 2017 to 4 July 2020.

1. The researcher will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.
2. Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should

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Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

be communicated in writing to the Unisa College of Science, Engineering and Technology's (CSET) Research and Ethics Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.

3. The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study.
4. Only de-identified research data may be used for secondary research purposes in future on condition that the research objectives are similar to those of the original research. Secondary use of identifiable human research data require additional ethics clearance.
5. Permission to conduct this research should be obtained from the applicable entities such as the state minister, Ethiopian Public Universities and applicable EthERNet entities prior to commencing field work. Permission letters should be send to the Ethics Committee once obtained.

Note:

The reference number 088/ZAA/2016/CSET_SOC should be clearly indicated on all forms of communication with the intended research participants, as well as with the Unisa College of Science, Engineering and Technology's (CSET) Research and Ethics Committee

Yours sincerely

Adele da Veiga

Dr. A Da Veiga

Chair: Ethics Sub-Committee School of Computing, CSET

Prof I. Osunmakinde

Director: School of Computing, CSET

(PROF IW ALDERTON)

Prof B. Mamba

Executive Dean: College of Science, Engineering and Technology (CSET)

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Appendix 2 – Permission Letter

በኢትዮጵያ ፌዴራላዊ ዴሞክራሲያዊ ሪፐብሊክ
የትምህርት ሚኒስቴር
Ministry of Education
Federal Democratic Republic of Ethiopia

ቀን/Date: [illegible]
ቁጥር / Ref: [illegible]

Addis Ababa University
Addis Ababa Science and Technology University
Haramaya University
Hawassa University
Mekelle University
Medda Wolabu University
Mizan Tepi University
Arba Minch University
Semera University
Aksum University
Adama Science and Technology University

Wollega University
Wollo University
Wolaita Sodo University
Debre Berhan University
Debre Markos University
Dire Dawa University
Dilla University
Bahirdar University
Gonder University
Jimma University
Jigjiga University
Adigrat University
Ambo University

Assosa University
Bule Hora University
Debre Tabor University
Mettu University
Wachemo University
Wolkite University
Woldia University
Arsi University
Gambella University
Civil Service University
Kotebe Metropolitan Unviersity

Subject: Permission to Collect Data for Dissertation

The purpose of this letter is to inform you that Mr. Zelalem Assefa is a PhD student in Computer Science at University of South Africa (UNISA). As part of his studies he is required to do a dissertation. In this regard he has planned to conduct a study on " The Impact of Ethiopian National Research and Education Network (EthERNet) on the Performance of Research and Education of Ethiopian Higher Education" and got permission from the Ministry of Education.

Hence, we request you to kindly permit him to collect the required data from concerned staffs of your institutions. The identity and information gathered from the participants will be strictly kept confidential and will be used for the research study purpose only.

Sincerely,

Samuel Kifle Kidane (PHD
State Minister

CC፡

- ***Mr. Zelalem Assefa***
  Ministry of Education

ራዕያችን ብቁ ዜጋ የሚያፈራ ጥራትና ፍትሃዊነት ያረጋገጠ
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Appendix 3 – Research Questionnaire

RESEARCH QUESTIONNAIRE

Dear Prospective Participant,

You are invited to participate in a survey conducted by Zelalem Assefa under the supervision of Bankole Felix, a Professor, in the School of Computing towards a PhD in Computer Science at the University of South Africa. The survey you have received has been designed to study "The Impact of National Research and Educational Network on Education and Research of Higher Education Institutions- A case of EthERNet Ethiopia".

The presence of a strong National Research and Education Network (NREN) can have a significant impact on the social and economic development in a country in addition to Research and Education. EthERNet is the Ethiopian NREN. EthERNet's mission is to build and operate world-class network infrastructure, develop state-of-the-art services, promote collaboration among national, regional, international research and education communities and build the capacity of the research and education community in Ethiopia. The purpose of EthERNet is to create national and international high-capacity Internet networks for research and education in Ethiopia.

The survey consists of five sections:

- General: Personal Details and Contact Information.
- Part A: For University staffs involved in teaching/NREN service for Education.
- Part B: For University staffs involved in Research/NREN service for Research
- Part C: For ICT Directors
- Part D: For EthERNet Staff

The questionnaire appears long, but it has been formulated to enable rapid response through selection from instant answers. The time required should be about 20 minutes.

All responses shall remain anonymous and confidential.

Thank you for your time

Please tick where appropriate and you can tick more than one item where necessary or write your responses in the spaces provided.

General

1. Your Name (Optional):
2. Your Email (Optional):
3. Name of your University/Institution:
4. Faculty/School/Institute:
5. Department:
6. Highest degree attained *(Select one option)*.

Bachelors	Masters	PhD

7. What is your academic rank? *(Select one option)*.

Professor	Associate Prof.	Ass. Professor	Lecturer	Assistant Lecturer	Other (Please specify)

Part A: For University Lecturers

The below questionnaires shall be filled by University Lecturers.

Please fill in this section if you perform any educational roles.

1. What are the main subjects that you teach?

2. How often do you need to access online material and/or data to support your teaching?

Very often	Often	Sometimes	Rarely	Never

2.1 If you access online material and/or data, please indicate how strongly you agree or disagree with the following statement. "**My institution's network never causes me any problems when I access online material and/or data.**"

Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Not Applicable (I do not access online material)

2.2 Could you give one or more examples of online material that you access (or would like to access)?

3. How often do you need to provide material and/or data online to support your teaching?

Very often	Often	Sometimes	Rarely	Never

3.1 If you need to provide material and/or data online, please indicate how strongly you agree or disagree with the following statement. **"My institution's network never causes me any problems when I put material and/or data online."**

Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Not Applicable (I do not provide material/ data online)

3.2 Could you give one or more examples of material and/or data that you provide (or would like to provide)?

4. How often do your students need to access online material and/or data in their learning?

Very often	Often	Sometimes	Rarely	Never

4.1 If your students need to access online material and/or data in their learning, please indicate how strongly you agree or disagree with the following statement. **“My institution’s network never causes me any problems when my students access online material and/or data.”**

Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Not Applicable (My students do not access online material/ data)

4.2 Could you give one or more examples of online material that your students access (or would like to access)?

5. How often do you need to access to online software to support your teaching?

Very often	Often	Sometimes	Rarely	Never

5.1 If you need to access online software to support your teaching, please indicate how strongly you agree or disagree with the following statement. **“My institution’s network never causes me any problems when accessing online software.”**

Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Not Applicable (I do not access online software to support my teaching)

5.2 Could you give one or more examples of online software that you access (or would like to access)?

6. How often do your students need to access online software in their learning?

Very often	Often	Sometimes	Rarely	Never

6.1 If your students need to access online software in their learning, please indicate how strongly you agree or disagree with the following statement. **"My institution's network never causes me any problems when my students access online software."**

Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Not Applicable (My students do not need to access online software in their learning)

6.2 Could you give one or more examples of online software that your students access (or would like to access)?

7. The following are potential networked services that might be useful in education. First, please indicate if you currently use or do not use a service. Second, for each service, please indicate how strongly you agree or disagree with the following statement. "The service would be useful in my teaching?"

Service	Currently, use?	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
Video- or web-conferencing services.	Y/N					
Collaboration tools such as wikis, event calendars and document repositories.	Y/N					
Recording tools to make lectures, etc. available online for students.	Y/N					
Online (web-based) teaching and learning resources.	Y/N					
Online teaching and learning environments (e.g. Moodle, etc.).	Y/N					
Massively Open Online Courseware (MOOCs).	Y/N					
Online library resources	Y/N					
The ability to log in at another institute with your local username/password	Y/N					
Facebook	Y/N					

Twitter	Y/N					
LinkedIn	Y/N					
ResearchGate	Y/N					
Other (please specify)						
	Y/N					

8. EthERNet could make it easier to deliver distance learning programmes. Please indicate how strongly you agree or disagree with the following statements.

"EthERNet would make it possible for me to create distance learning programmes in my country."

Strongly Agree	Agree	Neither agree nor disagree	Disagree	Strongly Disagree	Irrelevant

"An EthERNet would make it possible for me to create international distance learning programmes."

Strongly Agree	Agree	Neither agree nor disagree	Disagree	Strongly Disagree	Irrelevant

8.1 How many more students do you think an effective distance learning programme for your subject would reach nationally?

50	100	500	1000	More than 1000

8.2 How many more students do you think an effective distance learning programme for your subject would reach internationally?

50	100	500	1000	More than 1000

9. For each device that a student might use to access educational services, please indicate how strongly you agree or disagree with the following statement. **"The device is useful for students to access online educational services."**

	Strongly Agree	Agree	Neither agree nor disagree	Disagree	Strongly Disagree
Fixed PC					
Laptop					
Mobile device					
Other (please specify)					

10. Currently, what are the main problems with the network that you use in education? Please indicate how strongly you agree or disagree with the following statements.

	Strongly Agree	Agree	Neither agree nor disagree	Disagree	Strongly Disagree	Irrelevant
I cannot easily connect to the network						
My students cannot easily connect to the network						
The network is unreliable						

My students cannot easily get access devices such as computers or smart mobiles sufficiently						
I cannot guarantee data privacy						
The network is not secure						
Please add any other problems						

11. Overall, how would you assess the expected impact of a reliable network on education? Please indicate how strongly you agree or disagree with the following statements.

	Strongly Agree	Agree	Neither agree nor disagree	Disagree	Strongly Disagree	Irrelevant
It would have a significant impact on my teaching						
It would have a significant effect on the education of my students						
It would enable many more students to attend University through a distance learning programme						

It would enable students to have a better education by being able to interact with teaching staff through web-based conferencing systems						
It would enable life-long learning						
Please add any other issues that you would like us to consider						

12. Please add any research issues not covered above that you would like us to consider.

Part B: For University Researcher

The below questionnaires shall be filled by a University Researcher.

Please fill in this section if you perform any research roles.

1. What is your main research area(s)?

2. Please give a brief outline of a typical research project in your area. FREE TEXT

3. Are you currently using EthERNet network for your research?

YES	NO

3.1. If no, please provide reasons.

4. Does your research collaboration with the project partners involve large file transfer over a data communication network?

YES	NO

4.1. If yes, can you specify what the typical size of such files is?

1-100MB	100-250MB	250-500MB	500MB-1GB	More than 1GB

5. How often do you collaborate with other researchers nationally?

Very often	Often	Sometimes	Rarely	Never

6. How often do you collaborate with other researchers internationally?

Very often	Often	Sometimes	Rarely	Never

7. If you collaborate with other researchers internationally, please give the countries that you usually work with (or at least from your last project).

8. Please indicate how strongly you agree or disagree with the following statement. **“My institution’s network never causes me any problems when I want to work with other researchers internationally.”**

Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree

9. Could you give one or more examples of international collaboration that your network has prevented you from actively participating?

10. How often do you search for online conference and journal articles to support your research?

Very often	Often	Sometimes	Rarely	Never

11. If you search for online conference and journal articles, please indicate how strongly you agree or disagree with the following statement. **"My institution's network never causes me any problems when I search for online conference and journal articles."**

Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Not Applicable (I do not search for online conference and journal articles)

12. Could you give an example of search tools that you use (or would like to use)?

13. How often do you need to access online conference and journal articles to support your research?

Very often	Often	Sometimes	Rarely	Never

13.1. If you need to access online conference and journal articles, please indicate how strongly you agree or disagree with the following statement. **"My institution's network never causes me any problems when I access online conference and journal articles."**

Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Not Applicable (I do not need to access online conference and journal articles)

13.2. Could you give an example of a "typical" article that you download (or would like to)?

14. Other than conferences and journals, how often do you need to access data sets in your research?

Very often	Often	Sometimes	Rarely	Never

14.1. If you need to access data sets, please indicate how strongly you agree or disagree with the following statement. **"My institution's network never causes me any problems when I access data sets."**

Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Not Applicable (I do not need to access data sets)

14.2. Could you give examples of these data sets?

15. How often do you need to publish open access research work or data online to support your research?

Very often	Often	Sometimes	Rarely	Never

15.1. If you need to publish open access research work or data online, please indicate how strongly you agree or disagree with the following statement. "My institution's network never causes me any problems when I publish open access research work or data online."

Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Not Applicable (I do not need to publish open access research work)

15.2. Could you give an example of research work or data that you would like to publish online?

16. Apart from common "office" software such as word processors, etc., what other software do you need to use in your research?

16.1. Do you need to access this software online? If so, please indicate which software.

16.2. How often do you need to access this software online?

Very often	Often	Sometimes	Rarely	Never

16.3. If you do need to access software online, please indicate how strongly you agree or disagree with the following statement. **"My institution's network never causes me any problems when I access software online."**

Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Not Applicable (I do not need to access "office" software online)

17. Do you ever need to publish software that you have created online?

Very often	Often	Sometimes	Rarely	Never

17.1. If you do need to publish software online, please indicate how strongly you agree or disagree with the following statement. **"My institution's network never causes me any problems when I publish software online."**

Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Not Applicable (I do not need to publish software online)

17.2. Could you give examples of software that you would like to publish online?

18. How often do you need access to remote sensors online (e.g. for real-time climate monitoring)?

Very often	Often	Sometimes	Rarely	Never

18.1. If you do need to access remote sensors online, please indicate how strongly you agree or disagree with the following statement. **"My institution's network never causes me any problems when I access remote sensors online."**

Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Not Applicable (I do not need to access remote sensors online)

18.2. Could you give an example of these sensors?

19. General Network Support for Research

Please indicate how strongly you agree or disagree with the following statements.

	Strongly Agree	Agree	Neither agree nor disagree	Disagree	Strongly Disagree	Irrelevant
My local computing facilities support my research activity						
Access to remote computing facilities would enable me to carry out research activities that are currently impossible						
Access to high-performance computing will enable me to carry out research activities						

that are currently impossible						
I have access to enough data storage for my research						
Access to more data storage would enable me to carry out research activities that are currently impossible						
I would like to share my data with others online						
Being able to share my data online would enable me to carry out research activity that I cannot now do						
Being able to easily log-on at a different institute with my local username/ password would be useful in my research						
Network speed has made it difficult for me to participate in international conferences						
Network speed has made it difficult for me to participate in						

International Program Committees						
Network speed has made it difficult for me to participate in editorial boards						
Being able to participate in the international academic community is essential for my career						
Please add any other problems						

20. The following are potential networked services that might be useful in research. First, please indicate if you currently use or do not use a service. Second, for each service, please indicate how strongly you agree or disagree with the following statement. **"The service would be useful in my research to communicate with fellow researcher/scientists/project partners who are not at the same institution?"**

Service	Currently, use?	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
Video- or web-conferencing services.	Y/N					
Email						
Collaboration tools such as wikis, event calendars and document repositories.	Y/N					

Web-based portals to give secure access to online data, educational resources, software, computing, and sensor services to support a specific scientific community (a science gateway).	Y/N					
Online library resources.	Y/N					
The ability to log in at another institute with your local username/ password	Y/N					
Access to a Data Centre to store your resources						
Facebook	Y/N					
Twitter	Y/N					
LinkedIn	Y/N					
ResearchGate	Y/N					
Please indicate other services you currently use						

21. For each device that you might use to access research services, please indicate how strongly you agree or disagree with the following statement. **“The device is useful for me to access online research services.”**

	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
Fixed PC					
Laptop					
Mobile device					
Other (please specify)					

21.1.Please indicate your preferred device.

22. Currently, what are the main problems with the network that you use to support your research? Please indicate how strongly you agree or disagree with the following statements.

	Strongly Agree	Agre e	Neither agree nor disagree	Disagre e	Strongl y Disagre e	Irreleva nt
I cannot easily connect to the network						
The network is unreliable						
I cannot guarantee data privacy						
The network is not secure						

Please add any other problems						

23. Overall, how would you assess the expected impact of a reliable network on research? Please indicate how strongly you agree or disagree with the following statements.

	Strongly Agree	Agree	Neither agree nor disagree	Disagree	Strongly Disagree	Irrelevant
It would have a significant impact on my research at a national level						
It would have a significant impact on my research at an international level						
It would enable my research to have a major national impact						
It would enable my research to have a major international impact						
It would enable me to establish new collaborations						
It would enable me to work with colleagues across the world without leaving my home country						
It would enable me to work at different institutions across the world						
Please add any other issues that you would like us to consider						

24. Please add any research issues not covered above that you would like us to consider.

Part C: For ICT Director

University ICT Directors shall fill the below questionnaires

Please answer this section if you manage and/or provide networking technology and/or applications

1. Please indicate below if you currently provide any of the following technologies or services.

Service	Do you provide this technology/service (Y/N)
Institutional networks	
Institutional WiFi networks	
Network security	
Voice over IP services	
Video- or web-conferencing services	
Collaboration tools such as wikis, event calendars and document repositories	
Online (web-based) teaching and learning resources	
Online learning environments	
Massively Open Online Courseware	
Online library resources	
Other (please specify):	

2. If you have access to good, low-cost network connectivity in the future, please indicate how strongly you agree or disagree with the following statements.

	Strongly Agree	Agree	Neither agree nor disagree	Disagree	Strongly Disagree	Irrelevant
I would improve my institute's network infrastructure						
I would provide institute wide WiFi networks						
I would provide excellent network security						
I would provide Voice over IP services						
I would provide video- or web-conferencing services.						
I would provide collaboration tools such as wikis, event calendars and document repositories.						
I would provide online (web-based) teaching and learning resources						
Please add any other issues that you would like us to consider						

3. Currently, what are your main Challenges/barriers in using EthERNet to provide ICT services used for research and education purposes? Please indicate how strongly you agree or disagree with the following statements.

	Strongly Agree	Agree	Neither agree nor disagree	Disagree	Strongly Disagree	Irrelevant
Lack of standard Data Centre (e.g. lack of; backup power, cooling, room decoration, NOC, monitoring system etc.)						
Lack of standard wired and wireless campus network						
Lack of Security						
Insufficient Internet bandwidth						
Insufficient support from the network provider /ISP						
Lack of support and commitment from top level management						
Unavailability of Last mile connectivity for remote campuses (the branch campuses are not connected to the main campus)						
Unavailability of Institutional ICT Policy						

Institutional ICT Policy is not implemented						
Unavailability of Institutional ICT strategy						
Institutional ICT strategy is not aligned to the corporate strategy						
The difficulty of ICT strategy implementation						
lack of Enough budget allocated for ICT						
Lack of skilled ICT staffs						
Lack of retention mechanism for ICT staff						
Please add any other issues that you would like us to consider						

Part D: For EthERNet Staff

EthERNet Staff shall fill the below questionnaires

Please indicate below if you currently provide any of the following technologies or services

1. Occupational position?

CEO	CTO	System Admin	Network Admin	Other (specify)

2. Size of Population at EthERNet

Below 5000	5000-10000	10000+

3. Is EthERNet provide cloud services?

YES	NO

4. If Yes to Question 3, indicate which 'Cloud deployment models' EthERNet uses?

Public Clouds	Private Clouds	Community Clouds	Hybrid Cloud

5. If Yes to Question 3, What are the concerns while providing cloud services?

Security	Privacy	Reliability Location	Others (Please specify)

6. Please indicate below if you currently provide any of the following technologies or services.

Service	Do you provide this technology/service (Y/N)
Connectivity	
Tools for file sharing	
Storage backup disaster recovery	
Web hosting	
FEDERATED IDENTITY MANAGEMENT and SINGLE SIGN-ON	
NETWORK PEERINGS	
COLLABORATION SUITES	
REALTIME COMMUNICATION	

E-learning and education services	
FILE STORAGE AND SYNC	
Other (please specify):	

7. Currently, what are your main Challenges/barriers for EthERNet to provide ICT services used for research and education purposes to the member institutions? Please indicate how strongly you agree or disagree with the following statements.

	Strongly Agree	Agree	Neither agree nor disagree	Disagree	Strongly Disagree	Irrelevant
Insufficient Internet bandwidth						
Reliability of the network						
Insufficient support from the cable provider /ISP						
Unavailability of national ICT policy and strategy						
lack of Enough budget allocated						
Lack of skilled ICT staffs						
Lack of retention mechanism for staff						
Please add any other issues that you would like us to consider						

Thank you for your valuable time!