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Knowledge Transfer for Microgrids Sustainability – the Case of East Africa

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von

Paul Bogere

Erster Gutachter: Prof. Dr.-Ing. Katrin Temmen
Zweiter Gutachter: Prof. Dr.-Ing. habil. Stefan Krauter

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Zusammenfassung der Dissertation:

Wissenstransfer für die Nachhaltigkeit von Microgrids - der Fall Ostafrika

von Paul Bogere

Der geringe Anteil der ostafrikaknischen Bevölkerung mit Zugang zu elektrischer Energie steht der Verwirklichung des globales Nachhaltigkeitsziel (Sustainable Development Goal, SDG) 7 entgegen. Aufgrund ihrer dezentralen Energieressourcen und ihrer Fähigkeit, im Inselbetrieb zu arbeiten, werden Microgrids als Lösung betrachtet. Allerdings zeigt die Literatur verschiedene Herausforderungen auf, die die Nachhaltigkeit von Microgrids gefährden. Zu diesen Herausforderungen gehören unter anderem der Mangel an lokalen technisch versierten Fachkräften, die geringe lokale Kaufkraft, eine niedrige Anzahl von Netzanschlüssen sowie ein geringer Stromverbrauch. Der nachhaltige Betrieb von Microgrids ist daher ebenso wichtig wie ihr Bau. Der Wissenstransfer relevanter Inhalte zum Aufbau lokaler Kapazitäten wird dabei als eines der Schlüsselelemente für den nachhaltigen Betrieb von Microgrids angesehen. In dieser Arbeit werden verschiedene didaktische Bausteine zur Förderung des Microgrid-Wissenstransfers entwickelt, welche Schulungsinhalte, einen didaktischen Rahmenplan sowie eine virtuelle und interaktive Lernumgebung für Microgrids beinhalten. Diese richtet sich an drei Zielgruppen: (1) Studierende des B.Sc. Elektrotechnik, (2) Endverbraucher sowie (3) Schüler*innen im Alter von 14 bis 18 Jahren. Die Entwicklung der didaktischen Materialien erfolgt mit Hilfe des Design-Based Research (DBR) Ansatzes Analyse, Design und Evaluation (ADE-Model). Für die Entwicklungsphase des ADE-Modells werden didaktische Konzepte wie die überarbeitete Bloom'sche Taxonomie und Constructive Alignment herangezogen. Die Evaluation basiert auf dem Content Validity Index von Expertenantworten sowie qualitativen Evaluationen. Das ADE-Modell wird durch Daten gestützt, welche in Tansania und Uganda durch Fokusgruppendiskussionen, strukturierte Experteninterviews und Fragebogenbefragungen erhoben werden. Der Wissenstransfer beginnt als einzelnes Element der Steigerung der Nachhaltigkeit von Microgrids und entwickelte sich zu einem umfassenden didaktischen Rahmenmodell. Dieses ist ein wichtiges Referenzwerkzeug für die Entwickler fachspezifischer Curricula, für Schulungsverantwortliche in der Industrie sowie Akademiker zur Entwicklung von Lehrinhalten über Microgrids. In dieser Monographie hebt das didaktische Rahmenmodell den kontextuellen Wissenstransfer und die didaktischen Strategien um den Erwerb relevanter Fähigkeiten hervor. Während der Entwicklung des Rahmenmodells wird mit Hilfe der Bloomschen Taxonomietabelle gezeigt, dass die Inhalte (1) Studierenden des B.Sc. Elektrotechnik praktische, problemlösende, kreative und innovative Fähigkeiten vermitteln und (2) Abnehmer*innen elektrischer Energie sowie Schüler*innen praktische Fähigkeiten erwerben, um Herausforderungen in den ländlichen Gemeinschaften Ostafrikas zu lösen. Dies trägt zum Ziel 4.7 der SDGs bei, das darauf abzielt, „sicherzustellen, dass Lernende durch Bildung Wissen und Fähigkeiten zur nachhaltigen Entwicklung erwerben...“. Der Erwerb von Wissen und Fähigkeiten trägt zum Aufbau lokaler Kapazitäten bei und wirkt sich somit positiv auf eine zuverlässige Energieversorgung mit Hilfe dezentraler Microgrids aus. Eine darauffolgende Verbesserung des Anteils an Menschen in Ostafrika mit Zugang zu elektrischer Energie und trägt zur Verwirklichung von SDG 7 bei.

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Summary of the dissertation:

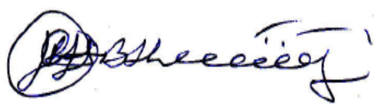
Knowledge Transfer for Microgrids Sustainability – the Case of East Africa

by Paul Bogere

The low East African population with access to electrical energy hinder the Sustainable Development Goal (SDG) 7 realisation. Due to their decentralised energy resources and island mode operation capabilities, microgrids are envisaged as a solution. However, literature reveals various challenges that jeopardise microgrids sustainability in East Africa. Such challenges include the lack of local technical skilled capacity, low electrical energy consumer purchase power, demand, and consumption among others. The sustainability of microgrids, therefore, is as paramount as their implementation. Microgrids-related knowledge transfer, to build local capacity, is envisaged as one of the elements of microgrids sustainability. To facilitate microgrids-related knowledge transfer; a didactics of technology paraphernalia is developed and it contains training content, a didactic architectural model, and a virtual and interactive microgrids learning environment for three stakeholder categories including: (1) Bachelor of Science in Electrical Engineering (BSc Elec Eng) students, (2) consumers of electrical energy services, and (3) secondary school learners aged 14 – 18. The didactics of technology paraphernalia development stages follow the design-based research (DBR) analysis, design, and evaluation (ADE) model. For the development stage of the ADE model; didactic concepts like the revised Bloom's taxonomy and the constructive alignment are employed. Evaluation on the other hand is based on the content validity index of experts' responses and descriptive evaluations. Data that support DBR's ADE model iterations are collected from Tanzania and Uganda through focus group discussions, expert-structured interviews, and administration of questionnaires. The concept of microgrids-related knowledge transfer started as a microgrid sustainability element and evolved into a comprehensive didactic architectural model. The didactic architectural model is a vital reference tool for curriculum developers, training officers in industries, academics and researchers to develop related training content for microgrids and other specialisations. In this monograph, the didactic architectural model highlights stakeholder contextual knowledge transfer and instructional strategies to enable skills acquisition for microgrids sustainability. During the development of the didactic architectural model, application of the taxonomy table reveals that the developed content enables: (1) BSc Elec Eng students to acquire practical hands-on, problem-solving, creative, and innovative skills. (2) Consumers and secondary school learners to acquire practical skills to solve challenges in rural communities. This contributes to SDG's target 4.7 aiming to "ensure that learners acquire knowledge and skills for sustainable development through education…". Knowledge and skills acquisition develops local capacity hence, positively impacts microgrids sustainability. Consequently, electrical energy access numbers increase and contribute to SDG 7 realisation.

Declaration

I **Paul BOGERE,** matriculation number 7327744, hereby attest that this monograph submitted in partial fulfilment of the requirements for the award of Doctor of Engineering in Electrical Engineering of Paderborn University is solely the result of my own effort unless otherwise referenced.

Signed  on this 13th day of January 2025 at Makerere, Uganda

Paul BOGERE, MSc (Elec Eng), MAK

Abstract

The low East African population with access to electrical energy hinder the Sustainable Development Goal (SDG) 7 realisation. Due to their decentralised energy resources and island mode operation capabilities, microgrids are envisaged as a solution to increase electrical energy access levels. Microgrids are particularly essential in rural communities of developing countries characterised by partial coverage of, and hence distant from, the central grid. However, literature reveals various challenges that jeopardise microgrids sustainability in East Africa. Such challenges include the lack of local technical skilled capacity, low electrical energy consumer purchase power due to low-income levels, and low electrical energy demand and consumption among others. The sustainability of microgrids, therefore, is as paramount as their implementation. Microgrids-related knowledge transfer, to build local capacity, is envisaged as one of the elements of microgrids sustainability. To facilitate microgrids-related knowledge transfer; a didactics of technology paraphernalia is developed and it contains microgrids-related training content, a didactic architectural model, and a virtual and interactive microgrids learning environment for three stakeholder categories including: (1) Bachelor of Science in Electrical Engineering (BSc Elec Eng) students, (2) consumers of electrical energy services, and (3) secondary school learners aged 14 – 18. The didactics of technology paraphernalia development stages follow the design-based research (DBR) analysis, design, and evaluation (ADE) model. For the development stage of the ADE model; didactic concepts like the revised Bloom's taxonomy and the constructive alignment are employed. Evaluation on the other hand is based on the content validity index of experts' responses and descriptive evaluations. Data that support DBR's ADE model iterations are collected from Tanzania and Uganda through focus group discussions, expert-structured interviews, and administration of questionnaires. The concept of microgrids-related knowledge transfer started as a microgrid sustainability element and evolved into a comprehensive didactic architectural model in this study. Certain that the didactic architectural model summarises the content development process; it is a vital reference tool for curriculum developers, training officers in industries, academics and researchers to develop related training content for microgrids and other specialisations. In this monograph, the didactic architectural model highlights stakeholder contextual knowledge transfer and instructional strategies to enable microgrids-related knowledge and skills acquisition for microgrids sustainability. During the development of the didactic architectural model, application of the taxonomy table reveals that the developed training content enables: (1) BSc Elec Eng students to acquire practical hands-on skills, problem-solving, creative, and innovative skills. (2) Consumers and secondary school learners to acquire knowledge and practical skills to solve challenges in rural communities. This contributes to SDG 4's target 4.7 aiming to "ensure that learners acquire knowledge and skills for sustainable development through education…". Knowledge and skills acquisition develops local capacity hence, positively impacts microgrids sustainability. Consequently, electrical energy access numbers increase and contribute to SDG 7 realisation.

Table of Contents

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List of Abbreviations

Abbreviation	Explanatory word/phrase
ABET	Accreditation Board for Engineering and Technology
ADE	Analysis, Design, and Evaluation
AfDB	African Development Bank
AFREA	Africa Renewable Energy Access
AI	Artificial Intelligence
API	Application Programming Interface
AR	Academic Registrar
AREI	Africa Renewable Energy Initiative
A:RT-D Grids	Africa: Research and Teaching platform for Development - Sustainable Modular Grids for Grid Stability
AU	African Union
BMBF	Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung)
BMZ	Federal Ministry of Economic Cooperation and Development (Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung)
BoK	Body of Knowledge
BSc Elec Eng	Bachelor of Science in Electrical Engineering
BTVET	Bussiness, Technical, Vocation Education and Training
CA	Constructive Alignment
CBC/E	Competence-Based Curriculum/Education
CE	Chair of Education in historical, systematic and comparative perspectives /Educational Science
CH	Contact Hour
CIU	Consumer Interface Unit
CPD	Continuous Professional Development
CU	Credit Unit
DB	Distribution Board
DBR	Design-based research
DEES	Distributed Electrical Energy System
DES/R	Distributed Energy System/Resources
DFID	Department for International Development
DG	Distributed Generation
DIT	Directorate of Industrial Training
EA	East Africa(n)
EAC	East African Community
EACREEE	East African Centre of Excellence for Renewable Energy and Energy Efficiency

Abbreviation	Explanatory word/phrase
ECOWAS	Economic Community of West African States
EDA	Energy Daily Allowance
ELP	Electronic Learning Platform
Envs	Environments
ERA	Electricity Regulatory Authority
ERT	Energy for Rural Transformation
ESS	Energy Storage System
EU	European Union
EWURA	Energy and Water Utilities Regulatory Authority
FTE	Full Time Equivalent
GEF	Global Environment Facility Trust Fund
GIZ	Corporation for International Cooperation (Gesellschaft für Internationale Zusammenarbeit)
GT	Graduate Training
HEI	Higher Education Institution
HoD	Head of Department
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
IEC	International Electrotechnical Commission
I(IoT)	Industrial (Internet of Things)
ILO	Intended Learning Outcome
IUCEA	Inter-University Council of East Africa
Ke	Kenya
KenGen	Kenya Electricity Generating Company
KWh	Kilowatt hours
LMS	Learning Management Systems
MCB	Miniature Circuit Breaker
MEM	Ministry of Energy and Minerals
MEMD	Ministry of Energy and Mineral Development
MEP	Ministry of Energy and Petroleum
NCHE	National Council for Higher Education
PLC	Programmable Logic Controller
QAC	Quality Assurance Committee
REA	Rural Electrification/Energy Authority
RECP	Renewable Energy Cooperation Programme
REP	Rural Electrification Programme
SADC	Southern African Development Community
SDG	Sustainable Development Goals
SHS	Solar Home Systems

Abbreviation	Explanatory word/phrase
SREP	Scaling Up Renewable Energy Program
SSA	Sub-Saharan Africa
SSMP	Sustainable Solar Market Packages
STEM	Science, Technology, Engineering, and Mathematics
TCU	Tanzania Commission of Universities
TD	Technikdidaktik (Didactics of Technology in English)
THE	Times Higher Education
Tz	Tanzania
Ug	Uganda
UNDP	United Nations Development Proramme
USAID	United States Agency for International Development
VAT	Value Added Tax
VIMLE	Virtual and Interactive Microgrids Learning Environment
V-Labs	VIMLE Laboratories
WBL	Work-based Learning
WebRTC	Web Real Time Communication
WP	Work Package
ZPD	Zone of Proximal Development

1 Introduction

Considering the case of East Africa (EA), the title for this research monograph is *Knowledge Transfer for Microgrids Sustainability*. Throughout the study and thus in this monograph, emphasis is invested in the sustainability of microgrids through knowledge transfer. The author believes that sustainable microgrids seamlessly yield sustainable electrical energy. The author, therefore, maintains that efforts for achieving sustainable electrical energy, and the associated infrastructure, should be directed towards the sustainability of microgrids.

This chapter, therefore, introduces the study. The chapter starts with a research background in section 1.1 that presents the project description under which this research work is conducted and highlights the population without access to electrical energy. The research motivation is then explored, in section 1.2, underscoring the significance of addressing challenges identified in the existing literature. The research objectives are then expressed in section 1.3 clearly outlining the general and specific objectives plus the essential research questions that guide this study. A summary of the research design is then presented in section 1.4. This is followed by research dissemination, in section 1.5, including conference presentations and peer-reviewed publications. An impression of how the monograph is structured is revealed in section 1.6 and the chapter is summarised in section 1.7.

1.1 Background to the Research

The background to this research is split into two subsections. Subsection 1.1.1 presents the description of the Africa: Research and Teaching platform for Development - Sustainable Modular Grids for Grid Stability (A:RT-D Grids) project under which the study in this monograph is conducted. Subsection 1.1.2, in light of the 2030 Sustainable Development Agenda; presents the status of electrical energy access levels starting with the global, to Sub-Saharan Africa (SSA), and lastly EA.

1.1.1 A:RT-D Grids Project Description

The research executed and reported in this monograph was conducted under the auspices of the A:RT-D Grids project. Funded by the Federal Ministry of Education and Research (BMBF); the A:RT-D Grids project objective is "to develop new ways of electrifying [introducing electrical energy to] remote regions in EA through microgrids and their interconnection" [1, p. 6]. The objective was set to be achieved through a collaborative international and interdisciplinary approach. The composition of the collaborating project consortium, both academic and non-academic institutions, reveals the international project orientation. With Paderborn University (UPB) in Germany as the lead implementer, overseeing all project activities, other associate collaborating universities include Makerere University in Uganda, University of the Witwatersrand in South Africa, Nelson Mandela – African Institute of Science and Technology, and University of Dar es Salaam in Tanzania. The ECOLOG Institute for Social-Ecological Research and Education in Germany plus other non-academic partners including Asantys Systems GmbH, and PI Photovoltaik-Institut Berlin AG in Germany, and the East African Centre of Excellence for Renewable Energy and Energy Efficiency (EACREEE) in Uganda, among others, make up the A:RT-D Grids project consortium [1].

Relatedly, the interdisciplinary bearing of the project is revealed by the specialisation of both the associate researchers and the professors. As the lead implementer, UPB employed 11 associate researchers 10 of whom come from Africa. The associate researchers work under the supervision of six professors from the Didactics of Technology (TD); Education in Historical, Systematic and Comparative Perspectives (CE) commonly referred to as Educational Sciences; Electrical Power Engineering – Sustainable Energy Concepts; Institutional Economics and Economic Policy; Power Electronics and Electrical Drives; and Sensor Technology disciplines [2, p. 1]. The work presented in this monograph is from the TD discipline that specialises in conceptualising the best practices for the instruction of technology-related subjects. In executing the mandate as TD; particular attention is paid to the relationship between the actors (the *who*), the knowledge content (the *what*), and the methods of instruction (the *how*) cf. [3, p. 102]. According to [4, p. 42], TD involves knowledge transfer and developing students' abilities to understand, describe, innovate, and solve technical problems. To this end and in line with the objective of the A:RT-D Grids project, the research work in this monograph focuses on microgrids-related knowledge transfer to selected stakeholders in EA. Therefore, the Work Packages (WPs) of the A:RT-D Grids project that appear in [1] to which the research work in this monograph aims to contribute to include the education and gender WP 2.1. Specifically, networking education, teaching microgrids-related technology, and innovation in scientific teaching. The research work in this monograph further aims to contribute to the development of a toolbox for WP 3.1 and the communication and training for WP 5.2. This research's specific contributions to the A:RT-D Grids project WPs are summarised in Table 28 of section 7.1. Before presenting the specific contributions, a systematic approach to the study is presented. Based on the objective and hence the electrical energy perspective of the A:RT-D Grids project, it is instructive that the status of electrical energy access is examined in light of the 2030 Sustainable Development Agenda. The status of electrical energy access is therefore presented in subsection 1.1.2.

1.1.2 Global and East African Status of Electrical Energy Access

Transforming the world is the goal behind the 2030 Agenda for Sustainable Development. According to [5], the Agenda is a plan of action for people, planet and prosperity. The agenda recognises that poverty eradication in all its forms and dimensions is the greatest global challenge and an indispensable requirement for sustainable development. To this end, 17 Sustainable Development Goals (SDGs) and 169 targets were announced as a new universal Agenda. Global partnerships were envisioned as a pillar for SDGs' achievement by the 2015 United Nations General Assembly [5]. The focus of this monograph is on the seventh SDG.

The United Nations' SDG number seven (SDG 7) aims to "ensure access to affordable, reliable, sustainable and modern energy services for all" by 2030 [5]. The attention is paid to the first target of SDG 7, specifically on electrical energy access [6, p. 1]. Globally, 20% of the urban population and about 84% of the rural in developing countries have no access to electricity [7]. Referring to Fig. 1; there was a significant improvement, on average, in electrical energy access levels globally between 2000 and 2019.

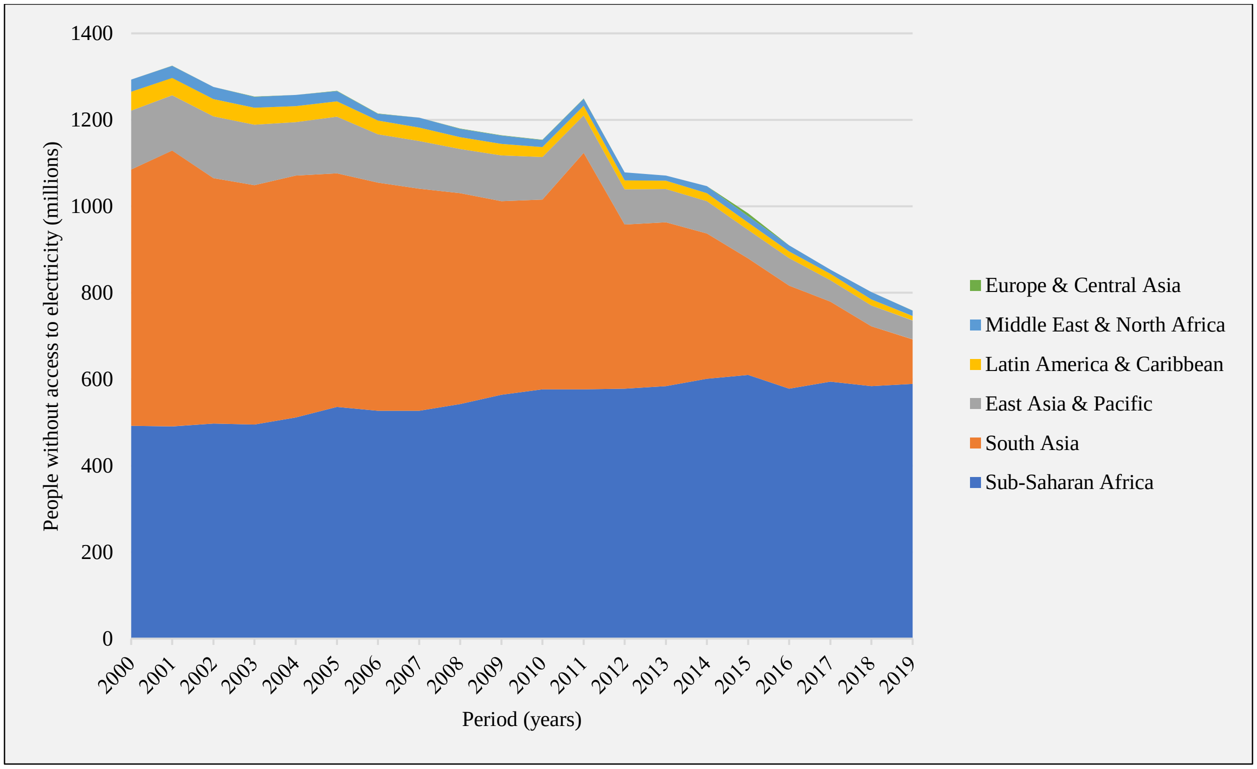


Fig. 1: Global population without access to electricity, adopted from [8].

The numbers in Fig. 1 are corroborated with those in [6, p. 1] stating that the lack of electricity access decreased from 1.2 billion in 2010 to 789 million people in 2018. The decrease is attributed to affordable options such as off-grid solutions deployment. Although there is a decrease in the number of people who had no access to electricity globally from 789 in 2018 [6, p. 2] to 675 million in 2021 [9, p. 8], the average annual growth rate reduced since 2019 through 2021 to 0.6 from 0.7 percentage points [9, p. 9]. Whereas the levels improved globally, on average, electricity access continued to decline for SSA in the same period as indicated in Fig. 1 and confirmed in Fig. 2 [8].

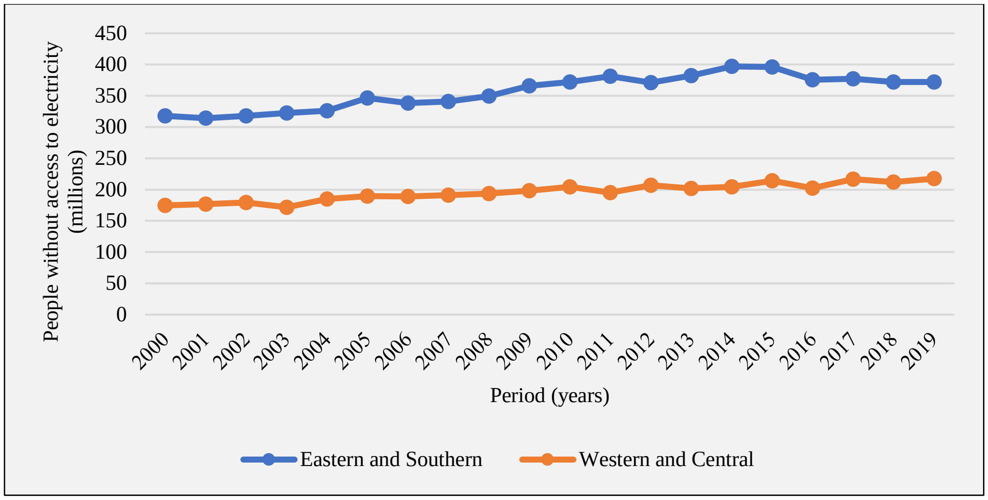


Fig. 2: Sub-Saharan Africa population without access to electricity, World Bank data from [8].

Despite efforts to increase electrical energy access, there are unmatched global demand increases. Efforts such as the African Union (AU) Agenda 2063 targeting a 50% increase in generation and distribution so that 70% of the population in Africa has access to electricity in 2023 are yet to yield results [10, p. 1]. The constant increases in demand are due to population growth that exceeds new connections [11, p. 19]. The population growth comes with electronic gadgets having uninterrupted energy requirements, among other causes of demand increases cf. [12, p. 29]. As such; the generation-consumption gaps, from the already constrained centralised grids, keep widening resulting in low levels of electrical energy access.

Low levels of electrical energy access hinder modernisation in developing countries. According to [13, pp. 10–11]; 560 million people, representing 74%, from SSA had no access to electricity in 2008. In 2018; SSA's population with no access to electricity reduced to 548 million people, close to 70% of the global rural population [6, p. 23]. According to [10, p. 1], about 70% of SSA's population has no access to electricity. Of the 548 million people; 25, 36 and 13 respectively lived in Uganda, Tanzania, and Kenya [6, p. 28]. Although there are notable variations of the statistics reported in the foregoing sentences compared to those in Fig. 2, what is revealed from different sources is that there are low electrical energy access levels in SSA. According to [9, p. 12], the number of people without access to electricity in SSA in 2021 almost remained the same as in 2010! More than 80% of the 524 million people in SSA's rural communities had no access to electricity in 2021. This accounts for close to 75% of the global population with no access to electricity out of which; 25, 36, and 12 million people are Ugandans, Tanzanians, and Kenyans respectively [9, p. 14]. In [8]; the respective urban and rural population with no access to electricity is 6% and 37.3% for Kenya, 27.1% and 78% for Tanzania, 30.1% and 67.2% for Uganda. According to [14], only 24% of households in Uganda have access to electricity through both the national- and off-grids. It should be noted that access to electrical energy is defined by [11, p. 19] as "having electricity for desired services". For rural areas, the desired services are "basic lighting, phone charging and radio for at least 4 hours in a day" [8] with a minimum household annual consumption of 250 kWh [15]. To this end, a statement of this research motivation is detailed in section 1.2.

1.2 Statement of Research Motivation

Based on the A:RT-D Grids project objective, this research is motivated by the low levels of electrical energy access in EA. Various factors contribute to the low levels of electrical energy access in developing countries. In Uganda for example; inadequate electrical power, grid instability due to vandalism, grid unreliability due to low voltages and power outages, high connection and electrical power tariff costs are some of the factors that contribute to the low levels of electrical connectivity and hence low electrical energy access levels cf. [14, p. 46]. Relatedly; income levels with poverty as a major constraint [16, p. 2], transmission and distribution losses that prompt distribution utilities to raise connection charges [17, p. 72], high connection charges that reduce new connection demand [17, pp. 65, 74], and unreliable services evidenced by outages [17, p. 94], [18, p. 127] contribute to low electricity access levels in SSA. Human population and hence energy requirements that grow at a higher rate than the electricity gross production [12, p. 29] and partial coverage of the traditional grid [19, p. 1] are additional causes of low electricity access levels. Partial coverage results in long distances between the grid and unconnected communities and hence; high investment and operational costs are required to minimise the long distances [14], [19, p. 1], [20, p. 1].

Microgrids, due to their distributed energy resources as opposed to the centrally controlled grids, have the potential to increase energy access levels cf. [21, pp. 1–2]. Microgrids, according to [22], are a cost-effective solution to SSA electrification challenges given their scalability and reliability among other advantages. Many scholars such as [23], [24, p. 4] have defined microgrids. Based on all the available definitions; the working definition in this monograph is that a microgrid is a locally decentralised collection of electrical energy generators with, preferably, storage facilities that power electrical loads in a well-defined electrical boundary. Microgrids have the capability to function in an island mode, as a single entity, and the option to connect to a national grid to import or export electrical energy. Many microgrid projects have been funded in Africa but the majority suffer sustainability challenges [20], [25]. According to [26], sustainability is defined as "the systematic preparedness for a project to maintain an electricity service provision over its life span [and beyond the funding period]". Various challenges jeopardise microgrids sustainability in EA and they are a second motivation factor for this research. The challenges include the lack of skilled technical local personnel to design, implement, operate, and maintain microgrids [27, p. 619]; low electrical energy consumer purchase power due to low-income levels and hence poor households in rural areas [28, p. 101]; low electrical energy demand and monthly household consumption of less than 10 kWh [29, p. 88], [30, p. 8] compared to an annual minimum of 250 kWh in [15] and a monthly household national grid consumption of 40 kWh in [17, p. 72]; high electricity tariff, and lack of PUE that hinder rural development [28, p. 104], [31, p. 3] among other challenges.

The author of this monograph envisions a didactic approach through sensitisation and instruction, training/skilling, as a solution to the mentioned challenges and thus a contribution to microgrids sustainability. Scholars such as [20], [26], [32] propose factors that impact the sustainability of microgrid projects. These factors include technological, financial, social, organisational, environmental, legal, regulatory, health and safety, gender, ethical, physical and political. The envisaged didactic approach majorly contributes to the social and technological factors. Specifically, the didactic approach is the microgrids-related knowledge transfer. The author of this monograph asserts that knowledge transfer can significantly contribute to minimising the challenges that jeopardise microgrids sustainability in EA. Knowledge transfer contributes to local capacity building that ensures the following: (1) The availability of a pool of future energy engineers with the expertise to design, install, operate, and maintain microgrids. (2) Sensitisation and skilling aimed at triggering a mindset change so that community inhabitants have divergent views regarding benefiting from any microgrid arrival. For example; instead of limiting microgrid application to the provision of light at night and power radios, inhabitants can be trained to create solutions and businesses tailored to community challenges. In essence; promoting PUE while ensuring effective and efficient electrical energy utilisation results in improved demand, monthly consumption, and income levels since consumers can earn money while utilising electrical energy. As [33] confirms, PUE is a key microgrids success factor.

Therefore, knowledge transfer is a vital element in the sustainability of microgrid projects. Indeed; various literature such as [34, pp. 4, 17–18] confirm that microgrids-related knowledge is a sustainability element. This research work is therefore set to contribute to knowledge transfer efforts, through designing social-technical approaches, to build local capacity in EA for microgrids sustainability. One of the social-technical approaches is the development of locally relevant and community-friendly training programmes cf. [24, p. 1]. The envisaged target groups that need to be trained are cf. [35, pp. 20–21]: the secondary school learners between the ages of 14-18 cf. [36, p. 1874], electrical engineering (Elec Eng) and technical teacher university students, plus consumers of electrical energy and the general public [37, pp. 1859–1860], [38, p. 7], [39, p. 1]. Trained secondary school learners can train inhabitants in their respective communities. The training of the mentioned target groups directly contributes to SDG target 4.7 and should certainly contribute to and achieve the grand aim of microgrids sustainability. With sustainable microgrids; electrical energy access levels improve hence, contributing to SDG 7. In a nutshell; this research work, motivated by the low levels of electrical energy access and the challenges that jeopardise microgrids sustained in EA, is set to achieve the objectives in section 1.3 and subsection 1.3.1 guided by the questions in subsection 1.3.2.

1.3 General Research Objective

Generally, this research work aims to develop a didactics of technology paraphernalia for microgrids-related knowledge transfer to build local capacity in the EA region for microgrids sustainability. It is believed that knowledge transfer is a sustainability catalyst, therefore, the didactics of technology missing factor ought to be added to the microgrids sustainability equation. The author of this monograph envisages the achievement of sustainable microgrids through microgrids-related knowledge transfer to: (1) Bachelor of Science in Electrical Engineering (BSc Elec Eng) students, (2) consumers of electrical energy services, and (3) secondary school learners aged 14 – 18 among other stakeholder categories. The author believes that if sustainable microgrids are achieved, microgrids consequently ensure a sustainable electrical energy infrastructure in the EA region and enable electrical energy access.

1.3.1 Specific Research Objectives

The specific objectives of this research work are to:

1. Develop microgrids-related knowledge content for the transfer of microgrids-related knowledge to the stakeholders mentioned in 1.3. The transfer aims at ensuring skills acquisition for microgrids-related jobs and workplace tasks that enable microgrids sustainability. In developing the knowledge content, the following is accomplished:
    a. Assessment of the degree to which BSc Elec Eng curricula content, from selected universities in EA, address microgrids-related knowledge and sustainability skills.
    b. Characterisation of skill sets for microgrids sustainability.
2. Develop a knowledge transfer didactic architectural model for microgrids knowledge transfer. In the didactic architectural model development process, the following is accomplished:
    a. Highlighted the instructional strategy for each of the stakeholders.
    b. Explored stakeholder-specific microgrids-related knowledge transfer strategies.
3. Design a virtual and interactive learning environment for didactic constructivism of microgrids-related knowledge. The learning environment aims at enhancing the availability of, through online access to, the content in 1 above and the associated laboratories. Therefore, a Virtual and Interactive Microgrids Learning Environment (VIMLE) is designed. In the process of designing VIMLE, the following is described:
    a. An architectural design based on Web Real-Time Communication (WebRTC) technology.
    b. A system design based on the Model View Controller (MVC) architecture.

1.3.2 Research Questions

This study is guided by the following questions:

1. To what degree are microgrids-related knowledge, sustainability, and workplace expected skills addressed in Elec Eng degree curricula for microgrids sustainability?
2. What skill sets are vital to meet microgrids-related requirements for job specifications and/or workplace tasks and enable solving electrical energy utilisation challenges in communities?

3. What plausible solutions can contribute to knowledge transfer efforts for microgrids sustainability while, at the same time, averting challenges that affect curricula development, implementation, and review?
4. What key system features, user requirements and factors need to be considered in the development of VIMLE and the virtual laboratories to enable learners to construct microgrids-related knowledge through the use of VIMLE?
5. What are the existing frameworks to enable microgrids knowledge transfer to, and hence skilling of, secondary school learners, BSc Elec Eng students and electrical energy consumers?

1.4 Research Design in Brief

To achieve the set objectives in section 1.3.1 and offer answers to the set research questions in section 1.3.2 of this monograph, the method of design-based research (DBR) is adapted. DBR is highlighted as a pragmatic method that bridges theory and practice through iterative cycles of the analysis, design, and evaluation (ADE) model applied to short-term research projects. The approach is particularly effective in developing contextually relevant didactic content that addresses stakeholder-specific challenges. The DBR approach, through its participatory nature, underpins stakeholder involvement. Stakeholders such as BSc Elec Eng students, consumers of electrical energy services, and secondary school learners are involved during this research to enhance the relevance and effectiveness of the developed training content. It is worth mentioning that the application of the micro, meso, and macrocycles to the ADE model of the DBR framework for each stakeholder category is elaborated in section 3.1.

The essential components of the research design considered in this monograph include data sources, participant selection, sampling strategies, and data collection tools. Data are collected from selected universities, microgrid operators, and rural communities in Tanzania and Uganda. Justification of the selected data sources is presented in section 3.2. Various sampling techniques such as convenience, purposive, stratified, proportional allocation, and systematic random sampling are applied in different contexts. Challenges that affected data collection, such as language barrier and illiteracy, are also mentioned. Additionally; data collection methods such as expert-structured interviews, focus group discussions, questionnaires, and digital analytics are applied. Consequently, the tools used for gathering the data and the comprehensive statistics are presented in section 3.3. The final part of section 3.3, that is subsection 3.3.2, presents the approaches to data analysis. The systematic approach to data analysis employed f4x[1] speech recognition and MaxQDA[2] 2020 software. Deductive coding, thematic analysis, document analysis, content analysis, and excerpt selection are the applied approaches to analyse data.

[1] A web-based "https://f4x.audiotranskription.de/en" service used to automatically transcribe audio files into text.

[2] A Qualitative Data Analysis (QDA) tool used to manage, code, analyse and visualise qualitative and quantitative data.

1.5 Research Dissemination

Dissemination of research findings is vital. While undertaking the research presented in this monograph, research findings were widely disseminated in Africa, Asia, Europe and the wider international community. Dissemination has been done through conference presentations, annual graduate training series, and peer-reviewed scientific publications as detailed in subsections 1.5.1 and 1.5.2.

1.5.1 Conference Presentations

The author made many presentations, during the operational period of the A:RT-D Grids project, in both conferences and the graduate training series (GTs). GTs are a sequence of annual 5-day training programs that bring together researchers, industrial experts, and students of Elec Eng, technical teacher education, economics and, educational and social sciences to share practices and research outcomes related to sustainable renewable energy development in EA. GTs, therefore, are an interdisciplinary approach to training/skilling. GTs are organised by UPB in Germany under the A:RT-D Grids project. In this subsection, conference and GT presentation details are presented.

The 1st GT took place from 28th June to 2nd July 2021. The virtual event was organised under the theme *Approaching Sustainable Energy Development in East African Countries through an Interdisciplinary project on Microgrids*. The author made two presentations titled: (1) *Goals, Objectives, and Intended Learning Outcomes* and (2) *Problem-Based Learning*. The two presentations were lectures but not results of the research reported in this monograph.

The conference of the section on 'Empirical Educational Research' (AEPF) of the German Society for Educational Sciences (DGfE) 2021. The online conference took place between 13th – 15th September 2021 and was organised by Johannes Gutenberg University, Mainz. The conference theme was *Breaking Boundaries - Connecting Research: Interdisciplinary Empirical Research Beyond Classical Fields of Action*. During this conference, a panel was organised by the TD and CE Chairs under the theme *Breaking Boundaries by Joined Efforts – Benefits of Interdisciplinary Research to Sustainable Energy Development*. The presentation made by the author of this monograph is titled *An Empirical Approach to Electrical Engineering Degree Curricula Assessment for Microgrids Sustainability*.

The 28th Congress of the German Society for Educational Science (DGfE) 2022. The conference took place, online, between 13th – 16th March 2022 and was organised by Bremen University. The conference theme was *Trends that Impose or Remove Boundaries in the Context of Education, Upbringing and Socialization*. A conference panel was organised by the TD and CE chairs under the theme *Transforming Boundaries by Crossing Them*. Together with Mr Henrik Bode, the presentation made during this conference is titled *Development of Participatory Education Formats and Materials for Sustainable Modular Electrical Energy Grids*.

The 2nd GT which took place between 5th to 9th of September 2022 focused on *Sustainable Renewable Energy Development in East Africa*. The author of this monograph made two presentations titled: (1) *Survey-Based Research for Microgrids Sustainability* and (2) *Virtual and Interactive Microgrids Learning Environment*. The two presentations reported partial results of the study in this monograph.

The 25th International Conference on Interactive Collaborative Learning and the 51st IGIP International Conference on Engineering Pedagogy. The conference took place from 27th – 30th September 2022 at the Hilton Park Hotel in Vienna, Austria under the theme *Learning in the Age of Digital and Green Transition*. The presentation made by the author is titled *Work-in-Progress: Development of a Virtual and Interactive Microgrids Learning Environment for Microgrids Sustainability – The Case of East Africa*.

The annual conference of the International Society for Research on Textbooks and Educational Media Research e.V. (IGSBi) 2022. The conference took place between 7th – 9th October 2022 at the University of Würzburg, Germany under the theme *Continuity and Change of Knowledge Stocks in Educational Media*. A conference panel was organised by both the TD and CE chairs. The author of this monograph contributed aspects of VIMLE development to the presentation titled *Sustainable Energy Development as a Key Issue of Social Change in East Africa: Educational Challenges*.

The annual conference of the Section for Intercultural and International Comparative Education (SIIVE) of the German Society for Educational Science (DGfE) 2023. The conference took place between the 9th and 10th of March 2023 at Freie University, Berlin Germany. The conference theme was *Transformation(s) in the Focus of SIIVE. Researching, Reflecting and Accompanying Transformation Processes*. The TD and CE chairs organised a conference panel under the theme *Transform or Die? Challenges and Results of Interdisciplinary Research on Education for Sustainable Energy Development in East Africa*. The author of this monograph made a presentation titled *Didactics of Technology for Sustainable Change? Dealing with the Challenges of Normativity in Teaching*.

The 3rd GT took place between 7th to 11th August 2023. The focus of the GT was *Approaching Sustainable Energy Development in East Africa through an Interdisciplinary Research Project on Microgrids*. The presentation made by the author of this monograph is titled *Skills for Microgrid Sustainability in Rural Communities of East Africa*.

The annual conference of the International Society for Research on Textbooks and Educational Media Research e.V. (IGSBi) 2023. The conference took place from 6th to 8th of October 2023 at Gdansk University, Poland under the theme *Educational Media for Adults*. Together with Mr Henrik Bode, the presentation made during this conference is titled *Teaching Microgrids to East African Adults in Formal and Non-formal Settings: Insights and Reflections on Media at Work.*

1.5.2 Peer-reviewed Publications

During this research, peer-reviewed scientific publications have been registered to benefit a wider international community readership. Interesting to note is that the first and the fourth publications, in the following list, received the best paper award in the respective conferences. All the peer-reviewed publications in the course of this research work are as follows:

1. P. Bogere, H. Bode, and K. Temmen, 'Work-In-Progress: Development of a Virtual and Interactive Microgrids Learning Environment for Microgrids Sustainability – The Case of East Africa', in *Learning in the Age of Digital and Green Transition. ICL 2022. Lecture Notes in Networks and Systems*, M. E. Auer, W. Pachatz, and T. Rüütmann, Eds., Switzerland: Springer Nature, 2023, pp. 671–679. **BEST PAPER AWARD**.
2. P. Bogere, K. Temmen, and H. Bode, 'Knowledge Transfer Concepts for Microgrids Sustainability - The Case of East Africa', in *IEEE Global Engineering Education Conference (EDUCON)*, Kuwait, Kuwait: IEEE Computer Society, 2023, pp. 1–6.
3. P. Bogere, H. Bode, and K. Temmen, 'Skill Sets for Microgrids Sustainability - The Case of East Africa', in *IEEE AFRICON Conference*, Institute of Electrical and Electronics Engineers Inc., 2023.
4. P. Bogere and K. Temmen, 'A Didactic Framework for Microgrids Knowledge Transfer – The Case of East Africa', in *2024 IEEE Global Engineering Education Conference (EDUCON)*, Kos Island, Greece: IEEE, May 2024, pp. 1–5.**BEST PAPER AWARD**.
5. P. Bogere, A. Belov, and K. Temmen, 'Teaching and Learning of Microgrids for Secondary School Learners – a Renewable Energy Sustainability Strategy for East African Communities', in *First International Conference on Sustainable Energy Education (SEED 2024)*, E. de la P. Plaza, A. Blázquez-Soriano, R. Wang, and A. Sereni, Eds., Valencia, Spain: Editorial Universitat Politècnica de València, Jul. 2024, pp. 128–136.
6. H. Asiimwe, H. Bode, P. Bogere, C. Freitag, and T. Mangeni, 'Which Media for Whom? The Implementation of Microgrids as a Trigger of Transformational Adult Learning Opportunities in Formal, Informal and Situational Settings in Times of Change', in *Educational Media for Adults*, E. Andrzejewska, E. Matthes, S. Schütze, and J. Van Wiele, Eds., Bad Heilbrunn: Verlag Julius Klinkhardt, 2024, pp. 245–255.

1.6 Monograph Structure

This monograph is organised into seven chapters excluding the preliminary pages, references, and appendices. Each chapter serves a distinct purpose in the overall research execution as explained in this section.

Chapter 1, the introduction chapter; sets the stage for understanding the study by introducing the research's background, presenting the research motivation statement, objectives, the guiding research questions, and the adopted research dissemination strategies. The chapter explains the microgrids knowledge transfer motivation by highlighting the challenges and the proposed solutions. With the objectives and the guiding research questions, the chapter provides a clear agenda for the subsequent research investigation and highlights the SDGs to which the research directly contributes.

Chapter 2, the literature review chapter; investigates the previous studies, theories, and key concepts that are relevant to the research topic. Section titles that the author considered relevant to this monograph's research topic include distributed energy systems which encompass the microgrid basic architecture, sustainable electrical energy, knowledge transfer, learning theories, and the education system in EA. Literature is therefore examined, guided by the topics within the boundaries of the section titles, and presented in Chapter 2.

Chapter 3, the research design chapter; presents the methodological approach employed in the development of stakeholder-specific microgrids-related knowledge content. The chapter explains the DBR framework, the iterative ADE model processes, the 3-m cycle concept and their application to every stakeholder considered in this research. The chapter describes the data sources and participants, participants' selection and sampling strategy, data collection methods, tools, statistics, and analysis approaches. The chapter also presents the justification for adopting a DBR methodology.

Chapter 4, the results, discussion, and content development chapter presents a comprehensive analysis of the collected data and the discussion of the results generated from the analysis. Results are discussed in the context of the research questions while highlighting significant patterns and insights in view of stakeholder-specific contexts. Research findings are integrated with the existing literature, theory and practice. The iterative nature of the DBR process is applied enabling stakeholder-specific microgrids-related knowledge content development.

Chapter 5 is the didactic architectural model and curriculum development processes. The chapter summarises the microgrids-related knowledge content development process into a microgrids knowledge transfer didactic architectural model. Didactic concepts in the development process and the stakeholder-specific instructional strategy are highlighted. For BSc Elec Eng students, the knowledge transfer strategy is to include the developed content in curricula. Therefore; the BSc Elec Eng curriculum development, implementation, and review processes and the associated challenges are discussed.

Chapter 6 is about knowledge transfer and virtual learning environments. The chapter presents microgrids-related knowledge transfer concepts as solutions to the challenges that affect curriculum development, implementation, and review processes. Online learning platforms being one of the knowledge transfer concepts, the chapter delves into virtual and interactive learning environments. Consequently, a VIMLE platform is designed and the architectural and system designs are discussed.

Finally, Chapter 7 summarises the key findings and contributions of this research and highlights those directly linked to the A:RT-D Grids project WPs. The chapter highlights the achieved objectives and the answered research questions. Further, it offers recommendations based on the research outcomes and suggestions for future research work.

1.7 Chapter Summary

This chapter presents the basis for understanding the aspects of this research. Microgrids-related knowledge transfer which is an essential component in the microgrids sustainability is highlighted. The chapter begins by exploring the background, underpinning this research's evolution and significance within the scope of the 17 SDGs. Informed by the objective of the A:RT-D Grids project; SDG 7 is singled out and the global, SSA, and EA electrical energy access levels are highlighted. The motivation driving this study is then articulated, emphasising the need for knowledge transfer to minimise challenges that jeopardise microgrids sustainability intended to improve electrical access levels. The research aim is presented and focuses on the didactics of technology paraphernalia development comprising didactically developed content, an architectural model, and a VIMLE platform for microgrids-related knowledge transfer. The research questions framed in this chapter guide the systematic inquiry, ensuring a thorough examination of the subject. The research methodological approach is then presented, in brief, highlighting the DBR ADE model. Dissemination of research findings at conferences and the author's peer-reviewed publications are then presented. Through this comprehensive approach, meaningful contribution is directly made to target 4.7 of SDG 4. The author aspires to propose knowledge transfer practical recommendations and theoretical advancements for microgrids sustainability. To this end, literature relevant to this monograph research topic is reviewed in chapter two.

2 Literature Review

A review of existing literature is vital in scientific research to provide an understanding of the research landscape based on the existing knowledge and this provides a foundation for one's research topic [40], [41]. The literature reviewed in this chapter is informed by the research topic and is arranged in six sections. The first section 2.1 presents distributed energy systems (DESs) since microgrids are a category of DES. Based on the conviction that sustainable electrical energy, and thus electrical energy access, can be achieved through sustainable decentralised renewable energy-based microgrids; sustainable electrical energy is explained in section 2.2. The description of the phrase knowledge transfer and the corresponding knowledge transfer mechanisms and characteristics are discussed in section 2.3. To underpin this research in the didactics of technology as a discipline, topics related to knowledge transfer including learning theories and the education system in EA are discussed in sections 2.4 and 2.5 respectively. The chapter summary appears in section 2.6.

2.1 Distributed Energy Systems (DESs)

Many times, the words minigrid and microgrid are used interchangeably. But; do the two words mean the same thing? In this section; distributed energy systems (DESs) to which minigrids and microgrids belong are classified. DES refers to a wide range of energy generation, storage, monitoring, and control technology solutions interconnected to provide electrical energy to consumers. Considering the distributed energy resources (DERs) definition given by [12, p. 31], DES and DER are synonyms cf. [42, p. 2]. According to [43, p. 29], DERs combine both distributed generation (DG) and energy storage (ES) technologies.

DGs are relatively small electrical power source components designed for installation near the consumers' side cf. [43, p. 29]. In [42, p. 2], DGs are referred to as electricity generated near utilisation points. Several DG technologies can be integrated to yield the required electrical power capacity. According to [12, p. 30], independent or groups of DG components can operate as standalone or optional grid-connected power systems. DGs on the market include a collection of both renewable and non-renewable technologies. To contribute to sustainable green carbon-neutral electrical power systems, renewable energy technologies that replenish naturally and are candidates for low operation and maintenance are considered in this monograph. In situations where diesel generators are mentioned in this monograph, the consideration is for backup purposes and increasing the reliability of DESs.

ES technologies are an important part of DESs. This is because DG components like solar PV and wind, among others, are characterised by weather-dependent low and high electrical energy production. The intermittent production does not necessarily correspond to minimum and peak consumption. This necessitates unutilised energy storage to energy storage systems (ESSs) during low consumption periods. Therefore, electrical energy supply is guaranteed during periods of low power production with high energy consumption. Hence; ESSs save energy that would rather be wasted, stabilise the electrical energy supply, and improve the reliability and power quality of DESs. In addition, ESSs are beneficial in reducing the cost of electricity production and consumption if implemented on the generation side (before the meter) and the demand side (after the meter) respectively.

DES, in general, are characterised by several advantages. Such advantages include high efficient energy use, low capital investments, and a broad mix of renewable energy technologies among others. For the high efficient energy use advantage; since DESs are located near the consumers/load/demand side, no electrical energy transmission is involved. In DES networks, therefore, generation and distribution subsystems are near each other which is not the case in centralised systems. Consequently, DESs achieve at least 80% energy use efficiency due to transmission loss elimination [43, p. 30].

For the low capital investments, the fact that there is no electrical transmission subsystem coupled with a relatively short or no distribution subsystem translates into a reduced capital investment since the costs of erecting a transmission part of the network are eliminated cf. [43, p. 30]. According to [12, p. 32], DESs do not only exhibit low operational costs but their installation is equally easy and swift. This makes DESs affordable for utilities in terms of implementation, operation and maintenance. Consequently, lower electrical power tariffs would be expected – making electrical energy consumption affordable for the rural community inhabitants and this improves economic development.

The broad mix of renewable energy technologies is another advantage that characterises DESs. DESs can employ a variety of renewable energy technologies such as geothermal, hydro, solar PV, and wind among others. Several technologies can be integrated to achieve the desired DES power output. In most cases, diesel generators are incorporated as a backup. The broad mix of renewable energy DG technologies offers an improved secure supply and enhanced power system reliability. The classification of DESs is described in the following subsection.

2.1.1 Classification of DESs

According to [42, p. 4], DESs can be classified based on: (1) whether they are grid-connected or not, (2) application, and (3) supply load capacity. Relatedly, [12, p. 38] indicates that DESs can be classified depending on: (1) the capacity of DG units and hence on the application, and (2) the fuel or technology of the DGs. In this monograph; standalone off-grid DESs in island mode are considered since the interest is in rural and remote communities assumed to be far from the grid. None of the microgrids where data was collected is connected to a centralised grid hence, the interest in off-grid distributed/decentralised systems. Off-grid DESs work in island mode – a situation that refers to a system powered or energised by its energy resource [44, p. 12]. Off-grid

DESs, therefore, are independent power systems that supply electricity from local energy resources [45, p. 5].

Reverting to the classification based on size, commonly capacity, DESs can be classified as: standalone systems, pico-, nano-, micro-, and mini-grids. When micro- and mini-grids are interconnected, they (trans)form (into)a macrogrid. Needless to mention that macrogrids are centralised electrical power systems. Various scholars quote differing sizes for purposes of DESs classification and a summary of the sampled literature is cited in Table 1.

Table 1: Classification of DESs based on capacity.

DES Grid nomenclature	Capacity (kW)					Applications
	[10, p. 6]	[46, p. 4]	[47, p. 266]	[45, p. 11]	[48, p. 6]	[10, p. 17], [45, p. 9], [47, p. 266]
Standalone*	0.1	N/A	0 – 5	0 – 0.1	N/A	Lighting, phone charging, appliances for residential & commercial.
Picogrid	1	0 – 0.5	N/A	0 – 1	N/A	Lighting, phone charging, appliances for residential & commercial.
Nanogrid	5	0.5 – 1	N/A	0 – 5	N/A	
Microgrid**	100	1 – 10	1 – 10	5 – 100	1 – 100	All uses for residential, commercial, and industrial.
Minigrid**	100,000	10 – a few MW	10 – a few MW	0 – 100,000	100 – 1,000,000	

*Standalone systems normally supply one customer and are characterised by no distribution network

** Characterised with a small distribution network in a defined boundary but no transmission network.

The reviewed literature provides limited distinction between the terms microgrid and minigrid based on capacity. For clarity; the term microgrid in this monograph refers to DES categorisation in the range of 5 – 100 kW. The foregoing range resonates well with the 100 kW microgrid boundary limit set by the International Electrotechnical Commission (IEC) – a body that established microgrid standards for rural electrification [45, p. 7]. According to [12, p. 38] on the other hand, capacity is an important decision enabler regarding a suitable technology for an envisaged application.

There exist various DES technologies on the market hence, the categorisation of DESs according to technology/fuel. Examples of DGs on the market include diesel generators, steam (or geothermal) turbines, solar photovoltaic (PV), wind energy conversion turbines, and hydro among others. The DG technology is dependent on a chosen/considered energy resource. Based on technology and/or fuel, DESs can be broadly classified as renewable or non-renewable. Examples of renewable energy resources include geothermal energy, solar energy, hydro, and wind energy. Examples of non-renewable resources on the other hand include diesel generators and natural gas-fired microturbines among others. A summary of DESs technologies is presented in Table 2.

Referring to Table 2, many candidate technologies exist for the deployment of DESs. Considering efficiency, installation, operation and maintenance costs; hydro is a befitting technology. However; to decarbonise and achieve an emissions-free electricity system in a bid to avert climate change effects, PV and wind are the suitable technologies given that they have no direct emissions as indicated in [12, pp. 39–40]. Considering operation and maintenance costs in Table 2 coupled with the abundant solar radiation in the EA region, solar PV is the most suitable DES technology.

Table 2: Classification of DESs based on technology [12, pp. 33–40], [42, pp. 7–12].

DES resource category	DES technology	Fuel	Efficiency (%)	Costs		Applications
				Installation (US$/kW)	O&M (US$/MWh)	
Renewable	Solar PV	Solar insolation	5 – 35	1,550–3,830	1 – 4	Standalone, peak shaving[1], residential, commercial, industrial, energy storage integration.
	Wind	Wind speed	30 – 40/45	900–1,400	10	
	Biomass	Organic material	10 – 60			Residential, commercial, industrial, combined heat and power (CHP).
	Hydro	Water	70 – 85/90	30–250	0.045–0.09	Residential, commercial, industrial, pumped water storage[2].
	Fuel cells	Hydrogen and methanol	30 – 70	1,500–3,000	5 – 10	Standalone, residential, hospitals, commercial, industrial, CHP.
	Geothermal	Earth's internal heat	10 – 15	3,000–5,000* 2,000–6,000**		
Non-renewable	Micro gas turbine	Natural gas	21 – 40	300–600	3 – 8	Standby, standalone, CHP, peak shaving, industrial.
	Reciprocating engines: a) Diesel	Heavy oil, diesel, natural gas, bio-diesel,	36 – 43	125 – 300	5 – 10	Standby, standalone, CHP, peak shaving, residential, commercial, industrial.
	b) Gas	Biogas, land-fill gas	28 – 42	250 – 600	7 – 15	Standby, standalone, CHP, peak shaving, residential, commercial, industrial.

*[49, p. 2] **[50, p. 31] [1]Reducing demand during peak periods through onsite energy generation or storage strategy. This majorly supports grid stability. [2]During low demand, surplus electricity pumps water into a reservoir. The water is released through turbines to generate electrical energy during high-demand periods.

According to [51, p. 28], solar radiation for Tz is estimated at 2,500 kWh/m^2/annum which falls within the range of 2,250 – 2,750 kWh/m^2/annum reported by [52, p. 108]. Relatedly, [53] provides average global solar radiation readings for several EA towns in the range of 4.5 – 7 kWh/m^2/day. Average solar irradiation values reported by [54, pp. 5–6] for Uganda's Central, Eastern, Northern, and Western regions are 4.3, 4.94, 5.16, and 4.2 kWh/m^2/day respectively. Although the aforementioned figures for Central and Western regions yield annual solar irradiation below the threshold of 1600 kWh/m^2/annum reported by [54, p. 10], the average solar irradiation levels in [53, p. 12] for Uganda yield values above the threshold. According to [54, p. 1]; installation of solar PV plants is possible, with minimal backup necessities, in regions that receive solar irradiation levels above the threshold. Notably; although solar PV is the preferred DES technology, the installation costs are high. According to [55, p. 8], capital installation costs in Africa are high and depend on the availability of skilled workers, customer load profiles, and availability of subsidies among others. So, microgrid project costs vary depending on country contexts and [55, p. 8] indicates a solar microgrid capital cost average of USD 9,510 per kWp.

2.1.2 Microgrids Architecture

Having given a working definition of microgrids in section 1.2 and the classification in subsection 2.1.1, Fig. 3 illustrates a basic microgrid architecture. The architecture indicates the generation (energy resources), distribution, and demand side subsystems plus an operation and control centre among other auxiliary components cf. [10, p. 13], cf. [45, p. 8]. Each of these subsystems is explained in the paragraphs that follow highlighting preferred options for implementation in the EA context.

The power generation subsystem of the basic architecture has wind, solar, standby diesel generator, and battery storage as the energy resources and the architecture is utility grid connected. It should be noted that, although not included, hydro is another energy resource that is sometimes used. As indicated in Fig. 3; the generated power is conditioned using rectifiers, inverters, and metered. Smart energy meters are used in this architecture hence, making the microgrid architecture smart. This enables remote monitoring and control of the entire network through an energy management system at the operation control centre. Many times, diesel generator backup, solar, and battery storage are the most common energy resources of microgrids in remote rural areas of EA. Although diesel generators are expensive, in terms of running costs due to fluctuating fossil fuel prices, they are included as backup and operated in times of heavy rains. According to [10, p. 14], the levelised cost of energy (LCOE) for diesel generators stands at USD 0.35 per kWh compared to renewables in the range of USD 0.05 – 0.25 per kWh. In Uganda, for example; [56, p. 38] indicates an LCOE of USD 0.14 per kWh for solar PV. Solar is therefore a preferred technology for microgrids implementation in EA as explained in subsection 2.1.1.

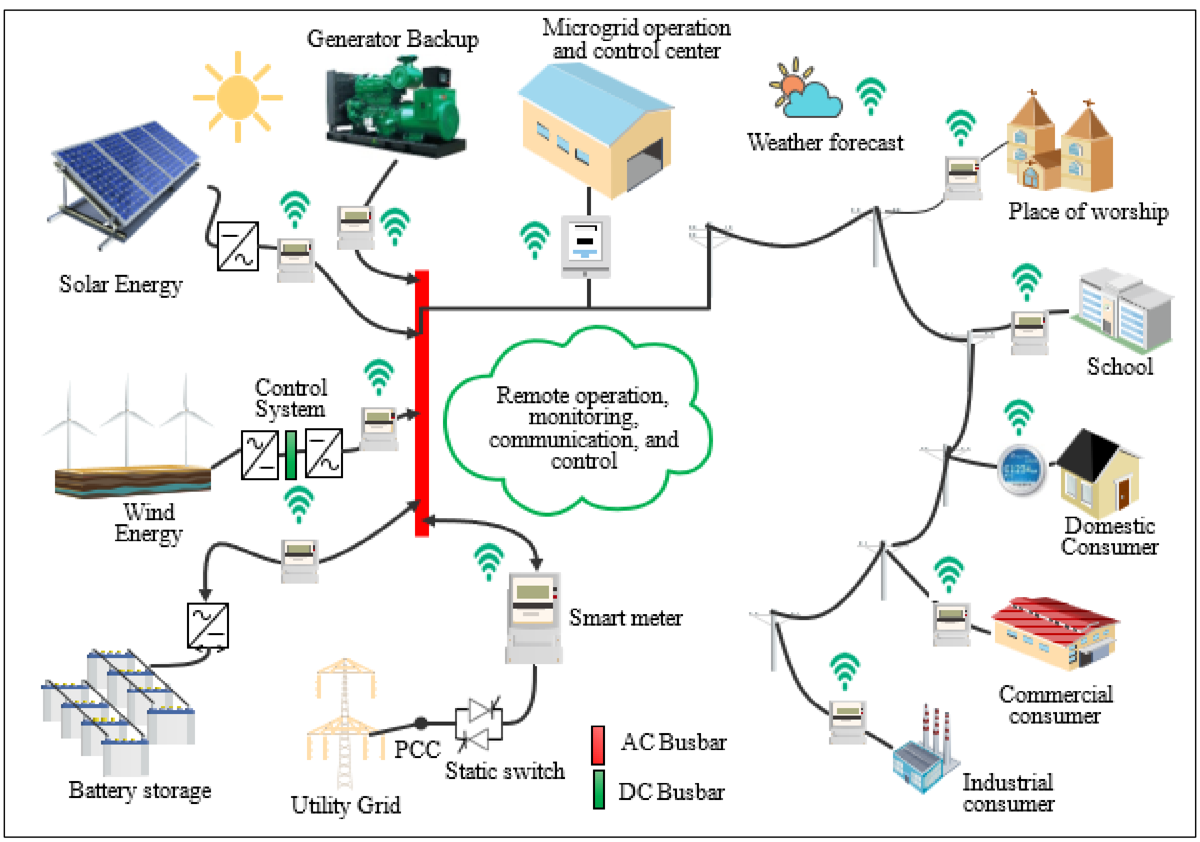


Fig. 3: Illustration of a basic microgrid architecture.

Electrical energy storage is vital given the intermittent energy generation in solar technology-based microgrids. The intermittent generation is due to non-insolation at night and during cloudy and rainy weather. Electrical energy storage, therefore, is an important element of microgrids to improve their reliability [10, p. 14], [48, p. 2]. There exist several electrical energy storage systems including batteries, flywheels, fuel cells, hydrogen storage, supercapacitors, and superconducting magnetic energy storage, among others. Battery storage systems are a preferred option and widely used in EA given that they are comparatively less expensive and easy to install [48, p. 2]. It should be noted though that storage is the most expensive component of a microgrid, costing up to 40% of the entire project according to [10, p. 15]. According to [12, p. 59], parameters that can be used to determine performance, and lifetime, and inform the choice of a battery system are "cost, ambient temperature, environmental impacts, state of charge, duty cycle, voltage effects, flexibility, rate of charging, energy density, and rate of discharging". There are two commonly used battery types in microgrid implementation and these are lead-acid and lithium-ion (Li-ion). According to [10, p. 15]; although they are a mature technology, lead-acid batteries are characterised by heavy weight, recharging cycles of approximately eight hours, less lifetime recharges and they require periodic maintenance. Further; Li-ion batteries on the other hand are characterised by superior energy density, more resilience and a lengthier life cycle. Li-ion batteries are therefore a preferred option to lead-acid batteries. On the contrary, however, [48, p. 2] states that due to their lower costs (capital and installation), 66% of the installed minigrids use lead-acid batteries while 32% use Li-ion batteries.

The distribution subsystem is that part of a microgrid that delivers electrical energy from the generation to the demand side (loads). The demand side subsystem is the aggregated electrical energy-consuming loads at individual consumer premises. Electrical energy distribution to the demand side is normally implemented using overhead cables on wooden or concrete poles delivering 240 V AC single phase 2 wire. In contemporary networks, energy consumption meters are installed on the poles and communication between them (meters) and consumer interface unit (CIU) is enabled via power line communication (PLC). The consumer interacts with only the CIU an arrangement that suggests a pre-payment billing system. According to [10, p. 16], distribution networks can be alternating current (AC) or direct current (DC). The former is preferred in microgrids delivering energy to loads of higher requirements whereas the latter is used in microgrids delivering to lower energy requirement loads such as LED lighting and phone charging among a few other appliances. Further; that an AC/DC hybrid system is also possible.

2.2 Sustainable Electrical Energy

As indicated in [57, p. 5], sustainable energy is indispensable for sustainable development to progress. For sustainable electrical energy to be realised, the development and application of renewable energy technologies is no exception. Renewable energy technologies, therefore, need to be supported across the entire policy spectrum from global to the lowest government administrative units cf. [35, p. 25]. The support and contribution of key institutions and agencies including financial, civil society, and academia is vital and should be harnessed [57, p. 5]. According to [35, p. 25], applicable policy initiatives include import duty and tax exemption on renewable energy technologies, nil subsidies on fossil energy, introduction of subsidies and incentives for renewable energy systems. In addition, the establishment of a knowledge database to provide the public with rural energy technology options, net metering policies, granting power producers based on renewable energy resources legal authority to sell to the national grid, establishment of structures to support decentralised or off-grid renewable energy initiatives in rural communities, promote public-private partnerships among others [35, p. 26]. As mentioned in Chapter 1, sustainable electrical energy can be achieved through sustainable decentralised renewable energy-based microgrids. The remaining part of this section, therefore, pays attention to microgrids in the context of EA.

Regional integration of microgrids implementation (policy, legal, and regulation) is enabled through the East African Community (EAC) working with the African Union (AU) [10, p. 21]. The AU enables coordination with other regional unions such as the Economic Community of West African States (ECOWAS) and the Southern African Development Community (SADC) within Africa and internationalisation outside Africa. The AU established several partnerships for the purpose of improving electrical energy access in the bid to achieve SDG 7. A summary of such partnerships is presented in Table 3.

Table 3: A summary of selected AU partnerships for improving electrical energy access [10, pp. 21–22], [58, p. 29], [59, pp. 83–84].

S/N	Programme/Project/Initiative	Funding Agency	Objective
1	Africa-EU Energy partnership.	European Commission, Germany and Italy	Energy infrastructure funding and microgrids deployment in particular
2	Africa-EU Renewable Energy Cooperation Programme (RECP)	European Commission	Support renewable energy market development
3	Africa Renewable Energy Initiative (AREI)	European Commission	Provide universal access to renewable energy sources by 2030
4	Africa Renewable Energy Access (AFREA) programme through Lighting Africa Initiative	World Bank's Energy Sector Management Assistance Programme	Provide access to off-grid energy by 2030 for 250 million Africans
5	AFREA through Africa Electrification Initiative	World Bank's Energy Sector Management Assistance Programme	Information sharing in regards to electrification initiatives implementation.
6	EletriFi Programme	European Commission & USAID's Power Africa	Supports renewable energy off-grid solutions*
7	New Deal on Energy for Africa	African Development Bank (AfDB)	Enable realisation of universal energy access by 2025. Increase off-grid generation and hence access by 75 million connections.
8	G20 Compact with Africa**	Germany government	Investment in Green Energy Projects, generally, to improve economic situations in member countries.

*Many stand-alone projects in the EAC including in countries like Kenya, Tanzania, and Uganda are supported.

**According to [60], the Democratic Republic of Congo and Rwanda are the only compact with Africa countries from EAC. Other member countries are Benin, Burkina Faso, Egypt, Ethiopia, Ivory Cots, Ghana, Guinea, Morocco, Senegal, Togo, and Tunisia.

Reverting to EAC, EACREEE was founded in 2012, approved in 2013 by the energy ministers of the EAC and launched in June 2016. EACREEE is charged with the responsibility of renewable energy policy coordination, renewable energy and energy efficiency knowledge exchange, support implementation strategies, market creation, and catalysing development in the region through increased access to more secure energy [10, p. 22], [61, p. 30]. According to [61, pp. 31–32], national ministries and designated agencies are the institutions in charge of renewable energy policy-making. Hence; EACREEE works in consultation with state-line ministries in the EAC region including the Ministry of Energy and Petroleum (MEP) in Kenya, the Ministry of Energy and Minerals (MEM) in TZ, and the Ministry of Energy and Mineral Development (MEMD) in Ug among others. The ministries in turn work through agencies some of which include the Rural Electrification Authority (REA) and Kenya Electricity Generating Company (KenGen) in Kenya, the Rural Energy Agency (REA) and Energy and Water Utilities Regulatory Authority (EWURA) in TZ, and the Rural Electrification Programme (REP) formerly Rural Electrification Agency and Electricity Regulatory Authority (ERA) in Uganda for implementation of renewable energy policies and projects. There exist several initiatives, for renewable energy implementation, in the EAC. With emphasis given to renewable energy and solar in both TZ and Ug, selected initiatives are summarised in Table 4.

Table 4: Selected initiatives for renewable energy implementation in the EAC [1, p. 6], [62, pp. 9–12], [63, p. 31], [64, p. 78].

S/N	Programme/Project/Initiative	Funding Agency	Objective
1	Africa Research and Teaching platform for Development – Sustainable Modular for Grid Stability (A:RT-D Grids)	Germany's Federal Ministry of Education and Research (BMBF)	Develop new ways of electrifying [introducing electrical energy to] remote regions in EA through microgrids and their interconnection.
2	Tanzania Energy Development and Access Project	World Bank's Global Environment Facility Trust Fund (GEF)	Promote Solar Home Systems (SHS) uptake in Tanzania
3	Scaling Up Renewable Energy Program (SREP) through minigrids, microgrids, and REA's Sustainable Solar Market Packages (SSMP) projects	European Union Climate Investment Funds	Provide electricity access to off-grid consumers in TZ's rural communities.
4	Green Mini Grid Program	UK's Department for International Development (DFID)	Provide electricity access in rural TZ communities
5	Cluster solar project	European Union	Install 15,000 SHS in TZ's Lake Zone
6	Microgrid pilot	Government of TZ	Construct 20 microgrids in rural TZ communities
7	Uganda photovoltaic pilot project for rural electrification (UPPPRE): Period 1998 - 2002	United Nations Development Programme (UNDP)	Ease conditions to enable end-users to access loans for SHS by establishing credit guarantees to local banks and finances to PV suppliers.
8	VAT exemption for imported PV components and a 5.5 USD/W_p (up to 50 W_p max) subsidy for household solar equipment. Period 2002 – 2013.	World Bank's Energy for Rural Transformation (ERT)	Stimulate private SHS market in Uganda through End-user cost reduction, rural-based micro-financing, support to business start-ups, training of PV suppliers
9	Promotion of Renewable Energy and Energy Efficiency Programme (PREEEP). Period 2019 – 2023	Germany's Federal Ministry of Economic Cooperation and Development (BMZ) and Government of Ug.	Promote renewable energy and improve energy efficiency in Ug.

The foregoing initiatives, among others at large, are aimed at ensuring a sustainable supply of electrical energy for sustainable development. With DESs encouraged as a sustainability venture for the provision of electrical energy, microgrids are installed. The sustainability of microgrids is vital in the sustainable electrical energy equation. As indicated in section 1.2, knowledge transfer is an important microgrid sustainability factor supported by scholars such as [24], [34]. It is therefore instructive that knowledge transfer is explored highlighting the mechanisms and characteristics for effective transfer. Knowledge transfer is, therefore, explored in section 2.3.

2.3 Knowledge Transfer

There exist many descriptions of knowledge transfer. According to [65, p. 151], knowledge transfer is a process through which one organisation's department is affected by another department's knowledge and practice. Relatedly, [24, p. 2] describes knowledge transfer as multiple channels used to transfer knowledge to gain an economic value or competitive advantage. The author of this monograph contends that knowledge transfer is not limited to an organisation's departments but also from one organisation to another. Similarly, knowledge transfer can also occur from an organisation, say academic institutions, to communities and vice versa and this is the case for this research. It is therefore imperative that any knowledge transfer process facilitates knowledge acquisition, that is, learning with or without teaching. It is vital at this point to explain what is meant by knowledge.

Knowledge in this monograph refers to realities, descriptions and information about microgrids. These can be acquired through formal school education or on-the-job informal experiences either theoretically or otherwise practically. The foregoing description resonates with that given in [66, p. 6] and asserts that "knowledge is acquired as a result of education, training or self-study". This therefore means skills or competency acquisition. It is therefore important that the terms skills and competence, and how they relate to knowledge, are clearly understood since they are sometimes used interchangeably. In [66, p. 6], competence is described as the "demonstrated ability to apply knowledge, skills and attitude to achieve desired results". Further; that skills are "abilities to perform certain functions and are supported by practical experience[s]". It is therefore clear that knowledge, competencies, and skills are closely related to each other as illustrated in Fig. 4. Understanding such relations is vital for introducing both microgrids training programmes and content in curricula cf. [66, p. 6].

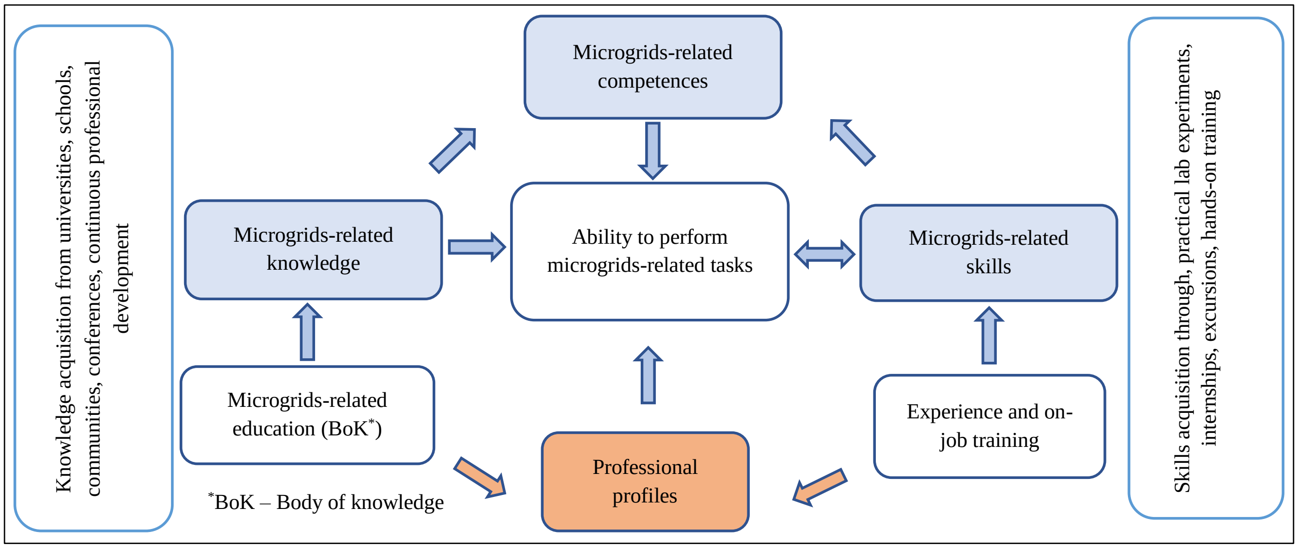


Fig. 4: Illustration of knowledge, skills, and competence relationships, adapted from [66, p. 6].

Reverting to knowledge transfer, [67, p. 8160] states that "knowledge transfer is a device to maximise the benefit from knowledge". A device can be equipment, a tool, an apparatus, a plan, a technique, a means, an approach, or a mechanism. The designed virtual learning environment in this study, the developed stakeholder-specific content, and the didactic architectural model are knowledge transfer devices. Furthermore, [67, p. 8160] indicates that knowledge transfer is vital in value creation from existing knowledge and triggers innovations through knowledge recombination. To enable effective knowledge transfer, attention has to be paid to the transfer mechanisms and knowledge characteristics. Therefore; knowledge transfer mechanisms and knowledge characteristics are presented in subsections 2.3.1 and 2.3.2 respectively.

2.3.1 Knowledge Transfer Mechanisms

In the process of reviewing literature, it is revealed that knowledge transfer is well-researched. Knowledge transfer is possible at various levels including individual, group, intra-organisational (same organisation departments or project units), inter- organisational, regional and national levels [24, p. 4], [68, p. 18]. The envisaged or desired level of knowledge transfer influences the transfer mechanisms employed. According to [69, pp. 1177–1178], knowledge transfer mechanisms are formal and informal methods, platforms, tools, and characteristics for "sharing, integrating, interpreting and applying know-what, know-how, and know-why embedded in individuals and groups" to support project tasks performance. Analogical transfer, knowledge compilation, and constraint violation are the knowledge transfer mechanisms reported by [70, pp. 3–5]. Analogical transfer is a process grounded on prior knowledge retrieval from memory, followed by making a connection between retrieved knowledge and the task at hand. The final step is crafting (or constructing) solutions, inferences or conclusions applicable to the task at hand cf. [70, p. 3]. The analogical transfer of knowledge is comparable to the constructivism theory of knowledge transfer. For novices, [70, p. 3] contends that the task at hand should be "similar on the surface and that [it should] share the same relational structure". The knowledge compilation transfer mechanism works as a tool that analyses prior knowledge instructions into a step-by-step procedure to solve problems [70, p. 3]. In other words; the tactics learnt in the process of performing a task such as reading a manual to install a PV module, can be applied to perform many other tasks. The constraint violation knowledge transfer mechanism on the other hand involves a generate-evaluate-revise knowledge transfer cycle [70, p. 4]. It is a repetitive cycle in which a restriction (constraint) in a task-solving procedure is revisited and evaluated so as to revise the procedure to perform a task. The foregoing discussion considers knowledge transfer mechanisms as characteristics rather than channels, methods, platforms, and tools. It is prudent that mechanisms such as methods, platforms, tools and processes through which knowledge transfer takes place are equally discussed in the following paragraph.

According to [24, p. 4], knowledge transfer takes place through people, research, publications, events, education, and technology infrastructure transfer mechanisms. Technology transfer is described as "the movement of know-how, skills, technical knowledge or technology from one organisational setting to another" by [24, p. 4]. As indicated in [24, p. 8], it is important to understand factors such as "what is transferred", why, who is participating, the transfer degree and "how [the] transfer leads to" the desired aim. Providing responses to the foregoing factors reveals the transfer process and thus the mechanism. Referring to the aim and objectives of this research, microgrids-related knowledge is transferred to achieve sustainable electrical energy through sustainable microgrids. Microgrids knowledge transfer is done through the education and training of the three stakeholders – school children aged 14 through 18 (corresponding to grades 9 through 13 in the German education system), BSc Elec Eng and technical teacher students, and electrical energy consumers in EA rural communities. The training programs for the three stakeholder categories are developed and a live microgrid demonstrator/laboratory is designed from UPB in Germany and installed in EA. The EA school system and the university education system structures are leveraged in the knowledge transfer efforts as detailed in the discussion in Chapter 5. A complete process and thus the knowledge transfer mechanism is presented in section 5.1 with specific-stakeholder knowledge transfer media elaborated in subsection 5.1.2.

2.3.2 Knowledge Characteristics for Effective Transfer

Characteristics of knowledge including codifiability, complexity, importance, tacitness, and teachability affect knowledge transfer effectiveness [67, p. 8156]. To achieve effective transfer; knowledge ought to be codifiable, relatively simple, important to the intended recipients, explicit – decreased tacitness, and teachable. Reference [67, p. 8156] indicates that tacitness can be reduced through high knowledge codification. Relatedly, [69, p. 1178] describes knowledge explicitness in regards to how codifiable knowledge is from tacitness to explicitness at the furthest ends of a continuum scale in decreasing complexity. Knowledge transfer effectiveness improves, with less effort, if recipients are familiar with the knowledge and if the complicatedness of the knowledge in question is reduced.

In addition, [69, p. 1178] mentions three other knowledge characteristic dimensions namely: reach, lifecycle and flow time. Knowledge reach refers to the knowledge sharing degree across different levels and/or boundaries and is vital in deciding a transfer method. For example; coaching is a suitable transfer method for knowledge sharing to an individual than training sessions for bigger groups of people. The knowledge lifecycle is a knowledge management process and illustrates knowledge progression from creation through to the evolution phase in a six-phase cycle, shown in Fig. 5, established by [71, pp. 29–32]. Creation is where new knowledge is discovered, then structured in the organising phase, and codified from tacit to explicit in the formalising phase. The explicit knowledge is availed to stakeholders in the distributing phase, used in the applying phase and improved during the evolving phase. The flow time knowledge dimension on the other hand is the time to move from one phase to another. The time flow dimension is short if the process for the knowledge to progress from one phase to another is fast and long for slow-moving processes. The time flow dimension is vital in aiding a knowledge transfer method selection for example, a face-to-face discussion is preferred for quick knowledge transfer whereas a post-project review is suitable for longer transfer [69, p. 1178].

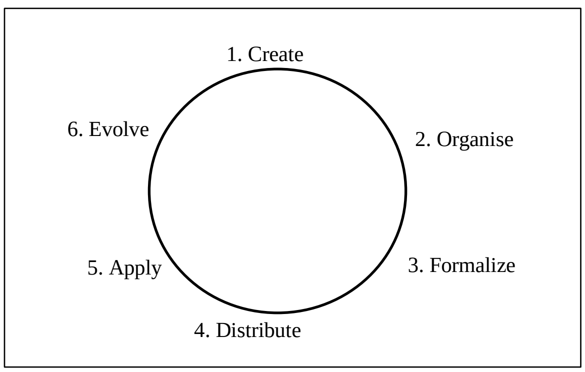


Fig. 5: Illustration of the knowledge management lifecycle, adopted from [71, p. 32].

To this end; in order to transfer microgrids-related knowledge with less effort and achieve a positive sustainability impact, microgrids-related knowledge has to be highly codified, explicit, less complex and familiar to the recipients to easily comprehend. In addition, the knowledge should be aimed at solving local challenges and meeting the interests of the intended recipients so that there is a high-importance (value) deliverable attached to the knowledge. For effective knowledge transfer; the reach, lifecycle and flow time knowledge characteristic dimensions are helpful in guiding to choose a suitable knowledge transfer method. Relatedly, learning theories are presented in section 2.4.

2.4 Learning Theories

Various scholars have extensively published several theories that explain how learners acquire knowledge and skills. Some of the published theories that support learning include the activity theory, behaviourism, cognitivism, connectivism, constructivism, and objectivist theory among others [72, p. 3], [73, p. 114], [74, p. 732], [75, p. 5], [76, p. 3]. Consideration of applicable learning theories and the teaching-learning activities, for their implementation, is vital during designing and developing Electronic Learning Platforms (ELPs), knowledge content and related educational materials. Selected theories are therefore presented in this section.

2.4.1 Objectivist Theory

Objectivists argue that knowledge is external and transferred to learners by experts. Experts include instructors, textbooks, magazines, and journal articles among others. As such, there is no new knowledge constructed by learners but rather learned from available knowledge sources [72, p. 3]. In [74, pp. 736–737], the objectivist theory is referred to as the traditional pedagogy. The authors assert that the traditional pedagogy contribution is valuable since instructors offer expert facilitation and assistance to learners through well-structured materials. One of the limitations of objectivist theory is that learners are passive knowledge receivers [74, p. 737].

Given that instructors' guidance is vital in the learning process, the objectivist theory is considered in designing ELPs such as VIMLE and in the implementation of knowledge content. Instructors can offer their expert guidance by preparing and uploading learning materials and pointing learners to relevant up-to-date references. In the same way, experts can deliver the developed stakeholder-specific content and materials during training. Content implementation can, therefore, be accomplished by instructors. Relatedly; the GT was implemented by instructors, and other experts, partly through the traditional pedagogical approach of lectures. This approach illustrates the objectivist theory where knowledge is independent of the learner but imparted to trainees by instructors who, based on expertise; control the materials, and manage the learning pace and direction [77, p. 31]. Scholars such as [77, p. 32], [78, p. 387] contend that objectivist and constructivist theories complement each other and thus, constructivism theory is explained.

2.4.2 Constructivism Theory

Although the terms constructivism and constructivist are related and used interchangeably, there is a slight difference between them. Scholars such as [79, p. 230] argue that constructivism is a philosophical description of how "learners create their own learning". Constructivism underpins constructivist theories such as cognitive constructivism and social constructivism [77], [79]. Constructivism explains how learning occurs through knowledge acquisition. It is a guiding principle for instructional (teaching-learning) methods that emphasise mental construction, that is to say, adding new knowledge onto the already known cf. [80, p. 66]. Constructivists argue that learners develop new knowledge based on their previous experiences and interactions. According to [72, p. 3], new knowledge is constructed through real-life experiences, social and environmental interactions. Active interaction with the learning materials enables learners to construct new knowledge. A learner's interaction with instructors and peers (other learners) in the learning environment leads to new knowledge construction. Due to differing individual perspectives, opinions and ideas; the human resource interaction results in socio-cognitive conflicts. Socio-cognitive conflicts arise in situations where people have diverging interpretations or assessments about the same topic, object, or subject, and this promotes learning, cognitive development, and positive social relations. The conflicts lead to improved psychological functions resulting in the growth of the zone of proximal development (ZPD) and thus, new knowledge construction is achieved [74, p. 740]. In other words, new knowledge is constructed once ZPD growth is attained.

ZPD, as defined by L. S. Vygotsky [81, p. 86], cited in [82, p. 1550], and [83, p. 238], is:

> … the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers.

In other words, ZPD is a learner's knowledge, skill, or competency gap between what is known or what they can independently do and what they can do if and only if guided, assisted, or supported by an instructor or peers. It is therefore vital that an instructor precisely defines a learner's ZPD based on what a learner knows or what they are able to learn or do without support and under guidance. Once the ZPD is defined, then suitable learning activities are developed targeting the ZPD growth. According to [74, p. 741], the learning activities should be collaborative and should "involve discussions and exchange (socio-cognitive conflicts) between learners".

The synchronous and cooperative features of ELPs are the constructivism theory implementation strategy for electronic platforms. The integration of messaging applications for communication, enabling ELP users to collaborate and interact, is another strategy for constructivism theory implementation. Learning tasks that compel learners to work in groups, and interact with industries, communities, or real work environments are other strategies for implementing constructivist theories. The mentioned learning activities align with the constructivist principles that emphasise knowledge construction through social interaction, hands-on world of work experiences while applying theoretical knowledge, and discovery learning.

2.4.3 Activity Theory

Activity theory is a social and psychological theory that supports learning through activity cf. [84, p. 220], cf. [85, p. 447]. The activity theory pays attention to human interaction when executing a given activity. According to [72, p. 3], it is through activity execution that human consciousness leads to learning cf. [86, p. 99]. When an activity is practised, it becomes an involuntary process over time. Hence, a learner has a better understanding of the concept in question and this leads to new knowledge construction.

Activity theory has evolved from the first- through to the third-generation. Models of the said generations are widely published and need not be reproduced here. However, a few pertinent issues are noted here. The first-generation model is characterised by three elements: the mediating artefact (environment/technology[digital] tools, instruments, procedures), the object (specific knowledge or the [learning] activities), and the subject (learners/participants) [84, p. 221], [87, p. 83], [88, p. 134]. In the first-generation model of activity theory, according to [84, p. 220], learning is a result of the subject's interaction with the products of the object in the mediating artefact but no emphasis is placed on the direct subject and object interaction. The same view is mentioned in [88, p. 134] that the first-generation is based on the concept of mediation. This is a historical perspective of the activity theory whose inadequacy is the individual focus rather than group actions. The second generation solved the inadequacy challenge of the first-generation by considering collective actions (individual and group) and the concept of direct interactions between the mediating artefacts, objects and the subject. Consideration of the group activity(ies), a social perspective of the theory, introduced additional elements that characterise the second-generation model and these are the community (learners' groups), division of labour (specific tasks assigned to group members) and rules (guidelines that control learning) [84, p. 221], [85, p. 448], [88, p. 135], [89, pp. 1–2]. The concept of direct interactions amongst the elements that characterise the second-generation model creates a complex activity system that emphasises contradictions. Contradictions, due to individual interpretations, lead to enhanced object/knowledge (implicitly or explicitly), improve the activity system and lead to learning cf. [84, p. 221], cf. [88, p. 134].

One drawback of the second-generation model of the activity theory is that it is insensitive to diversity – culture, traditions, and divergent views. The solution to diversity insensitivity of the second-generation is a third-generation with interacting activity systems as opposed to a single activity system [84, p. 221], [88, pp. 135–136]. The third-generation activity theory "increases the openness and interactivity of activities" and "focuses on the negotiation and conversion of goals and motivations in the learning process" [84, p. 221]. According to [88, p. 135], the third-generation activity theory "needs to develop conceptual tools to understand dialogue, multiple perspectives, and networks of interacting activity systems". Based on the third-generation, a model applicable to the context of this monograph is presented in Fig. 6.

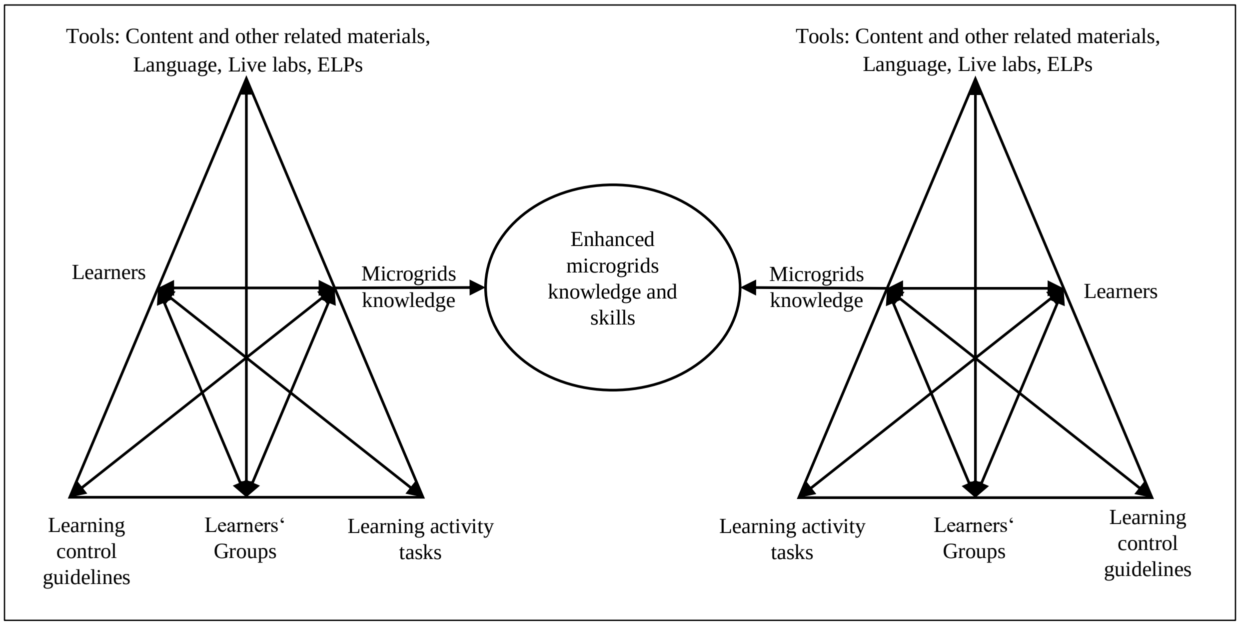


Fig. 6: The third-generation activity theory, adapted from [84, p. 221], [88, p. 136].

Both the activity and constructivism theories have a social aspect and they play a complementary role in learning. Own knowledge is constructed when learners are actively engaged during the learning process [73, p. 114]. The author of this monograph asserts that the development of interactive electronic activities (e-tivities) is the implementation, application and operationalisation of the activity theory, in ELPs, on one hand. Since the e-tivities actively engage learners and there is collaboration or interaction with instructors and peers on the other hand cf. [75, p. 5]; constructivism theory application comes in hence, benefiting from the complementary role of activity and constructivism theories. Problem-based learning (PBL) is another example through which activity and constructivism theories' principles can be coupled, when implemented in learning environments, to a learner's benefit – meaningful learning. Specifically, as indicated in [90, p. 39], PBL is a form of activity theory implementation. As [91] reveals, one of the ways to implement PBL is through internships and internships are a student-centred approach to learning. Most teaching-learning activities for realising learning theories are student-centred and aim to ensure that learners acquire relevant skills and competencies. Competency-based education is vital in preparing learners to acquire the world of work skills. To this end, the education system in EA is discussed in section 2.5.

2.5 The Education System in East Africa

The education system in EA has undergone significant improvements and the most recent is the introduction of competency-based curriculum (CBC) otherwise referred to as competency-based education (CBE). According to [92, p. 74], the move from knowledge-based to CBE is aimed at equipping learners with relevant life competencies. CBE is being implemented at various levels and in different disciplines in EA including secondary schools, higher education, medical and technical education [93], [94], [95], [96], [97]. The structure of the education system indicating the various levels from pre-primary to tertiary education for EAC countries is summarised in Table 5.

Table 5: The education system structure in EA, adopted from [98, pp. 13–14].

Education level		**Level no.**	**Qualification**
Pre-primary	Early Childhood Development (ECD)	1	Certificate of General Basic Education[1]
Primary	Primary	2	Certificate of Primary Education
Secondary	Lower Secondary	3	Certificate of General Basic Education Certificate of Vocational Basic Education Artisan certificate (Theory and Practice)
	Upper secondary	4	Certificate of General Secondary Education Certificate of Vocational Education Diploma of Vocational Secondary Education
Higher (Tertiary)	Post-secondary training	5	Diploma (Technical & none technical)
	Undergraduate	6	Bachelors degree
	Masters Programmes	7	Master's degree Postgraduate Certificate Postgraduate Diploma
	Doctoral	8	PhD, Doctorate Post-Doctorate

Although there are individual country variations, all qualifications frameworks in EA fall within the education system structure in Table 5. As variation examples, the structures for Tanzania and Uganda start at primary education as their level 1 and end at doctoral education with respective levels 10 and 9 [99, pp. 6–7], [100, p. 4]. Even though the Tanzania and Uganda structures don't reflect the pre-primary education level, ECD is offered in both countries by private education institutions. The structure of the EA education system offers various paths encompassing basic, business, industrial/technical, vocational, and professional education and training. With the introduction of CBC at various levels in the education system structure, the concept of microgrids-related knowledge transfer fits well in the CBE strategy for both secondary and tertiary education levels whose content is developed in this study. This is because, generally, the CBE strategy is to enable competency mastery for work readiness to address the employability gap and align with the global standards [101]. Most important; a workforce that contributes to solving microgrids-related challenges in general and electrical energy utilisation challenges in particular for sustainable economic development especially in the rural communities. Integration of microgrids-related training in EA education systems, therefore, supplements the CBE strategy.

One avenue of microgrids-related training integration into the EA education system is at vocational level. There exist numerous opportunities for vocational training in EA. In addition to vocational training, business and technical training are pivotal in sustainable economic and skills development. Collectively referred to as business, technical, vocational education and training (BTVET) are career trades, among others, catered for in the EA education system structure. Citing examples of EA countries, [102, p. 40], [103, p. 50] argue that BTVET is an effective strategy in the development of a skilled human workforce for a country's development. BTVET is mainly funded by governments, church-based, for-profit, and non-profit organisations [102, p. 42]. The training takes place in BTVET institutes and/or training centres that admit primary leavers and award artisan/craft certificates. Lower and upper secondary school leavers on the other hand are admitted to BTVET colleges and respectively awarded certificates and diplomas. Other students prefer university training to BTVET and thus pursue degrees at universities ranging from bachelors to doctorates. According to [103, p. 51] non-formal training and awarding of certificates is also possible and in Uganda, this is done by the Directorate of Industrial Training (DIT). DIT is a quality assurance body that develops both BTVET, the formal, and the non-formal certification standards. The microgrids-related knowledge content proposed in this study is a candidate for non-formal DIT standardisation.

2.6 Chapter Summary

This chapter provides an overview of the existing literature on aspects related to this monograph research title. The chapter begins with distributed energy systems, discussing the vital aspects of distributed generation and battery energy storage. DES characteristic advantages and DES classification are explained highlighting the distinction between micro- and minigrids and indicating solar PV technology as a preference. The basic microgrid architecture is illustrated and sustainable electrical energy is explored revealing AU partnerships and EAC initiatives for improving electrical energy access levels. The chapter also delves into the principles and the role of DESs, particularly microgrids, in promoting energy efficiency, and sustainability. The chapter further examines the importance of knowledge transfer in microgrids sustainability stating the definitions and illustrating the relationship between knowledge, competencies, and skills. Relatedly, knowledge transfer mechanisms and knowledge characteristics for effective transfer are explored. Additionally; relevant learning theories that underpin the design and development of LMS, knowledge content and related educational materials are reviewed. The chapter further discusses the education system in EA, mentioning the introduction of CBE and indicating the education structure from the ECD to the doctoral level. Most importantly, revealing how the stakeholder-specific microgrids-related knowledge content proposed in this study fits into the EA education structure. By integrating insights from all the mentioned aspects, the literature review chapter lays a foundation for understanding how to effectively educate and engage stakeholders towards sustainable microgrids and thus improve electrical energy access levels. To this end, the research design and methods are discussed in Chapter 3.

3 Research Design/Methodological Approach

Mixed methods are employed in this research and as such numerical (quantitative) and descriptive (qualitative) data are collected. The use of both quantitative and qualitative research techniques is described in [104, p. 384] as a pragmatism philosophy – that focuses on practical applications and outcomes. A key pragmatism principle employed in this research is deriving knowledge from experience and experimentation. As such, one of the methods employed in this research is document analysis for example the empirical approach to BSc Elec Eng curricular analysis performed in subsection 4.1.1. Document analysis and other techniques used to analyse data in this research are described in subsection 3.3.2. Other methods used include expert-structured interviews, focus group discussions, and questionnaires presented, together with research data statistics in section 3.3. On the other hand; a modelling and simulation approach is employed in the design of VIMLE and the development of virtual laboratories. Data sources, selection of research participants, and the sampling strategy are highlighted in section 3.2. All these approaches consequently integrate into the design-based research (DBR) framework which, as indicated in [105, p. 4], is well aligned to the pragmatism philosophy/practical viewpoint for knowledge transfer. The DBR framework, which is predominantly applied in this research, is explained in section 3.1.

3.1 Research Framework (Design-based Research)

As indicated in [106, p. 34], [107, p. 187], the DBR framework is widely applied in educational, or rather didactic, related research. DBR applies to knowledge creation [108, p. 209], curriculum design [109, p. 67], online platform development [110], and online training and learning [107][108]. It should be noted that the phrase DBR symbolises nomenclatures like (educational)design research, design experiments, development(al) research, engineering research, and formative research among others that are used by various researchers [107, p. 187], [109, p. 4], [111, p. 6], [112, p. 85]. Although the nomenclatures are crafted by researchers to reflect the slight focus differences, the approach remains the same [111, p. 6]. DBR basically consists of the analysis, design, and evaluation stages collectively referred to as the ADE model. DBR is defined by [111, pp. 6–7] as:

> a systematic but flexible methodology aimed to improve [didactic] practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories.

The foregoing definition includes development and implementation stages that account for the AD(DI)E model employed by some researchers. The definition suits the context of the research work reported in this monograph given that there is collaboration with a secondary school, universities, experts and consumers as recommended by the key message in [112, p. 83]. The collaboration resulted in data collection from respondents in Table 8 of subsection 3.3.1 and invaluable support to the ADE stages. The collaboration consequently led to the development of contextual stakeholder-specific training content. However, the definition ignores a vital evaluation stage in the ADE model. Nevertheless, a three-stage ADE model of the DBR framework that appears in [112, p. 86] and [113, p. 83] is applied in this research.

In applying the ADE model, refinement of ideas is done after evaluation and iterations are performed until a desired goal is achieved. This requires plenty of time which is the reason for DBR's application to long-term projects. However, [114, p. 78] treats the ADE stages of the DBR framework as micro cycles – an approach that reveals the possibility of using DBR as a methodology for short-term projects. As indicated in Fig. 7, any single DBR stage forms a micro-cycle. Meso-cycles are a combination of more than one micro-cycle and macro-cycles, on the other hand, combine more than one meso-cycle [2, p. 2].

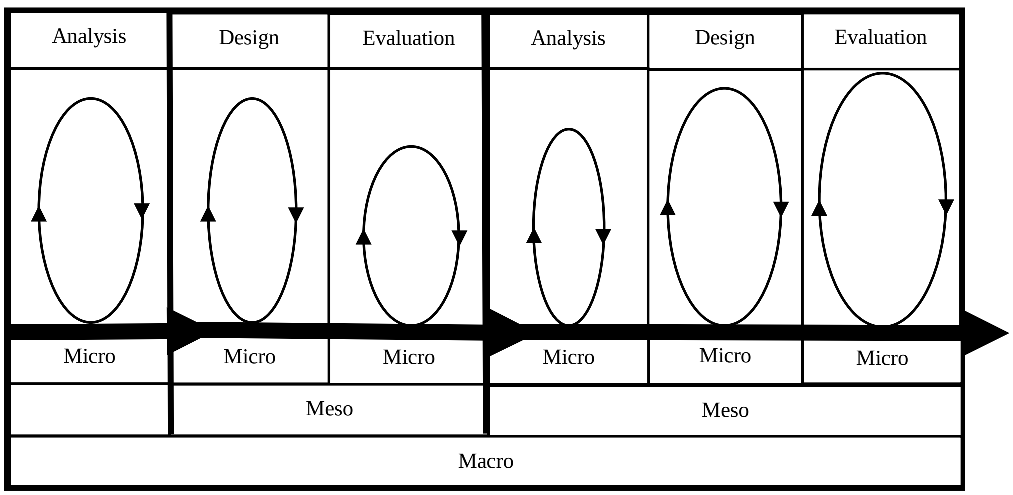


Fig. 7: Illustration of micro, meso, and macro cycles of DBR, adopted from [114, p. 78].

Following the suggestion in [114] to treat ADE stages as micro-cycles, [105] applied the micro, meso, and macro cycles and revealed that it is possible to use DBR for short time projects such as Masters and PhD theses. Fig. 8 represents the DBR concept in [105, p. 8], that is to say, the ADE model as cycles of micro, meso, and macro processes.

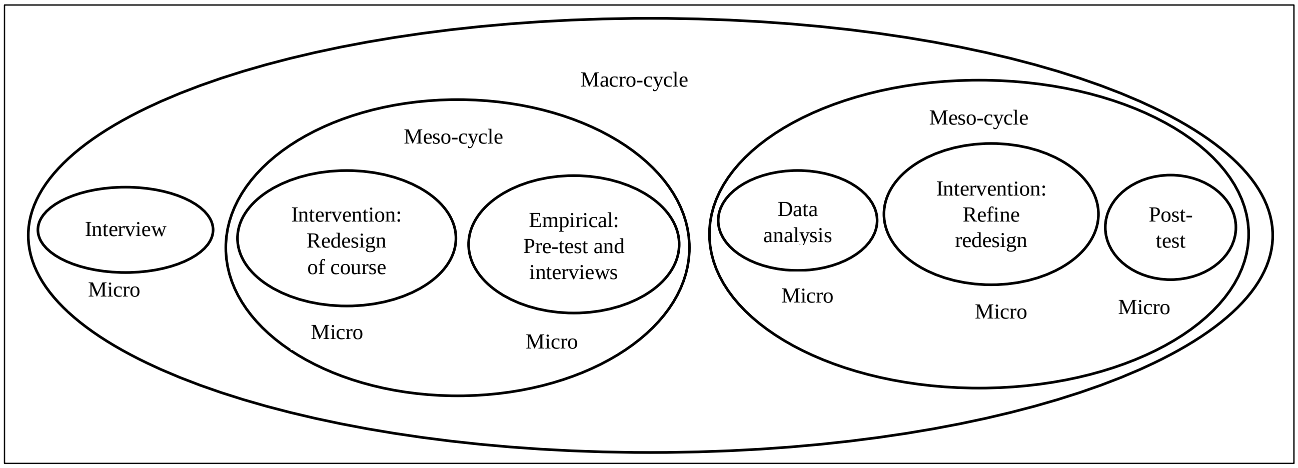


Fig. 8: Micro, meso, and macro cycles – a DBR approach for short-term projects, adopted from [105, p. 8].

Subsections 3.1.1 through 3.1.3 give a synopsis of how the concept of micro-, meso-, and macro-cycles (hereafter referred to as the 3m-cycle) is applied to the ADE model in the development of stakeholder-specific microgrid-related training content. The considered stakeholders are BSc Elec Eng students, electrical energy consumers, and secondary school learners aged 14 – 18.

3.1.1 Application of the 3m-cycle Concept to the DBR Framework's ADE Model for BSc Elec Eng Students

Fig. 9 illustrates the application of the 3m-cycle concept to the ADE core stages of the DBR framework in the development of microgrids-related training content for the BSc Elec Eng students.

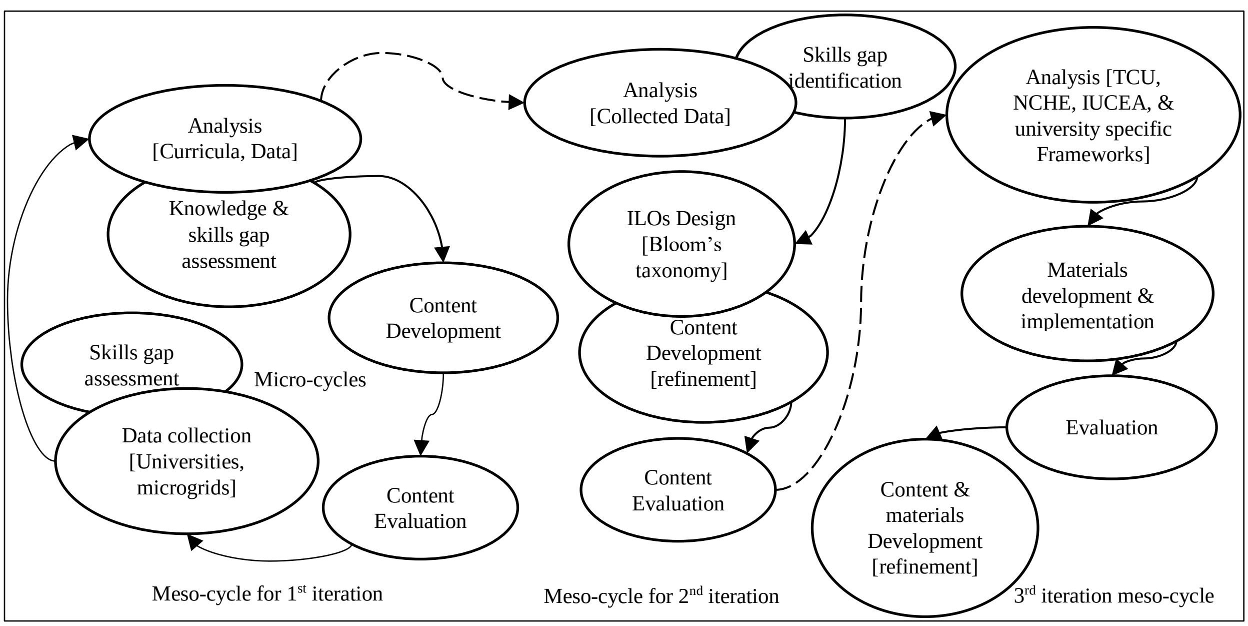


Fig. 9: Application of the 3m-cycle concept to the DBR's ADE model in the development of a microgrids course content for training BSc Elec Eng students.

The first micro-cycle for this stakeholder category is curricula analysis which appears in subsections 4.1.1 and 4.1.2. It is worth mentioning that for this analysis; the method of document analysis is applied to gather facts, from curricula, regarding microgrids knowledge and the related skills gap. The document analysis method is briefly explained in subsection 3.3.2 and detailed explanations appear in [115], [116], [117], [118]. Following curricula analysis, content development is the second micro-cycle of the first iteration meso-cycle. Through reviewing related literature, content to fill microgrids-related knowledge and skills gaps is developed and this appears in Appendix A. Development of the content is supported by [105, pp. 4–5] who states that probable solutions to problems identified during the analysis stage are generated during the design stage. Following content development, the third micro-cycle of the first iteration meso-cycle is content evaluation. The evaluation is performed by lecturers of power-related courses, junior, and senior students of the BSc Elec Eng study programme from both Uni A and Uni B where data for this research was collected. The worthiness of the content in light of the prevailing curricula is evaluated, weaknesses and strengths identified, and suggestions are made. The final micro-cycle in the first iteration meso-cycle is data collection from universities and microgrid operators. Details of the data collection micro-cycle are intertwined with those of electrical energy consumers and presented together in sections 3.2 and 3.3.

The second meso-cycle iteration starts with the analysis of the collected data and the analysis is presented in subsection 4.1.3. The analysis is aimed at establishing what students know about microgrids and whether they are interested in pursuing a career in microgrids or not. Secondly; the analysis captures the perspectives of students, lecturers, and microgrid operators regarding microgrids career-required skills. This consequently leads to skills gap identification in light of the curricula at the time of data collection. Another part of the analysis is done in subsection 4.2.1 to generate microgrids-related workplace-required skills based on job descriptions and other collected data. In the analysis micro-cycle of the second meso-cycle: (1) collaboration with professionals as emphasised in [111, p. 6] is evident. (2) document analysis for subsection 4.1.3, thematic analysis [119, p. 47] and content analysis [118, p. 22], [119, p. 49] for subsection 4.2.1 are the employed methods of analysis. Based on the identified skills gap and workplace-required skills; ILOs are designed, using Bloom's taxonomy, in the second micro-cycle of the second meso-cycle iteration. The designed ILOs are then used to refine the developed content, which appears in Appendix B, and ensure the inclusion of skills to enable BSc Elec Eng students to acquire microgrids-related workplace required competencies. The refined content is evaluated in the third micro-cycle of the second meso-cycle iteration. The evaluation that appears within subsection 5.1.3, performed using a taxonomy table, is aimed at establishing the contextual relevance of the developed content. The evaluated redeveloped content appears in Appendix C.

The third meso-cycle iteration has to be performed in line with the frameworks of the respective country statutory bodies that oversee university operations and the procedure in subsection 5.2.1

for inclusion of the course content in the BSc Elec Eng curricula. Development of the materials and implementation can only be done, by lecturers, once the content is included in the BSc Elec Eng curricula. The materials can then be evaluated to feed into the refinement of the content and the materials development micro-cycle.

3.1.2 Application of the 3m-cycle Concept to the DBR Framework's ADE Model for Electrical Energy Consumers

Application of the 3m-cycle concept to the development of microgrids-related content for skilling electrical energy consumers is illustrated in Fig. 10. For the electrical energy consumers, the first micro-cycle of the first iteration is an analysis of the existing literature using the document analysis method.

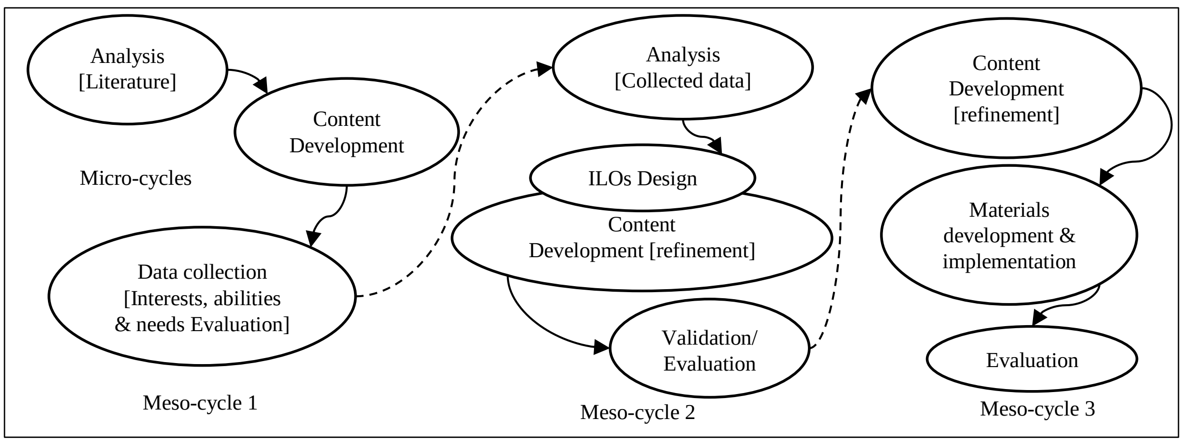


Fig. 10: Application of the 3m-cycle concept to the DBR's ADE model in the development of a microgrids training programme content for electrical energy consumers.

The analysis led to the development of the content, that appears in Appendix F, during a second micro-cycle of the first meso-cycle. Data is then collected in the third micro-cycle. Data collection is aimed at establishing consumer challenges, training interests, transferrable skills, and their training needs among others. In the first micro-cycle of the second meso-cycle; data is analysed as indicated in subsection 4.2.2 using both thematic analysis [119, p. 47] and content analysis [118, p. 22], [119, p. 49]. Results from the analysis including consumers' challenges and interests, among others, then guide ILOs design. Consequently, the ILOs are used as the basis for content refinement in the second micro-cycle of the second meso-cycle. The redeveloped content is evaluated in the third micro-cycle of the second meso-cycle as elaborated in section 4.3. Following evaluation, refinement of the content is done in the first micro-cycle of the third meso-cycle and the refined content appears in Appendix G. Materials development and implementation are performed in the second micro-cycle of the third meso-cycle and finally, evaluation of the developed materials is performed in the third micro-cycle of the third meso-cycle.

3.1.3 Application of the 3m-cycle Concept to the DBR Framework's ADE Model for Secondary School Learners

For secondary school learners, the application of the 3m-cycle concept started with the analysis of the physics syllabi in the first micro-cycle as indicated in Fig. 11. The analysis is performed using the document analysis method.

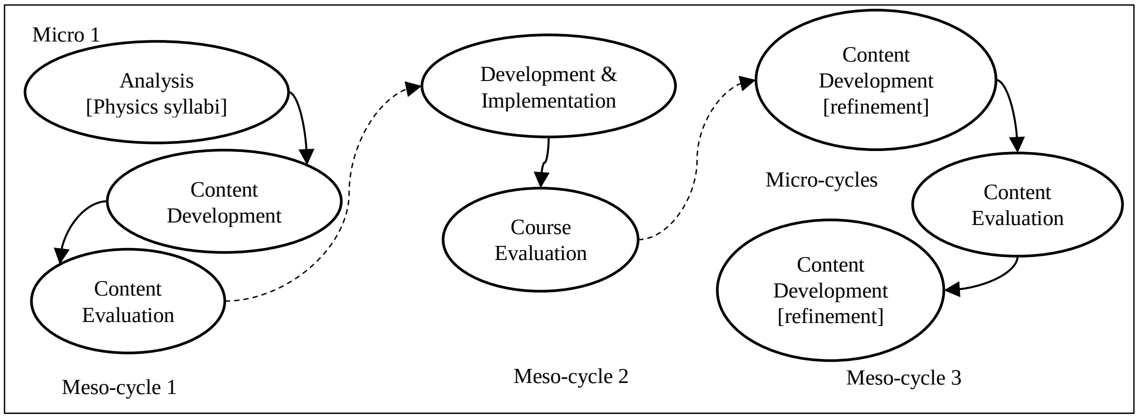


Fig. 11: Application of the 3m-cycle concept to the DBR's ADE model in the development of a microgrids course for secondary school learners.

Following physics syllabi analysis, content for a secondary school microgrids course is developed in the second micro-cycle of meso-cycle 1. Content evaluation is performed in the third micro-cycle of meso-cycle 1. Meso-cycle 2 on the other hand consists of two micro-cycles – materials development and implementation as the first and course evaluation as the second micro-cycle. The third meso-cycle consists of three micro-cycles two of which are content refinement appearing in the first and third positions and content evaluation micro-cycle in the second position. The three meso-cycles constitute the macro-cycle. Details of the 3m-cycle concept application to the DBR framework's ADE model for secondary school learners are explained in subsection 4.2.3. The operationalisation of the DBR framework, through the application of the 3m-cycle concept to the respective stakeholders in subsections 3.1.1, 3.1.2, and 3.1.3; is supported by the collected data. Data sources and participants are therefore described in section 3.2.

3.2 Data Sources and Participants

Data, both qualitative and quantitative, are collected from selected Universities in EA. For purposes of anonymity, the universities where data are collected are coded as Uni A and Uni B. Respondents from the universities include Heads of Departments (HoDs) administering the Elec Eng degree program, lecturers of power-related course units, laboratory technicians/engineers, plus junior and senior students pursuing BSc Elec Eng.

More data are collected from microgrid operators. The phrase microgrid operators in this monograph include technicians, electrical engineers, managers and owners of microgrids. These are individuals in charge of day to day operational affairs of microgrids. Microgrid operators from two firms that identify as solar energy developers, that is, Winch Energy Limited – Uganda and Ensol Tanzania Limited were interviewed. One microgrid operator from a community-owned microgrid in the Dodoma central region of Tanzania was also interviewed.

In addition, electrical energy consumers in selected rural communities of Tanzania and Uganda provided data. The consumers include domestic, commercial, and institutional consumers connected to microgrids operated by Winch Energy (U) Ltd, Ensol (T) Ltd, and the community-owned microgrid mentioned in the foregoing paragraph. The numbers of all respondents who provided data for this study are indicated in Table 8 subsection 3.3.1. Further; the selection and sampling strategy of participants are explained in subsections 3.2.1 and 3.2.2 respectively.

3.2.1 Selection of Participants

The first step in the selection of participants is to decide which EA Universities should be considered for data collection. As indicated in Table 6, the decision is informed by the world university rankings of the Times Higher Education (THE) for 2021, and 2020. However; THE rankings for 2024, 2023, and 2022 are included in Table 6 for completeness and as a testimony that the selected universities continue to perform well in their respective countries. THE rankings are based on a university's performance in areas of: (1) international outlook, (2) knowledge transfer, (3) research, and (4) teaching. The considered universities are the best in their respective countries. Best in terms of local, regional, and international rankings and; the impact they make in terms of partnerships, community outreach, teaching, development, innovations, research and publications.

Table 6: THE world ranking of selected universities.

UNIVERSITY CODE	Year of Establishment	Times Higher Education World University Rankings					Country Education System (Years)	
		Year	Rank	No. of FTE students	Female to male student ratio	No. of students per staff	Nursery: Primary: Lower Sec. Sch.: Upper Sec. Sch. (years)	BSc Elec Eng duration (years)
Uni A	1961	2024*	1501+	36, 666	47:53	21.1	3: 7: 4: 2	4
		2023*	1501+	37, 385	44:56	24.8		
		2022	1201+	34, 259	43:57	20.5		
		2021	No results	No results	No results	No results		
		2020	1001+	30, 139	32:68	19.1		
Uni B	1922	2024	801 – 1000	29, 510	46:54	19.2	3: 7: 4: 2	4
		2023	801 – 1000	31, 233	51:49	21.0		
		2022	801 – 1000	32, 113	44:56	22.0		
		2021	401 – 500	30, 486	52:48	20.8		
		2020	601 – 800	34, 651	45:55	23.6		

*For 2024 and 2023, Uni A is ranked second in the country however; the university that was ranked number one offers human medicine-related study programmes and not Elec Eng.

Although the idea was to collect data from universities in three EA countries including Tanzania, Uganda, and Kenya; Kenya was eliminated based on the country's education system. Given the education system in Kenya, the BSc in Electrical and Electronic Engineering of the qualifying university is 5 years. The duration of the course notwithstanding, data from Kenya would enrich the findings of this research. However, it was difficult to secure appointments with the target respondents. Worse still, appointments that had been secured were skipped by the probable respondents! THE rankings for the selected universities are indicated in Table 6.

Following BSc Elec Eng curricula analysis for Uni A and Uni B, a decision is made to collect data from junior and senior students pursuing BSc Elec Eng. This is because: (1) students are expected to acquire microgrids-related practical competencies and skills from third- and fourth-year courses that are under the *applied engineering sciences and design* category of Fig. 15. (2) juniors and seniors are expected to be more focused regarding career aspirations than freshmen and sophomores. Through class coordinators, students from the third- and fourth-year classes of BSc Elec Eng are requested to participate in the research. The respective class coordinators then compiled names of students willing to participate but making sure that males and females are represented in each group. Hence, a convenience technique of non-probability sampling is applied [120, pp. 1–2]. Not to be confused with the voluntary sampling technique, students who participated were requested by their class coordinators.

For microgrids, operators of microgrids that signed memoranda of understanding (MoUs) with the A:RT-D Grids project are considered. The A:RT-D Grids project signed MoUs with Ensol (T) Ltd, Winch Energy Ltd – Uganda, and a community microgrid in Dodoma central Tanzania. Ensol and Winch are solar energy developers that implement, operate and maintain microgrids in some parts of Tanzania and Uganda respectively. For Ensol, data is collected from all the five sub-villages supplied by one microgrid located in the Tanga region, Korogwe district. For Winch, data is collected from microgrids in both the central and northern regions. For the central region, data is collected from three villages supplied by two microgrids in Mpigi district whereas for the northern region, data is collected from nine villages in the Lamwo district. The nine villages are representative of nine microgrids, out of the 25, that are operated by Winch in the northern region. The selection of the nine microgrids is based on the author's judgement guided by the utilisation percentage against the installed capacity of microgrids. The idea is to have a sample comprising of a microgrids spectrum with very high, intermediate, and very low utilisation percentages. Hence, a purposive technique of non-probability sampling is applied [120, p. 2]. Selected microgrids are indicated in Appendix D. The sampling strategy of electrical energy consumers is explained in subsection 3.2.2.

3.2.2 Sampling Strategy

For electrical energy consumers, the consideration is that consumers are selected according to their villages of location - considered as homogeneous groups (strata). The required minimum number of sampled consumers, n_{min}, out of those, N, connected to a microgrid in a given (sub)village, i, is determined by the *proportional allocation* method in [121, p. 264]. The applied proportional allocation equation is given in (1) and n_{min} for each (sub)village i is as indicated in Table 7.

$$n_{min_i} = \frac{N_i}{\sum_i^m N_i} * n_{td} \qquad (1)$$

Where: $i = 1, \dots, m; m$ is the number of (sub)villages from which data was collected
n_{td} is the regional total desired consumer sample.

The choice for the proportional allocation method was based on two reasons (1) the microgrids have varying numbers of consumers and as such, the proportional allocation approach ensures that data is collected from a minimum commensurate number of consumers supplied by a given microgrid in each village. (2) The proportional allocation method is characterised by simplicity as opposed to other methods such as Neyman allocation, optimum allocation, Cochran's formula, and finite population correction which are more time-consuming. For example, Neyman allocation as seen in equation (2) requires the determination of variance for every stratum (subvillage in our case). Cochran's formula, on the other hand, requires specifying the error margin and confidence level of the population.

$$n_{min_i} = \frac{Var_i}{\sum_i^m Var_i} * n_{td} \qquad (2)$$

Table 7: Minimum required and actual sample numbers of electrical energy consumers.

No.	Microgrid village name i	Region total number of consumers $\sum_i^m N_i$	Number of consumers connected N_i	Total desired sample n_{td}	Minimum required sample n_{min_i}	Actual number of sampled consumers n
1	Silale (Central Tanzania)	60	60	30	30	**39**
2	Mpale (Northeastern Tanzania)	257		100		**82**
	Kwenwohoyo		66		26	24
	Kwemuhole		44		17	17
	Kweulasi		32		12	15
	Milongwe		61		24	12
	Ubiri		54		21	14
3	Bunjako (Central Uganda)	278		60		**58**
	Senyondo		170		37	40
	Buzaami		108		23	18
4	Lamwo (Northern Uganda)	924		100		**84**
	Agoro		206		22	9
	Ogili TC		186		20	10
	Pangira		102		11	11
	Oboko TC		59		6	6
	Loromibeng		98		11	9
	Moroto East		48		5	11
	Lapidiyenyi		89		10	10
	Apyetta TC		101		11	10
	Pawena		35		4	8

*Mpale is a rather unique microgrid in the sense that it serves 257 customers in five (5) sub-villages! This is achieved by rationing power consumption based on energy daily allowance (EDA).

After determining the required minimum number, *systematic random sampling* is then applied to collect data from electrical energy consumers. The sampling interval k_i for selecting consumers on microgrid village i is obtained using equation (3).

$$k_i^* = \frac{N_i}{n_{min_i}} \tag{3}$$

*Resultant values of k that are non-integers are rounded off to the nearest whole number.

The beginning point is randomly selected between 1 and k and the sampling interval is then applied. In case the k^{th} consumer is unavailable; the neighbouring consumer $k + 1$, is considered and the sampling interval applied thereafter. Sample sizes for each (sub)village are indicated in Table 7.

Challenges such as language barrier and illiterate levels affected data collection. Majority of the consumers are unable to read or write, and some can neither speak English nor the Swahili language! It was therefore imperative that an interpreter be present. Interpretation and filling in questionnaires took a lot more time than expected and this is partly the reason for not acquiring the minimum required sample numbers. It was possible to acquire the minimum sample for Silale given that data was collected during the dry season. It should be noted that since farming is the main economic activity of the Silale village, coupled with the relatively small area covering approximately two kilometres, many consumers were reached. For central Uganda, the microgrids where data were collected are located close to Lake Victoria. Fishing is the area’s economic activity and thus, the majority of the inhabitants sleep during the day since they go fishing at night. For northeastern TZ; the sub-villages are on hills and thus not easy to move through. Access roads become very slippery whenever it rains heavily. In northern Uganda, the villages are far apart. All these factors affected data collection. As confirmed in [122, p. 4]; time, access to and a limited number of available respondents are some resource constraints that always limit sample sizes. The use of data from sampled respondents (consumers) below the required minimum is a limitation of this study. Challenges and thus the limitation as a consequence notwithstanding, data from 263 consumers were collected and are considered adequate to inform this research. Data collection tools and detailed statistics are explained in section 3.3.

3.3 Data Collection Methods, Tools, Statistics, and Analysis

It is mentioned at the beginning of Chapter 1 that expert-structured interviews, focus group discussions, and questionnaires are some of the data collection methods employed in this research. The tools used to collect data, the statistics of primary data, and data analysis approaches are highlighted in this section. Interview guides that appear in Appendix K and Appendix L are the tools used to collect data from HoDs and Lecturers respectively. The WS-853 Olympus digital voice recorder is another tool used to record and store all interviews and group discussions.

In addition to the audio recorder, discussion guides/protocols were used during group discussions with BSc Elec Eng junior and senior students. Paper-based forms were utilised as data collection tools through the questionnaire method. Questionnaires that appear in the indicated appendices were used to collect data from consumers – Appendix E, laboratory instructors – Appendix N, microgrid operators – Appendix O, and BSc Elec Eng students – Appendix M. A Likert scale measurement tool in Appendix J was used, in the evaluation of consumers' training content, given that it is commonly employed in educational research contexts [123, p. 838]. Research dataset statistics are indicated in subsection 3.3.1.

3.3.1 Research Data Statistics

Data that form the fundamental foundation for analysis, conclusion, and recommendations in this study was collected through both primary and secondary sources. The statistics of respondents who provided primary data are indicated in Table 8.

Table 8: Statistics of primary data respondents.

Respondents / Country	Universities				Rural communities				
						Electrical energy consumers			
	Heads of Departments	Laboratory engineers/technicians	Power courses lecturers	BSc Elec Eng Junior and senior students	Microgrid operators	Domestic	Commercial	Institution	Country Subtotal
Tanzania	01	01	03	20	03	79	36	06	121
Uganda	01	01	03	19	04	63	69	10	142
TOTAL	02	02	06	39	07	142	105	16	263

Primary data utilised in this research were collected through face-to-face expert-structured interviews, focus group discussions, and questionnaires. Secondary data on the other hand were collected through document analysis – an empirical approach to curricular and secondary school physics syllabi analysis. Face-to-face expert-structured interviews were held with HoDs and other lecturers. The mentioned respondents are considered experts given their academic qualifications and work experience in line of duty as indicated in Table 9. Laboratory instructors are also included for completeness. In addition, focus group discussions were held with BSc Elec Eng junior and senior students of Uni A and Uni B. Fig. 12 shows photos taken during some data collection sessions with BSc Elec Eng students.

Table 9: Description of university experts with whom face-to-face structured interviews were held.

Country	Expert (E) ID	Gender	Age (Years)	Highest academic qualification	Designation	Work experience (Years)
Tanzania	E1	Male		PhD	Senior Lecturer, HoD	16
	E2	Male	40's	PhD	Senior Lecturer	15
	E3	Male		PhD	Lecturer	4
	E4	Male	46	PhD	Senior Lecturer	18
	E5	Male	38	Higher Diploma in EE	Lab Technician	6
Uganda	E6	Male	40	PhD	HoD & Lecturer	14
	E7	Male		PhD	Lecturer	15
	E8	Male	36	MSc	Assistant Lecturer	9
	E9	Male	34	MSc	Assistant Lecturer	3
	E10	Male		Higher Diploma in EE	Senior Technician	19

Fig. 12: Photos taken during some of the focus group discussions with BSc Elec Eng students.

Notably, data from the universities were collected from 28th March to 10th June 2022. Data from rural communities, on the other hand, were collected between 14th November 2022 and 20th January 2023. Other followup data collection and feedback phases were from 31st July – 3rd August; 28th – 29th August; 25th – 27th September; 18th – 22nd December 2023; 2nd – 30th January 2024. Approaches to data analysis and the steps of both document and content analysis techniques are explained in subsection 3.3.2.

3.3.2 Data Analysis

Document analysis, content analysis, and thematic analysis based on Kuckartz, in addition to excerpt selection, are some of the approaches applied as appropriate to analyse data in this monograph. Before data analysis, transcription of the recorded audio files is done using f4x speech recognition software. Data collected using paper-based forms are manually entered into Excel spreadsheets and Word files as appropriate. Coding of the transcripts is then done using the MaxQDA 2020 software version. As guided by [124, p. 48], coding is aimed at providing an interplay between the author's insights and the stakeholders' perceptions of the subject studied. For example; before data collection, there was developed content for different stakeholders. Therefore, themes to categorise data during analysis are based on the earlier developed content. Coding then revealed a relationship between the collected data (stakeholders' perceptions) and the developed content themes (author's insights) so as to establish relevancy to maintain, identify gaps or emerging concepts to supplement, otherwise eliminate irrelevant content. Hence, a deductive coding approach is employed during data analysis as opposed to an inductive one where coding starts from scratch. Codes, sometimes referred to as categories, are an essential aspect of qualitative and quantitative data analysis [125, p. 183]. Although there are various definitions and meanings of the term category, categories in this monograph refer to headings that classify text descriptions into themes having desired but related characteristics [125, p. 184]. The development of categories in this monograph follows a concept-driven deductive approach informed by the state of research [125, p. 184]. Since the document analysis method is applied to BSc Elec Eng curricula analysis and the content analysis method is suitable for, and therefore applied to, the analysis of open-ended question responses; the steps followed to analyse data according to Kuckartz in both methods are explained in the following paragraphs.

The document analysis method begins with planning and preparation. In this first step, the relevant documents are selected based on the purpose for which the analysis is required. The purpose for the analysis is informed by the research question(s). For this monograph, the documents of interest for which the analysis is required are the BSc Elec Eng curricula and the lower secondary schools' physics syllabi from selected EA countries. The selection of documents is followed by document examination. During the document examination stage, the content and structure of the documents are analysed by reading and interpretation. The examination is followed by the coding and categorisation stage and for the BSc Elec Eng curricula, the course contents are classified into five categories. The categories are then subjected to analysis and interpretation during which, among other things, the weight of each category is established based on course credit units (CUs). The analysis and interpretation stage, generally, includes thematic analysis, contextual analysis, and content analysis. The thematic analysis focuses on pattern detection to establish emerging themes as categories [117, p. 32]. Contextual analysis concentrates on a wider perspective of the documents in light of the purpose for the analysis. According to [115, p. 18], content analysis and document analysis are synonymous. Document analysis, however, is a good method for extracting retrospective information [118, p. 19] whereas content analysis is good for analysing open-ended questionnaire questions [118, p. 22]. The final step in document analysis is synthesis and reporting in which stage findings and conclusions are documented. The content analysis steps explained in the following paragraph, reveal the similarity between the two methods of data analysis.

The content analysis steps include data preparation, forming categories, analysing categories and presenting results, reporting and documentation [125]. The data preparation stage includes activities such as data transcription, reading of the transcripts and making necessary corrections. Coding and establishment of categories include the assignment of transcript text to (sub)codes and/or categories and this is an iterative process. The categories are then analysed in an approach called category-based analysis in which categories of a particular question of interest are explained [125, p. 186]. The category-based analysis enables a focus preference to either qualitative or quantitative characteristics of the text [125, p. 192]. In the final step, reporting and documentation; results are presented, discussed, and documented with supporting visual diagrams as appropriate.

3.4 Chapter Summary

The chapter reveals the DBR as the methodology in this research. DBR is employed in the development of stakeholder-specific content through iterative ADE model cycles. The chapter highlights the integration of the 3m-cycle concept into the DBR framework ADE model that enables stakeholder-specific merger of theoretical insights with practical application. The approach ensures the development of effective, contextually relevant, and stakeholder-tailored training content. To support the iterations in the content development process; the chapter reveals that data are collected from selected universities (majorly Uni A and Uni B), Winch Energy Ltd and Ensol Ltd microgrid operators, and rural communities in Tanzania and Uganda. The chapter further reveals that sampling techniques such as convenience for BSc Elec Eng junior and senior students, purposive for microgrids in northern Uganda, stratified, proportional allocation, and systematic random sampling for consumers are applied. Additionally; the chapter narrates the data collection methods such as expert-structured interviews for HoDs and lecturers, focus group discussions with BSc Elec Eng junior and senior students, and questionnaires with electrical energy consumers, among others that are applied. Accordingly, the tools used for collecting the data such as the interview and discussion guides, the questionnaires, the audio recorder, the complete data statistics, and the description of experts are presented. The chapter finally explains the data analysis approaches including the f4x[3] speech recognition and MaxQDA[4] 2020 software usage. The deductive coding and other analysis techniques like thematic analysis, document analysis, content analysis, and excerpt selection are also highlighted in the chapter. Following the analysis, results, discussions, and content development are presented in Chapter 4.

[3] A web-based “https://f4x.audiotranskription.de/en” service used to automatically transcribe audio files into text.

[4] A Qualitative Data Analysis (QDA) tool used to manage, code, analyse and visualise qualitative and quantitative data

4 Results, Discussion, and Content Development

In line with the set objectives in section 1.3 of this monograph; Chapter 4 reports the analysis, findings, and discussion of the results and their integration leading to microgrids-related knowledge content development. The discussed results, that lead to content development in this chapter, are based on the data collected and analysed using techniques explained in Chapter 3. Chapter 4 is therefore structured in four sections. Section 4.1 narrates the required current and future skills for microgrids sustainability. In section 4.2, stakeholder content for microgrids knowledge transfer is developed and skill sets are characterised. The developed content, on the other hand, is evaluated in section 4.3 and in section 4.4, the chapter is summarised.

4.1 Current and Future Skills for Microgrids Sustainability

With the green energy transition in focus, the need to equip communities, populations and other stakeholders with relevant skills to support microgrids sustainability cannot be over-emphasised. In this section 4.1, the identification of required skills for microgrids sustainability is done. Although the skills mentioned in this section are cited from the literature, they later equally emerge from questionnaires and interview data analysis to form part of the results. Skills are identified with a focus on SDG 7 and SDG 4. According to [126, p. 176]; skills for the future have to be linked to Artificial Intelligent (AI), the Internet of Things (IoT) and/or the Industrial Internet of Things (IIoT) systems. In agreement, [127, p. 20] indicates IoT and embedded sensors as skills that should be emphasised for Elec Eng. Given their ability to enable collection, exchange, and analysis of data; AI and I(IoT) systems are essential elements in designing, implementing, operating, maintaining, and automating energy systems including microgrids. With automation accomplished through the application of AI and I(IoT) systems; management of microgrids including metering and billing, customer complaints handling, troubleshooting, control and monitoring is achieved. Relatedly; the availability of electrical energy versus utilisation is achieved hence, demand and supply side imbalances are managed. All the aforementioned services can be made possible by intelligent networks enabled by advanced sensors and IIoT expertise. It should be noted though that deployment and management of AI, I(IoT) systems can only be realised with the availability of reliable internet connectivity. Reliable internet connectivity requirement notwithstanding, linking both AI and I(IoT) to skills for microgrids sustainability is in the right direction.

Many reports such as [128], [129], [130] indicate a global green-skilled worker force shortage for the green energy transition. Green-skills training and reskilling are therefore advocated. According to the skills and employability department of the International Labour Organisation's office, as indicated in [131]; renewable energy skills are required across the entire renewable energy sub-sector value chain. The renewable energy sub-sector value chain encompasses equipment manufacturing, distribution, project development, installation, operation and maintenance of renewable energy systems. Further; that the essential skills in renewable energy sub-sectors, which this monograph's author equally finds applicable to microgrids, include the ability to:

- Install, inspect, operate, and carry out maintenance and repair of solar energy (PV and thermal) systems. These skills are equally essential in Uganda as [132, p. 12] indicates.
- Analyse risks: Safety, Health, and Environment (SHE).
- Perform simulations and modelling of distributed energy resources and
- Assess the sustainability of renewable energy projects, that is to say, skills for sustainability quality assurance.

Reference [133, p. 509], on the other hand, indicates both software- and hardware-based skills as those required in the microgrids industry. Furthermore; that software skills include the use of simulation software, writing algorithms and computer programmes whereas hardware skills include microcontroller designs. The aforementioned skills are vital in the development of competencies in microgrids design – modelling and operation analysis, microgrids optimisation through real-time data analysis, and microgrids control.

All the skills mentioned in this section 4.1 are vital for microgrids sustainability and the competencies required can be partly met by BSc Elec Eng graduates. As highlighted by [133, p. 509], it is vital to integrate microgrids knowledge within current coursework frameworks so that engineering graduates can acquire the essential competencies to design, install, operate, deploy and generally manage microgrid projects. To this end, BSc Elec Eng curricula are analysed in subsection 4.1.1 to establish the degree to which microgrids-related knowledge and workplace expected skills are addressed for microgrids sustainability. Consequently, the derived skill-based competencies and microgrids' career-required skills are presented in subsections 4.1.2 and 4.1.3 respectively.

4.1.1 BSc Electrical Engineering Curricula Analysis

Undergraduate Elec Eng degree curricula from two universities, coded as Uni A and Uni B, are analysed. The courses in the curricula are classified into five (5) categories including basic sciences and mathematics, applied engineering sciences and design, renewable energy, sustainability, and others. *Basic Sciences and Mathematics* – these foundation courses prepare students to understand the contents of higher-level courses by exposing them (students) to basic sciences and theoretical concepts. *Applied Engineering Sciences and Design* – These courses are the core backbone of Elec Eng study programmes with fundamental content to Elec Eng and design. These courses introduce students to fundamental concepts of Elec Eng and the design of related technologies built on earlier basic science courses. *Renewable Energy* – Courses with renewable energy content are included in this category. *Sustainability* – Courses with soft skills, humanities, social and economics sciences content are placed under the sustainability category. It is important to note that the courses under the sustainability category address sustainability in a diverse nature including but not limited to social and economic dimensions. The sustainability salient issues of gender, culture, and economics are all addressed in this category. Others – Finally, the Others category includes Projects & Internships. The others category, therefore, includes courses that complement the study programme's technical content in line with institutional policy and programme objectives [134, p. 19].

The credit weights of the course categories, in terms of contact hours (CHs), equivalent to credit units (CUs), are then summed up as indicated in Fig. 13. The Minimum requirement for the award of a BSc Elec Eng of Uni A is 135 CUs whereas that of Uni B is 155 CUs. It should be noted that a CU is a value that numerically quantifies academic load in terms of the required/mandatory time for a student to achieve established learning outcomes [99, p. 32], [100, p. 13]. The analysed curricula from both universities are based on a rather outdated credit system, which is the current practice though, in which a CU is equivalent to one CH. In the current practice, one CH is one hour of lectures, one hour of clinical work, or two hours of tutorials/laboratory/practical work per week for 15 weeks that make a semester. For internship/placement training, a CU is equivalent to 4 hours of hands-on practice. The recommended credit system is one, based on notional hours, where a CU is equivalent to 10 notional hours [98, p. 56], [99, p. 50], [100, p. 13], [135, p. 12]. The notional hours credit system is comparable to the European Credit Transfer System (ECTS) and incorporates/aggregates all learning workload activities that learners are involved in as opposed to only CHs [100, p. 13], [135, p. 11]. According to [100, p. 13] the rule of thumb is that one CH, or CU for that matter, requires two additional notional hours of self-study and other learning activities for undergraduate study programmes and three hours for postgraduate masters, postgraduate diplomas and certificates.

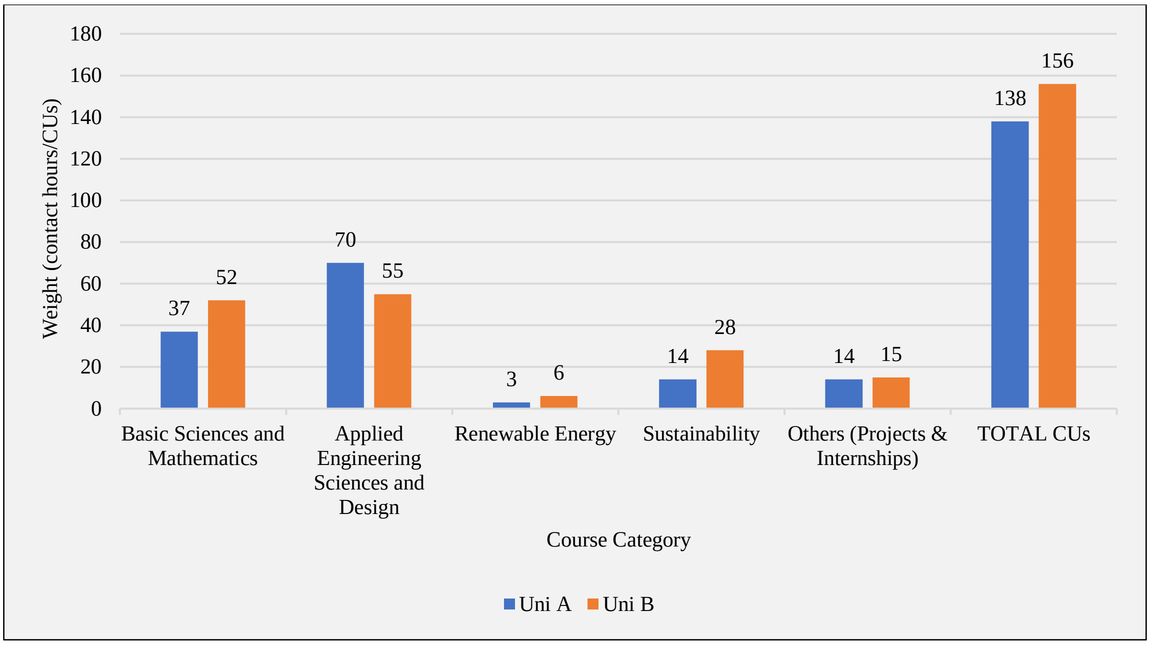


Fig. 13: Course categories with their respective total credit units.

Percentages of the course categories based on CUs are then obtained as presented in Fig. 14. The analysis indicates that Uni A curriculum has 27% basic sciences and mathematics of the entire programme content and that of Uni B is 33%. Out of these; the content which is relevant to microgrids is 7% for Uni A and 9% for Uni B. For the applied engineering sciences and design, Uni A has 51% and Uni B has 35% of the entire programme content. Out of these; the content which is relevant to microgrids is 39% and 26% for Uni A and Uni B respectively.

The renewable energy content from the analysed curricula is 2% for Uni A and 4% for Uni B. The analysis also indicates that a student who graduates with a BSc Elec Eng from Uni A will have 10% sustainability knowledge of all that was studied and a graduate of Uni B will have 18% sustainability knowledge. Vocational workshop practice, final-year projects and internships form 10% of the Others category for each University.

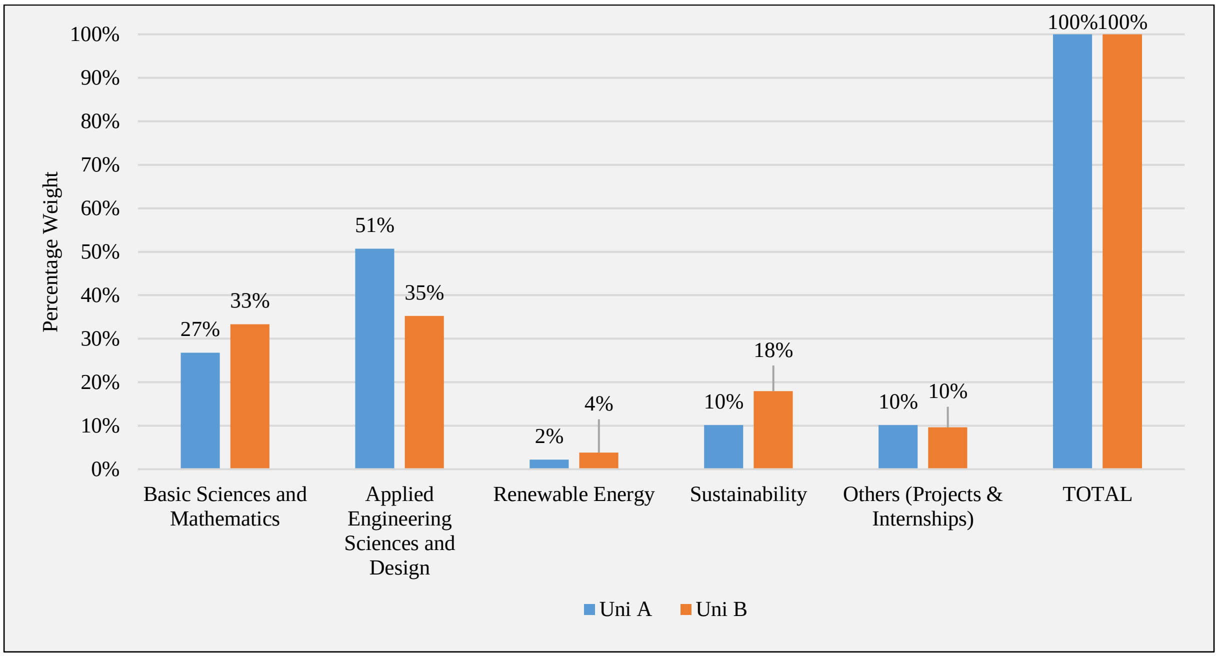


Fig. 14: Course categories with their respective total percentage credit units.

Overall, 48% of all Uni A content weight categories and 42% of Uni B is relevant to microgrids as indicated in Fig. 15. It should be noted, however, that this is content that is relevant to but not specifically addressing microgrid technologies.

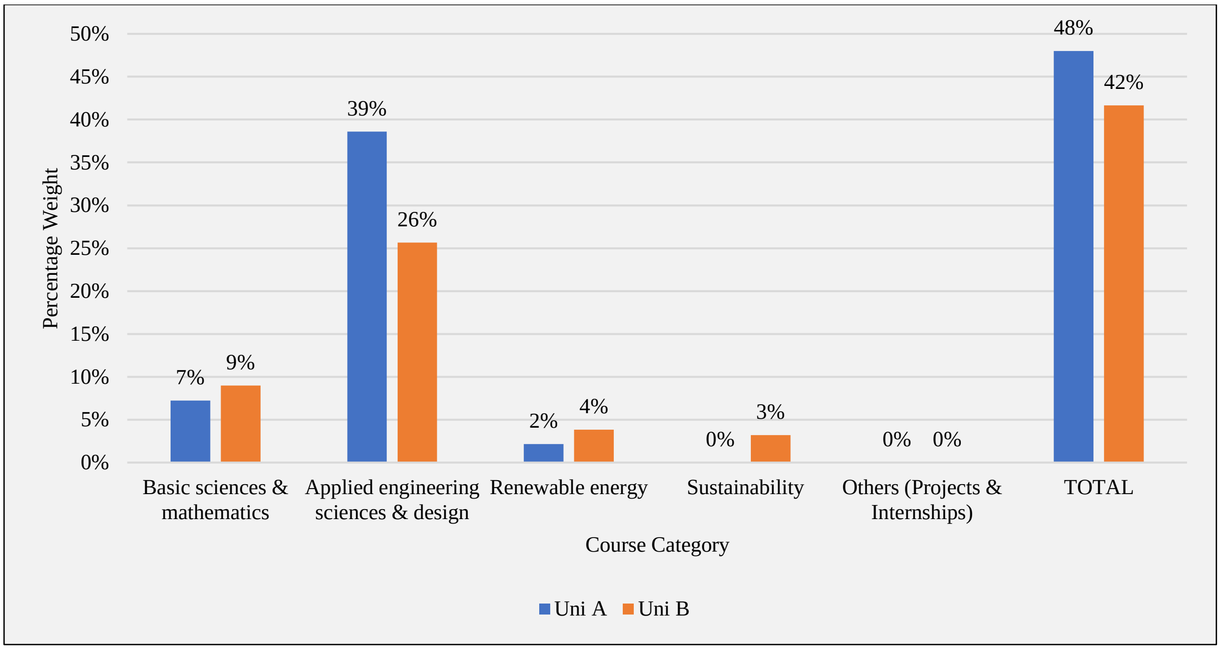


Fig. 15: Microgrids relevant content per course category.

4.1.2 Skill-based Competencies Derived from BSc Elec Eng Curricula

Based on curricula content; analysis of the basic sciences and mathematics, applied engineering sciences and design course categories is done through document analysis. The analysis reveals some skill-based competencies that place a graduate in a position to take up occupations and execute tasks, generally, in electrical power system environments. That is to say; graduates can work in installations where electrical energy is produced (the generation or supply side), and they can work in installations used to transmit electrical energy from the supply side to the consumers on the demand end, that is the transmission and distribution networks. The curricula can produce graduates with competency to design, operate and maintain an electrical power system.

Sustainability-related competencies are also identified as indicated in Table 10. Uni A Elec Eng graduates are expected to have the competencies to manage other technical employees and to integrate economics principles in the planning through to maintenance of electrical power systems. However, such graduates might need additional skills in business management and project planning and management to ably execute tasks as an early career manager.

Table 10: Skill-based competencies derived from Uni A curriculum. Competencies in boldface are also identified in Uni B curriculum.

Basic sciences & maths	Applied engineering sciences & design	Sustainability
• Test and characterise semiconductor devices. • **Analyse DC circuits. Compare AC with DC circuits.** • **Measure AC, DC and Impulse high voltages.**	• Design power electronics converters. • Design and plan electrical power transmission and distribution networks. • Calibrate energy meters. • **Classify sensors and recommend appropriate applications.** • **Detect faults in electrical power systems networks.** • **Design domestic and industrial electrical wiring diagrams.** • Develop BoQs for domestic and industrial electrical installations. • Recommend appropriate coupling mechanisms for grid control and interconnection stability. • **Recommend appropriate sources of electrical energy generation.** • **Design protection schemes for generators, transmission lines, and transformers.**	• **Manage the Technical Human Resources (Engineers)**. • **Integrate economics principles and concepts in the planning, operation and maintenance of electrical power systems**.

According to curriculum content, more skill-based competencies expected of a Uni B Elec Eng graduate are presented in Table 11. Considering the sustainability-related competencies, a Uni B graduate can ably execute tasks as an early career manager given that they are introduced to engineering projects management, and given skills on how to execute feasibility studies, but most importantly they are expected to involve the communities in the science/technology since they are likely to be aware of the community cultural, conflict, and gender dynamics.

Table 11: Skill-based competencies derived from Uni B curriculum.

Basic sciences & maths	**Applied engineering sciences & design**	**Sustainability**
• Design and analyse DC and AC circuits. • Characterise components for use in the construction of converters. • Characterise photonic devices and lasers for application in solar energy.	• Test power electronics devices and recommend applications. • Test and inspect domestic, commercial, and industrial electrical installations. • Recommend appropriate measuring instruments to suit a required application. • Design, install and carry out maintenance of standby energy supply systems.	• Manage engineering projects. • Integrate economics principles and concepts in electrical power systems planning, implementation, operation and maintenance. • Execute feasibility studies and recommend cost-effective energy tariffs. • Design sustainable electrical energy systems based on renewable energy technologies. • Analyse power systems performance, forecast and manage load. • Develop relevant technologies well aware of community cultural, conflict, and gender dynamics for social development.

In conclusion; the BSc Elec Eng study programmes, as evidenced by curricula, provide adequate skills for graduates to take up occupations in electrical power system environments. However; the curricula do not specifically address microgrids-related technologies thus, they do not enable microgrids-related knowledge and skills transfer to BSc Elec Eng graduates. Although sustainability matters are handled with a total content percentage of 10 for Uni A and 18 for Uni B as revealed in Fig. 14, the missing link to support microgrids sustainability is knowledge content that is specific to microgrids-related technologies. Therefore, to bridge the gap; knowledge content that enables BSc Elec Eng graduates to acquire microgrids required skills is proposed for inclusion in both curricula. The content is designed and included in a course with a proposed name Distributed Electrical Energy Systems (DEES) whose draft appears in Appendix A.

4.1.3 BSc Elec Eng Microgrids Career Required Skills – Students’, Lecturers’, and Microgrid Operators’ Perspectives

Following curricula analysis; data are collected from two Universities – Uni A and Uni B, and from selected rural communities in EA. Respondents whose data and results are discussed in this subsection include junior and senior students, lecturers of the BSc Elec Eng power-related course units, and microgrid operators. The intended purpose is to establish microgrids’ career-required skills that graduates subjected to the BSc Elec Eng degree curricula, at the time of data collection, from both universities might miss.

To begin with, junior and senior BSc Elec Eng students from Uni A and Uni B are asked “Do you know what a microgrid is?”. The closed-ended question in Appendix M is an entry point in establishing students' microgrids-related knowledge. It is interesting to note that although the curricula that are analysed do not contain microgrids-specific content, 45% of the students from Uni A and 100% of Uni B answered in the affirmative as indicated in Fig. 16. From Uni A, 40% of the students are not sure while 15% do not know what a microgrid is. Further inquiry during focus group discussions reveals that what students know about microgrids is passed on to them by their lecturers. This information is confirmed by lecturers who argue that it is vital to keep students informed about recent advancements in technology. However; the same lecturers highlight limitations of teaching content that is not in curricula including limited freedom to examine such content since external examiners would query the basis of examining content that is not in the curricula.

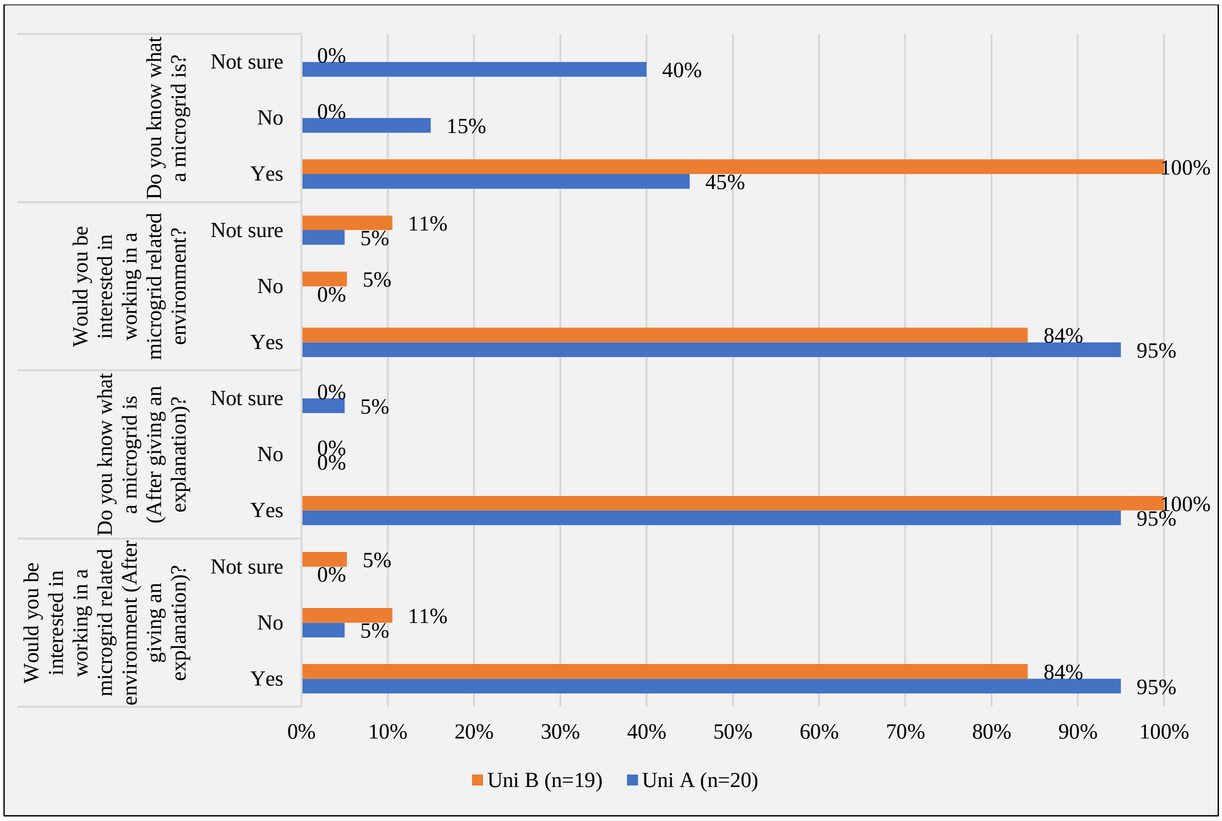


Fig. 16: Junior and senior BSc Elec Eng students' responses to (1) "Do you know what a microgrid is?" and (2) "Would you be interested in working in a microgrid-related environment?" before and after an explanation of what a microgrid is.

To further interrogate students' microgrid-related knowledge, those who answered yes or not sure are asked what they know about a microgrid and responses are given in Table 12. For students from Uni B who answered yes, 63% responses are right however; 37% have a few issues that invalidate them as per the arguments Arg. B1 through B6. On the other hand, 85% of the students from Uni A responded to what they know about microgrids. These include the 45% who answered yes and 40% who answered not sure. Some of the responses from Uni A are also not right as per the arguments Arg. A1 through A6. It should be noted that the queried responses are those highlighted in grey.

Table 12: Responses to what students know about microgrids – queried responses are highlighted in grey.

Uni A	Uni B
Microgrids are the connection of subgrids which mainly consist of sources of energy (alternate) which may be combined with the main grid network. Read Arg. A1	A microgrid is an energy source *meant to serve a specified small location*.
A microgrid is a small grid connected to the national grid which *can work independently*. It is usually used in areas with small populations and it can be fed with electrical power from renewable sources such as solar energy, wind energy, etc. Read Arg. A2	Microgrids are small subsections of the major grid (electric grid). Read Arg. B1
It includes a power supply system that *serves a certain area in a community* (mainly using renewable energy sources) but is not connected to the main country's grid system.	A Microgrid is a smart electricity transmission and distribution line which performs its work majorly on artificial intelligence. Read Arg. B2
Microgrids involve the integration of smaller grids of the country. These smaller grids are interconnected or fed through what is called a distribution generation. Arg. A3: Microgrids are not subsections (smaller grids) of the main grid.	A microgrid is a small system complete with power generation, transmission and distribution capability that is separate from the main grid. Read Arg. B3
A microgrid is an *interconnection of renewable energy sources to form a grid*. For example, solar energy, and wind energy. All this can be connected to obtain the so-called microgrid.	A microgrid is a *decentralised grid* that does not normally feed from a centralised generation source. *In more developed settings, a microgrid can sell power to the main grid*.
A microgrid is the production of electricity using other sources of energy (like sun, and biomass) rather than those used in the national grid and uses advanced technology.	Microgrids are based on *distributed generators* and *can supply to the main grid during peak hours*. Monitoring them requires artificial intelligence and their supply is unstable.
Microgrids are an interconnection of electrical renewable energy sources, that is to say, solar energy, biomass, wind and so on.	They can save energy that can be kept for future use or sold for a living. Arg. B4: Storing energy for a long period (the "future") is very challenging.
A microgrid is an electricity supply system that derives its power from the main grid and covers a relatively smaller area for supply compared to that of the main grid. Read Arg. A4	Microgrids are *stand-alone electric systems for isolated areas or loads*.
Can be referred to as uses of electricity normally from *the local source which may be connected to the national grid or may not*, but can also work *independently*.	Small *independent sources* of electricity that comprise many other sources of power like solar that provide power to other loads.
A microgrid is a group of electricity sources that are connected to the grid and can disconnect and function alone/ autonomously. Read Arg. A2	A microgrid is a small section of a power system supplying small specific users. These can be seen as having a source such as renewable energy.
A microgrid is a group of electricity sources and loads that is connected to the grid but can disconnect from the interconnected grid and function autonomously. Read Arg. A2	A microgrid is a small network of electricity users such as homes, schools, and churches *with a local source of supply*.
A microgrid is a *local energy grid* with control capability.	A microgrid is where *power is generated next to the consumer*, that is to say, a *solar power plant*.
A microgrid is an *interconnected local network that supplies electrical power to users of a given area which* can also be connected to the main grid	A collection of *distributed generation units* that can supply a given load independently or together with a centralised grid.
A microgrid is a *small generation unit of power in a certain area that is the collection of distributed energy sources to produce electricity*. For example, solar and wind.	A small network of electricity with *a local source and operates independently*, it can be connected to the national grid as well
A microgrid is an energy-efficient system using other renewable energy sources and connecting to the main grid system. Read Arg. A5	A microgrid is a connected network to a power system of lower voltage levels than the main grid.
Small-scale power system network which is *independent* from the national grid	A microgrid is a small-scale-based *power network that serves the needs of a community*, village, etc. It can be served by power generated from renewable *energy sources that are closer to the consumers* like solar
Microgrids are small power systems that increase power to the grid system. Arg. A6: This response suggests that microgrids feed the national grid which is not necessarily the case.	A microgrid is a small power grid that is usually supplied by renewable sources of energy such as solar. It *can exist independently but it can also be connected to the main grid*.
	A microgrid is a small scale and it can be from a renewable or non-renewable source of energy. It can be fed in a transmission line for distribution. Read Arg. B6
	These are grids which are separate from the main grid and *are used to supply a specific community*. They continue to operate even when the main grid is off. They use renewable energy sources.

Arg. B1: Microgrids are not necessarily subsections of the national grid, they ought to be independent. Of course, the option of connecting microgrids to the national grid is acceptable but they should not necessarily be part of the national grid.

Arg. B2: The response ignored a vital generation subsystem and included the transmission subsystem which is not desirable. There should technically be no transmission subsystem in a microgrid since this would hike the production, operation, and maintenance costs and jeopardise sustainability. In fact, considering challenges related to obtaining wayleaves, it is desirable and cost-effective to have the generation as close to the load as possible.

Arg. B3: Although the respondent included a microgrid's vital generation and distribution subsystems, a transmission subsystem is undesirable as mentioned in Arg. B2.

Arg. B6: Whereas a microgrid can indeed use renewable or non-renewable energy sources, to keep the sustainability aspirations, the idea of a microgrid having non-renewable energy sources (coal, natural gas, oil, and nuclear energy) should be suppressed.

Arg. A1: The respondent suggests that a microgrid is a connection of subgrids…. In the opinion of the author of this monograph, the response suggests that a microgrid cannot work independently but rather, has to be clustered with others! Although microgrids can be clustered, some precautions have to be taken into consideration. That said, clustering cannot be an attribute to the definition of a microgrid.

Arg. A2: Although it is true that a microgrid can function autonomously, the responses suggest a connection to the main grid which should not necessarily be the case.

Arg. A4: Although a microgrid indeed supplies a relatively small area compared to a main grid, microgrids do not necessarily derive power from the main grid as indicated by the respondent.

Arg. A5: A microgrid is indeed energy efficient since it avoids transmission losses due to the absence of a transmission subsystem. However; connection to the main grid should be an option, not a requirement.

To this end; it is noted that although 47% of the students from Uni A and 37% from Uni B did not give precise correct answers to what they know about microgrids, their responses indicate that they have an idea of what microgrids are. Although curricula from both universities have no content specifically addressing microgrids, lecturers from both institutions update their students with relevant technological advances like microgrids. These efforts further make the case for the formal inclusion of microgrids-related knowledge in curricula. The formal inclusion of microgrids-related knowledge would then eliminate the limitations surrounding teaching and examining content that is not in curricula as indicated by lecturers.

Further; students, since they know about microgrids, are asked whether they would be interested in pursuing a career in microgrid-related environments. The closed-ended question appears in Appendix M. As indicated in Fig. 16; 95% of the students from Uni A answered in the affirmative whereas 5% were not sure. From Uni B, 84% answered yes, 5% no, and 11% were not sure.

Those who answered yes, are then asked what skills they think are required for one to work in a microgrid-related environment and responses appear in Table 13. The open-ended question in Appendix M is aimed at establishing the required skills as identified by the students but most importantly, the question aims at guiding to establish a skills gap. Comparing the skills mentioned by the students and those offered by both universities as per the analysed Elec Eng degree curricula, in force at the time of this research, microgrids career-related knowledge and skills that such graduates might miss are established and appear in Table 13.

Table 13: Microgrids career required skills – BSc Elec Eng junior and senior students' perspective**.**

Uni A students' responses	Uni B students' responses	Missing skills/Skills gap
• Power systems management skills (HVDC). • Professional skills, teamwork, leadership and planning. • Distribution and transmission of microgrids for fresh graduates. • Knowledge of microgrids, electrical and mechanical. • Power systems analysis and control. • Awareness about different types of electrical energy sources and their generation means. • Electrical power systems and computer skills • How to generate electricity from different sources – hydro, wind, solar. • Auto CAD design skills, electronics skills, and renewable energy skills.	• Electrical installation skills. • Power transmission and distribution, knowledge of power systems and fault analysis • Knowledge of computers and artificial intelligence. • Solar systems design and installation. • [Microgrids] Design and installation skills, Artificial intelligence for monitoring. • Skills related to how renewable energy works and how to interconnect different energy sources. • Safety, power systems stability and analysis. • Design, implementation, and maintenance of power systems. • Knowledge of renewable energy and distributed generation. • Systems design, power management, safety, and projects management. • Knowledge of microgrids and power systems	• Basic microgrids-knowledge • Solar systems design and installation. • Auto CAD design-related skills • Microgrids design and installation skills • Artificial intelligence for monitoring and control of microgrids • Distributed generation.

Examining Table 10 and Table 11, it is evident that some skills mentioned by the students can be imparted by their respective universities. Although other skills such as those regarding microgrids transmission subsystem are not required as per argument Arg. B2, the analysed curricula cover them. Other skills that students might miss are vital but this monograph's author envisions artificial intelligence (AI) as one that should be highly rated. The author, informed by [136, p. 3], agrees with students that AI can be used to supervise (monitor) and regulate (control) microgrids. Therefore; students can be trained, for example, to write AI algorithms that can analyse sensor data (collected during monitoring, controlling and conditioning of microgrid components) and predict components failure. Hence, trigger or inform components' preventive maintenance. With timely preventive maintenance, power outages are eliminated and microgrids reliability is improved.

Lecturers are also asked what skills they think should be imparted to undergraduate Elec Eng students to prepare them for any microgrids-related career. The open-ended question that spears in Appendix L aims to guide skills gap establishment. Lecturers' responses and the skills gap are given in Table 14.

Table 14: Microgrids career required skills - lecturers' perspective.

Uni A lecturers' responses	Uni B lecturers' responses	Missing skills/ Skills gap
• Protection skills - how to design protection and coordination systems. • Knowledge of distributed energy resources. • Fault finding and grid codes, that is to say, understating different types of faults as well as grid codes. • Creativity and problem-solving skills. • Balancing between the economics and technological advances to design and implement affordable technologies. • Communication and negotiation skills • Control, stability, and scheduling issues regarding microgrid-to-grid connection and islanding.	• Designing and operating microgrids considering different energy sources: solar, wind, hydro, and geothermal. • Optimisation of [power] systems. • Monitoring and control – students should have some skills in control engineering to apply to controlling microgrids. • Coding and programming skills. Programming is important whether it is in terms of AI or the basic programming in C, python all that is vital to extend to automation of [microgrid] systems. • Communication systems engineering skills. • Data processing – Some skills in data processing are also very important. • Ability to establish potential electrical demand requirements based on existing standards. • Ability to match generation requirements to potential demand. • Power distribution planning. • Power systems analysis and modelling using appropriate software packages. • Network planning and optimisation • Actual installation, testing, and fault diagnosis of an entire power system from generation to distribution. • Ability to repair and maintain is another [required] skill students need to be conversant with as they move out of the university.	• Knowledge of distributed energy resources. • Design, implementation, testing, operation, fault diagnosis, repair and maintenance of microgrids. • Storage and backup. • Programming in terms of AI to enable automation of [microgrid] systems. • Control, stability, and scheduling regarding microgrid-to-grid interconnections and islanding. • Grid codes and standards to ensure safe and cost-effective microgrid functioning.

Referring to the analysed Uni A and Uni B Elec Eng degree curricula, scrutinising Table 10 and Table 11 and considering the required skills as emphasised by lecturers in Table 14, microgrids-related knowledge and skills that graduates produced might miss are established. The skills graduates might miss add to the graduates' skills gap and are indicated in Table 14. The author of this monograph emphasises that students should be introduced to more practical sessions in the acquisition of skills related to microgrids design, implementation, testing, and fault finding.

Lecturers also indicated that AI is vital in enabling microgrid systems automation. What stands out from this category of respondents is the grid codes and standards to ensure safe microgrid operation. Students may be introduced to standards and protection guidelines to meet grid code-specific requirements for microgrid-to-main grid interconnections with an emphasis on the regulation of both voltage and frequency levels. Although it is paramount that students are adequately prepared to design, implement, operate, repair, and maintain microgrids in conformity with best industrial practices, much time should not be spent on grid codes given that none of the microgrids surveyed during data collection is connected to the main grid. This then informs the choice of the used verb "define" which is in the lowest level "remember" of the revised Bloom's Taxonomy [137, p. 268], in the relevant ILO of the developed revised content in Appendix C.

To further get insights into the required microgrids skills in the world of work, microgrid operators are asked what skills higher institutions of learning should consider teaching students to enable their employability in microgrids-related environments. The open-ended question appears in Appendix P and Appendix O and the operators' responses are given in Table 15.

Table 15: Microgrids Career required skills – Microgrid Operators' perspective.

Operators from Tanzania	Operators from Uganda	Missing skills/ Skills gap
• Batteries connection – series and parallel circuits • How to carry out measurements of solar PV modules • What direct current (DC) is and what sources of DC are • Basics of microgrids • Importance of microgrids • Solar and wind as sources of electrical energy • Connecting solar PV modules • Maintenance of microgrids • Fault finding especially issues to do with short circuits • Efficient utilisation of energy • Ready to work in remote areas • Configuration of microgrids using computers • Remote control and monitoring	• They [higher education institutions (HEIs)] should actually teach what is in the field physically [practically]. • Social skills • Technical report writing • Communication skills • Practical work should be more than theory • Each college/university should establish a microgrid or a yard for practical purposes • Students should spend half of the time [ought to be spent at college/university] in the field. • Starting from primary schools, learners should be introduced to the ideas of what they should study in HEIs, especially in Elec Eng • Customer care • Wall chiselling work [for electrical installation] • Quotations for houses [Bills of Quantities]	• Social skills [interaction and communication with consumers]. • Readiness to work in remote areas. • Basics of microgrid. • Maintenance of microgrids. • Solar and wind as [distributed] sources of [electrical] energy. • Connection of solar PV modules [to achieve a desired system output]. • [Ability] to carry out measurements on solar PV modules. • Connection [wiring] of batteries – series and parallel circuits. • Configuration of microgrids using [up-to-date] computer [software]. • Remote monitoring and control [of microgrids]. • Shift from theory to a more practical-oriented teaching-learning process.

The microgrid operators' responses are examined. Referring to Uni A and Uni B Elec Eng degree curricula used at the time of data collection; microgrids-related knowledge and skills that graduates produced might miss are identified as indicated in Table 15. Social skills to enable BSc Elec Eng graduates to interact and communicate with consumers, graduates' readiness to work in remote areas, and provision of more practical-oriented teaching-learning approaches are key aspects emphasised by the microgrid operators.

With the skills that students might miss, representative content must be included in the proposed DEES course for onward inclusion in the BSc Elec Eng curricula. Therefore, HoDs and lecturers are asked the open-ended question in Appendix K and Appendix L. The question is, "Do you think it is appropriate to propose an independent microgrid course unit for inclusion in the curriculum or better to incorporate microgrids-related content in existing course units?". As indicated in Fig. 17**,** 12% of the respondents say a course unit on microgrids is not necessary whereas 88% mention that a microgrids course unit is necessary. Out of the 88%; 38% of the respondents suggest that the content is distributed in existing curricula power course units whereas 50% recommend an independent microgrids course unit.

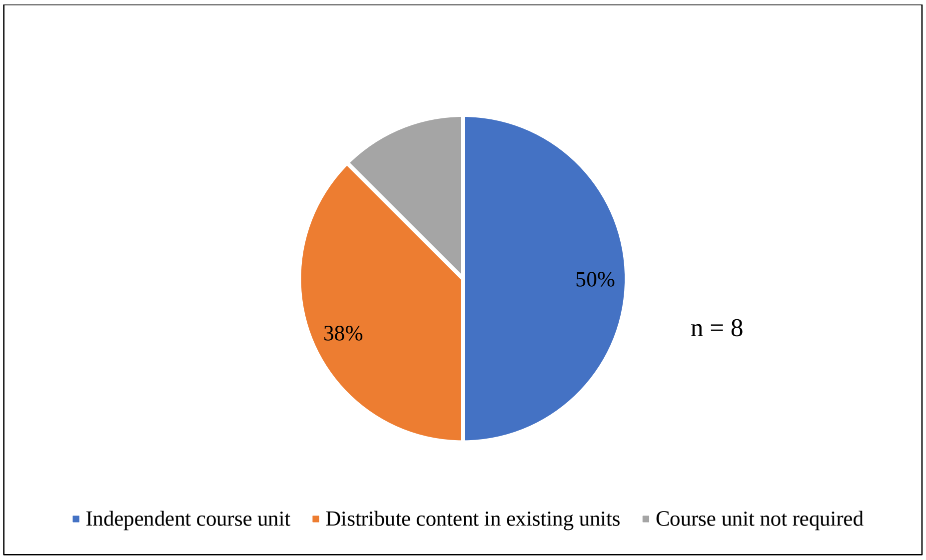


Fig. 17: Lecturers' (n = 6) and HoDs' (n = 2) responses regarding the inclusion of microgrids-related knowledge content in curricula.

Relatedly, the following excerpt by one of the students during a focus group discussion suggests an independent course. The student wrote that "solar DEES should be an independent course. Looking at the loads, in the near future developing countries will depend more on renewables especially solar as the source of electricity than hydropower. Thus, students should have deep knowledge of solar systems in order to have more expertise in the field". In addition, the student's assertion of solar systems resonates with that of lecturers who consider solar as one of the vital microgrid energy sources to teach students. Lecturers' responses to the open-ended question in Appendix L, about DER, are indicated in Fig. 18 and solar PV DES technology is recommended.

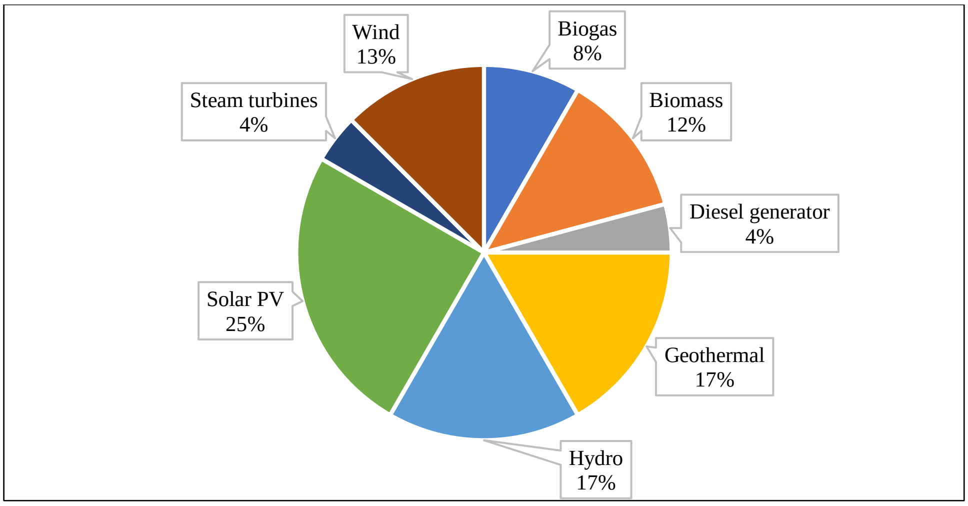


Fig. 18: Lecturers' (n = 6) responses to the open-ended question "What Distributed Energy Resources (DER) would you recommend or consider teaching students as vital energy sources for microgrids?".

To this end, it is inspiring to learn that the majority of the respondents acknowledge the importance of microgrids skills acquisition and hence, endorse the idea of related knowledge inclusion in curricula. For that reason; this monograph's author is motivated to establish more about curriculum development, review and implementation at both universities as discussed in section 5.2. However, stakeholder-specific content development and the associated skill sets for microgrids sustainability are first discussed in section 4.2 that follows.

4.2 Content Development for Stakeholder Skills Acquisition

This section narrates the stakeholder-specific microgrids-related knowledge content development process. The section reveals that the analysed data which is collected through questionnaires, focus group discussions, and from job descriptions form the basis of the developed content. In light of the CBE, attention is paid to the skill sets that stakeholders trained using the developed content shall acquire. Characterised skill sets required for microgrids sustainability in the rural communities of EA are therefore presented. The characterisation is in the quest to provide solutions to some of the challenges that affect microgrids sustainability. To contribute to microgrids sustainability, this monograph's author asserts that stakeholders such as Elec Eng students, electrical engineers and technicians who operate microgrids, consumers of electrical energy services in communities, and secondary school learners are potential key players. Therefore, there is a need to build the capacity of the key players and equip them with essential skills. To this end, training content is developed and skill sets for stakeholders envisaged to play a core role are characterised and presented in subsections 4.2.1 through 4.2.3 of this section.

4.2.1 Skill Sets for BSc Elec Eng Students

It is envisaged that HEIs need to produce engineering graduates who are equipped with employability skills, entrepreneurial skills, and appropriate microgrids knowledge. Once appropriately skilled, engineering graduates can significantly improve the available local capacity to design, supervise, develop/implement, operate, and maintain microgrids in EA. This guarantees the availability of a pool of locally trained human resources for the implementation of even complex microgrid projects and contributes to microgrids sustainability.

To characterise the skill sets for this category of stakeholders, the BSc Elec Eng students, the beginning point is curricular analysis in section 4.1.1 followed by the development of the content in Appendix A. Data is then collected from selected universities and microgrid operators. Fig. 19 illustrates DBR's ADE model application in the development of the content for microgrids knowledge transfer to BSc Elec Eng students.

To impart the right skill sets, junior and senior BSc Elec Eng students, lecturers of power-related courses, and microgrid operators all from Tanzania and Uganda are consulted during data collection. Microgrid operators including electrical engineers and operations Managers who oversee the operations of microgrids are asked "What are some of the tasks that engineering employees involved in the day-to-day operation of the microgrid execute?". The open-ended question appears in Appendix P. On the other hand, microgrid operators such as technicians and electrical engineers in charge of the day-to-day operations are asked "What tasks do you execute in the day-to-day operations of the microgrid?". The open-ended question appears in Appendix O. The recorded responses are examined and categorised under the themes indicated in Fig. 19.

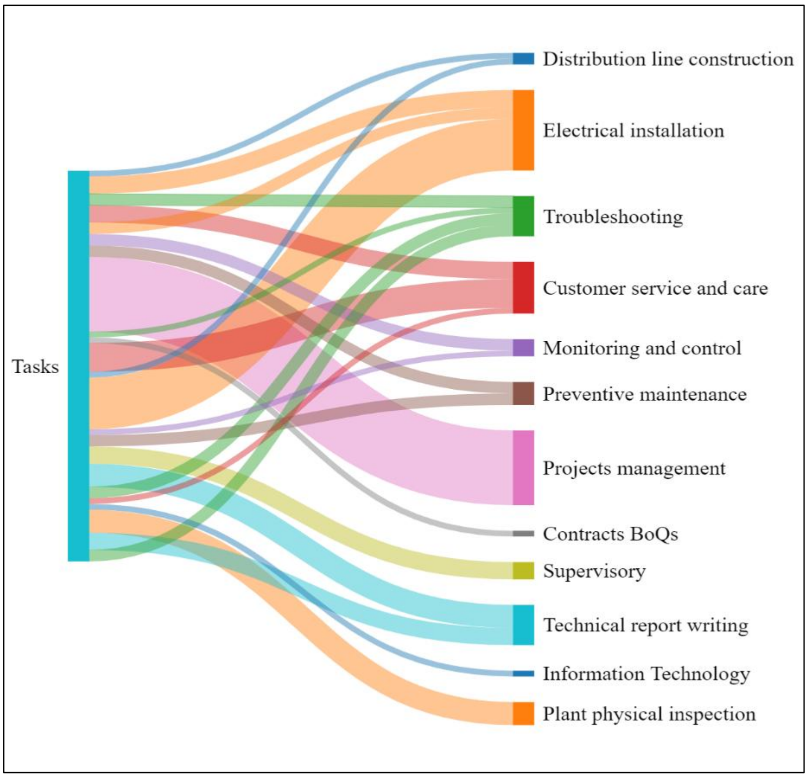


Fig. 19: Themes representing microgrid operators' (n = 7) responses to tasks executed by engineering employees in charge of day-to-day microgrid operation.

The themes in Fig. 19 are vital in aiding the development of skills and competencies required for the day-to-day operations of a microgrid. The themes illustrate what microgrids technical employees are expected to be able to do. It is therefore instructive that HEIs prepare students to execute tasks, in line with the indicated themes, by imparting appropriate skills.

To guide the establishment of such appropriate skills, three questions are asked to microgrid operators. Those who oversee microgrids operations – electrical engineers and operations managers are asked the following questions which appear in Appendix P:

1. In your opinion, what skills (or competencies) do engineering employees in charge of day to day running of microgrids need to have?
2. What skills, if any, do you find lacking in the engineering employees involved in the day-to-day operation of the microgrid?
3. What skills should higher institutions of learning consider, for inclusion into their curricula or emphasise, to enable the employability of their students in microgrids-related environments?

Similarly; technicians and electrical engineers in charge of the day-to-day microgrid operations are asked the following questions which appear in Appendix O:

1. What skills do you need to have to ably execute your duties for the day-to-day running of the microgrid?
2. What skills, if any, do you lack and hinder your efficient execution of duties in the day-to-day operation of the microgrid?
3. What skills should higher institutions of learning consider teaching students to enable their employability in microgrids-related environments?

Responses are examined and categorised into themes indicated in Fig. 20.

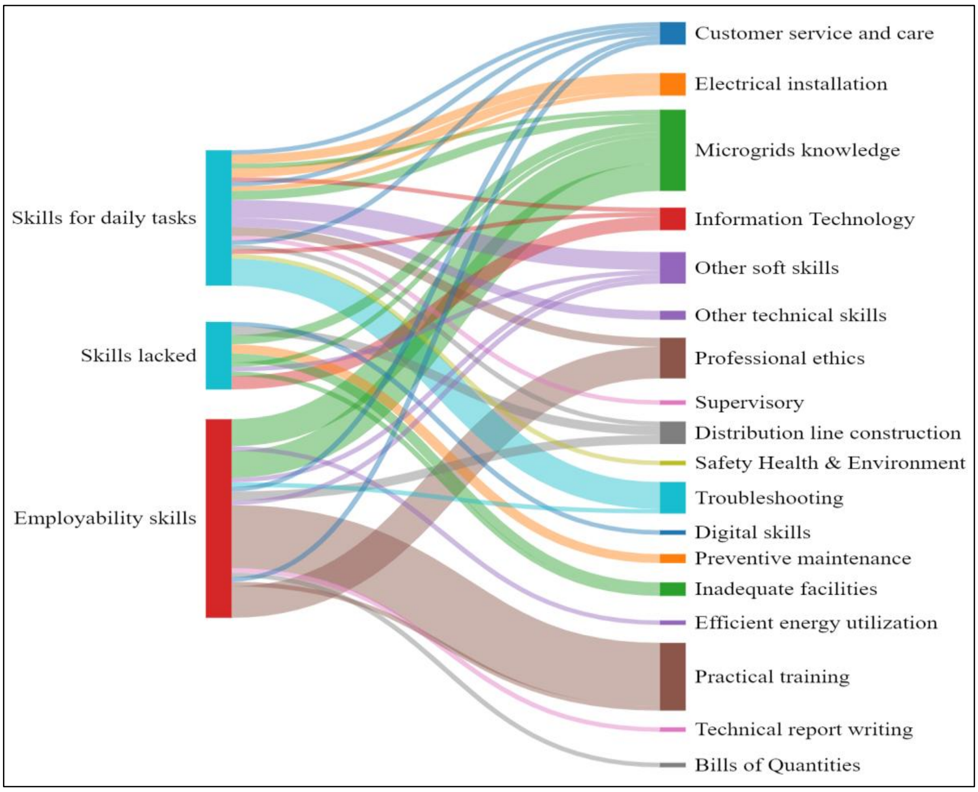


Fig. 20: Themes of microgrid operators' (n = 7) responses to required skills for microgrids daily tasks execution, lacked skills, and skills for employability of BSc Elec Eng students.

On the other hand, lecturers of power-related courses are asked "What employability skills do you consider appropriate for microgrids career-related environments?". Similarly; junior and senior students from both Uni A and Uni B are asked, what employability skills they think are required for one to work in a microgrid-related environment. The questions to the lecturers and students aim at aiding the establishment of employability skills that HEIs ought to instil in students. Responses are examined and categorised under the themes indicated in Fig. 21.

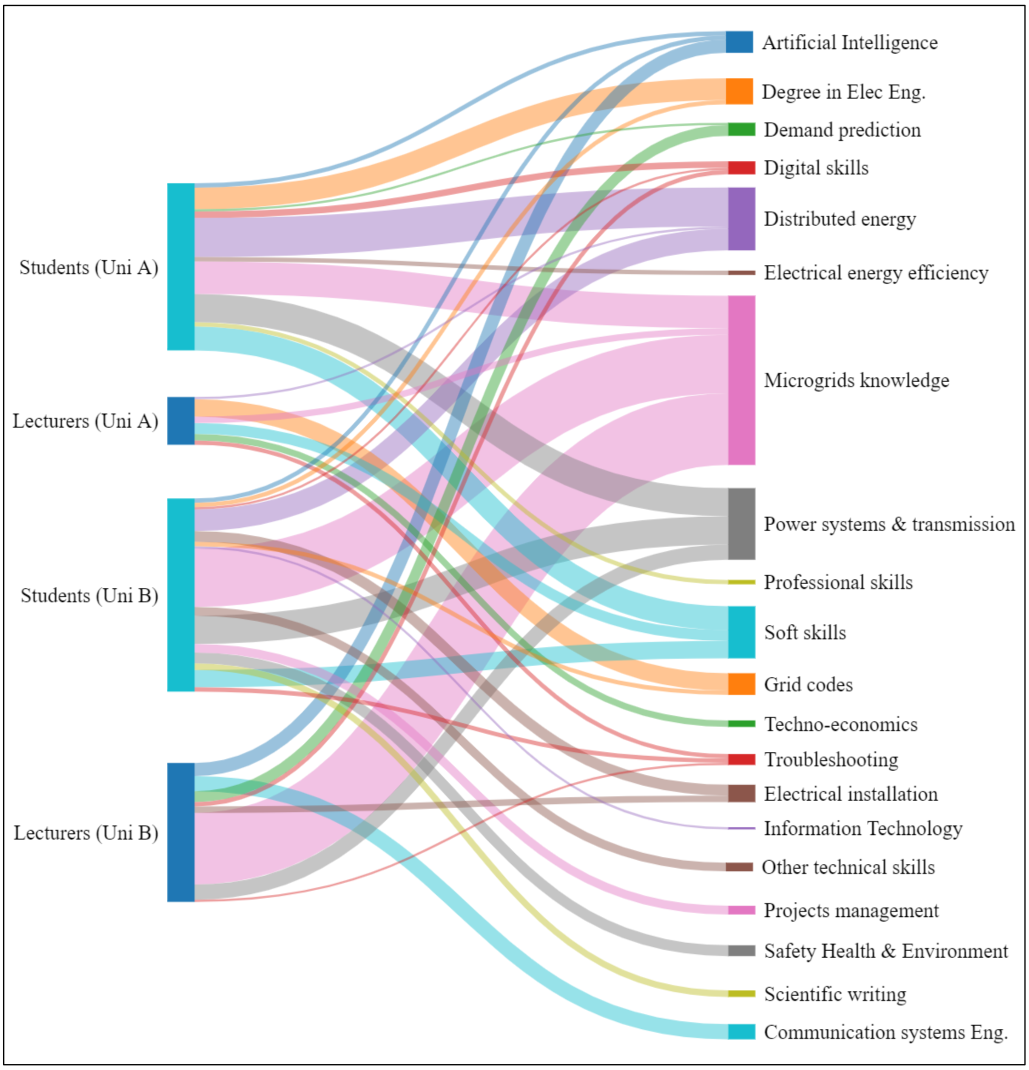


Fig. 21: Themes for microgrids career employability skills – lecturers' (n = 6) and BSc Elec Eng students' (n = 39) perspectives.

To corroborate the themes for microgrids employability skills in Fig. 21, job descriptions from selected Elec Eng employee positions working in microgrid environments are extracted. Competencies that correspond to the job descriptions, as indicated in Table 15, are then established. Including ILOs, in the DEES course content, to ensure the acquisition of such microgrids-related work competencies is a good link between academic institutions and the world of work.

Table 16: Job descriptions of selected positions, from Tanzania and Uganda, and the corresponding required competencies.

S/N	JOB DESCRIPTION TASK	ENVISAGED COMPETENCY/SKILL
A	**Project Engineer**	
1	Responsible for all technical aspects of the microgrids	Possess technical microgrids knowledge
2	Responsible for sizing and analysis of new microgrids	Able to design (size) and analyse new microgrids
3	Supervise the construction and operation of microgrids	Supervise microgrids installation and operation
4	Participate in the installation and maintenance of microgrids	Participate in microgrids installation and maintenance.
4	Responsible for liaising and creating a good working atmosphere with any concerned stakeholders such as ERA, REA, Ministry of Energy and Mineral Development (MoEMD) and others as may be required	Communicate effectively with stakeholders, such as clients, policymakers (ERA, REA, MoEMD), and the public. This calls for soft skills – Team player/People management skills: Interpersonal, coordinating, and communication skills.
5	Responsible for keeping any records as required in the installation, operation and maintenance of microgrids	Record keeping: Able to keep microgrids installation, operation and maintenance records.
6	Liaising with and supervising any subcontractors in developing microgrids	Supervise and coordinate microgrids development projects
7	Innovating new ideas that will boost the performance of microgrids	Invent new ideas to boost microgrids performance
8	Liaising with local authorities and the community professionally and creating a good working relationship with them	Soft skills – Team player/People management skills: Interpersonal, coordinating, and communication skills.
9	Assist in business development activities	Business acumen: Propose practical business development activities
10	Attend meetings and conferences on behalf of Winch Energy	Attend meetings and conferences
11	Account for all and any money advanced to you to facilitate Winch Activities	Account for advanced finances
12	Look after company equipment provided to you and maintain them in proper working order.	Maintain company equipment in proper working order
13	Any other activities suited to the skillset of the Project Engineer as may be required.	
B	**Technicians**	
1	Carry out maintenance of the microgrid components on a monthly and quarterly basis as appropriate.	Maintain microgrid components in proper working conditions
2	Perform repairs of the microgrid components.	Carry out repairs of microgrids' components
3	Fault finding and rectification at both the microgrid generation and distribution subsystems	Fault find and rectification
4	Carry out electrical installation at consumer premises.	Electrical installation
5	Attend to reported consumers' challenges.	Customer service and care
6	Ensure that consumers pay house installation loans	Soft skills including customer service and care, communication, financial literacy, negotiation, empathy, problem-solving abilities, organisation and time management, patience and resilience, and analytical – analysis of risks based on payment patterns and trends.
7	Ensure cleanliness and safety of the microgrid generation subsystem components such as solar modules, charge controllers, inverters, cable system, standby diesel generator, batteries and so on.	Technical knowledge, safety procedures and protocols knowledge, and cleaning techniques for each of the components.

Considering the day-to-day tasks execution themes in Fig. 19 as contributed by employees in charge of microgrids operation; the themes representing required skills for microgrids day to day tasks execution and BSc Elec Eng students' employability skills as suggested by microgrid operators, lecturers and students in Fig. 20 and Fig. 21; and the competencies in Table 16; the DEES course content in Appendix B is reviewed and redesigned. In addition; skills in section 4.1 and the evaluation of the DEES course draft in Appendix A done by lecturers, BSc Elec Eng junior and senior students are also considered during the course review and redesigning. The review is intended to ensure that the training content encompasses and hence enables the acquisition of all the aforementioned skills. The author asserts that with all the skills incorporated in the redesigned content as ILOs, the BSc Elec Eng graduates shall acquire the world of work-required competencies to meet microgrids job specifications. The redesigned DEES course content, which appears in Appendix C, comprises 10 topics. The 10 topics include DESs, microgrids introduction, solar cells and PV modules, microgrids maturation, energy storage systems, energy distribution costs, demand-side management, revenue management, Artificial Intelligence, and IIoT & Embedded Sensors.

In light of the redesigned content; for BSc Elec Eng students to contribute to microgrids sustainability and hence sustainable electrical energy, they ought to exhibit the world of work expected competencies set as objectives in Appendix C. The objectives are characterised by the ILOs that should enable BSc Elec Eng students to acquire the world of work-required competencies. To this end, the competencies characterised by the ILOs form the BSc Elec Eng skill sets for microgrids sustainability and they include the following:
Skill set 1 – Design microgrid energy systems cognisant of a community's electrical energy requirements. For the BSc Elec Eng students to develop this competence which is indicated as an objective in the DEES course, they should be able to perform certain functions. BSc Elec Eng students should acquire skills expressed as the ILOs from the designed DEES course. That is to say, BSc Elec Eng students should be able to:

- Perform technical evaluations and feasibility studies for implementation of energy projects.
- Produce models of a microgrid system using physical laboratory components to represent a real microgrid.
- Predict electrical energy demand for a microgrid project in a given community.
- Design a microgrid system for a specified load/predicted demand.
- Construct microgrids from installation, testing for commissioning, through to operation.

Skill set 2 – Propose suitable *Demand* versus *Supply* Management interventions for optimal energy use and generation relationships. Some of the ILOs that characterise, and enable BSc Elec Eng students to perform functions and thus form part of this skill set are that a BSc Elec Eng student should be able to:

- Design innovative demand- and supply-side imbalance management systems to ensure microgrid stability.
- Implement innovative demand- and supply-side imbalance management solutions to ensure microgrid reliability.

Skill set 3 – Examine techno-economic case scenarios for efficient and reliable microgrid systems at realistic production costs and fair customer tariffs. As part of this skill set, a BSc Elec Eng student should be able to:

- Assess the economic, environmental, and social impacts of DESs on local communities.

- Perform technical evaluations and feasibility studies for implementation of distributed energy projects.
- Implement control strategies for managing microgrids – monitoring and control; optimisation of resources for optimised and cost-effective performance.

Skill set 4 – Apply AI, IIoT and sensor technology to optimise microgrids operation and reliability. For this skill set, a few ILOs that a BSc Elec Eng student should be able to perform are:

- Design AI-based solutions for energy management - demand prediction versus (re)sources mix.
- Set-up sensor networks for data acquisition and monitoring in microgrid environments.
- Develop [and implement] control algorithms and logic based on sensor data input to optimise microgrid operation - load management, and energy dispatch.

Other ILOs that characterise the skill sets appear in the DEES course in Appendix C. With the indicated set of skills, BSc Elec Eng graduates will be competent and equipped with appropriate knowledge for microgrids sustainability. Relatedly; the skill sets to enable electrical energy consumers to contribute to microgrids sustainability, and the process leading to the skill sets, are highlighted in subsection 4.2.2.

4.2.2 Skill Sets for Electrical Energy Consumers

To characterise the skill sets for electrical energy consumers, the beginning point is literature analysis followed by developing the training content appearing in Appendix F. Data is then collected using the questionnaire in Appendix E to establish consumers' electrical energy utilisation challenges, training interests, abilities, and needs. Fig. 10 in subsection 3.1.2 illustrates DBR application in the development of the training content for microgrids knowledge transfer to electrical energy consumers in rural communities. The training content is developed to ensure that there is consumer awareness about microgrids, what microgrids are, how they operate and how to efficiently utilise the electrical energy. With this knowledge transferred through training, consumers are expected to be more mindful and ensure that they use efficient electrical energy appliances to achieve manageable electrical energy costs and this; directly feeds into the sustainability of microgrids. Secondly, some consumers are trained to perform basic household electrical installations. All these interventions plus productive use of energy sensitisation, among others, contribute to the sustainability of microgrids and hence, sustainable electrical energy.

To develop the right skill sets for electrical energy consumers, it is incumbent that the challenges consumers face are well known. The skills then ought to be deliberate and aim to enable the consumers to solve the challenges faced in their day-to-day electrical energy utilisation activities. Such skills would be embraced, consumers would be motivated and interested in receiving the skills through training. To this end, therefore; using the questionnaire in Appendix E, during data collection in rural communities, electrical energy consumers are asked "What electrical energy utilisation-related challenges do you face as a consumer?". Responses are examined and consumer challenges are categorised as indicated in Fig. 22.

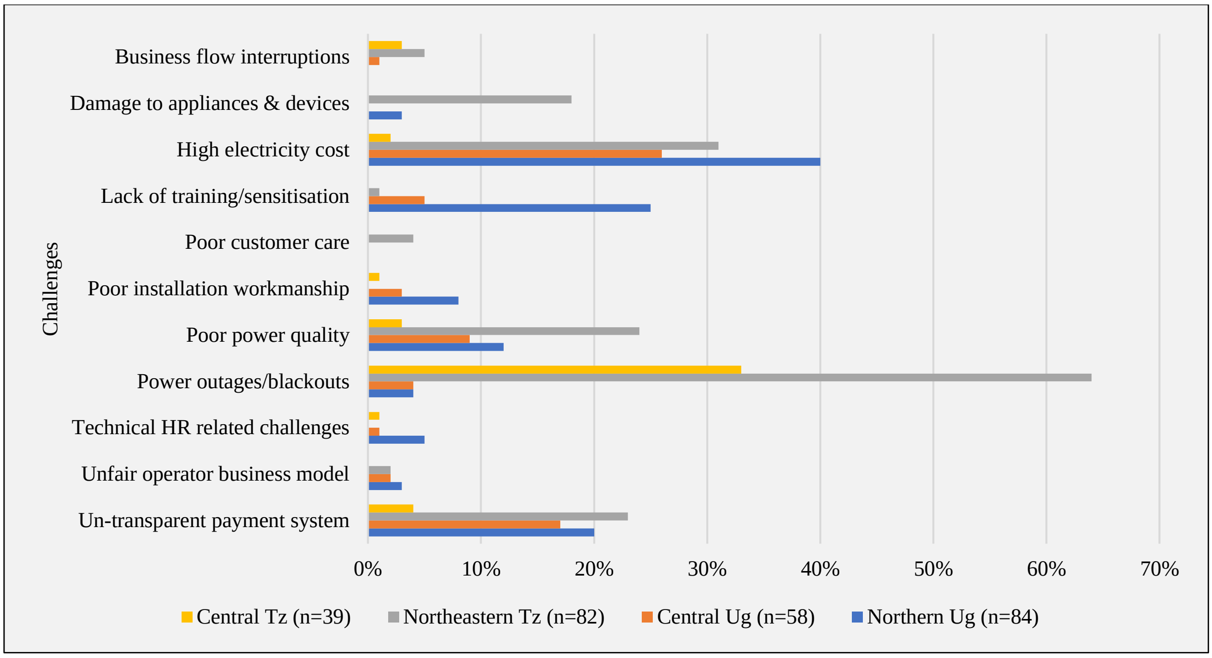


Fig. 22: Categories of consumers' electrical energy utilisation-related challenges, adapted from [2, p. 3].

Challenges related to power blackouts recorded the highest total frequency for both Tanzania and Uganda combined. This is followed by the high electricity cost, un-transparent payment system, poor power quality, lack of training/sensitisation, damage to appliances & devices, poor installation workmanship, through to poor customer care.

Power outages/blackouts – Since the microgrids in central Tz, northeastern Tz, central Ug and northern Ug were commissioned in 2015, 2017, 2021 and 2022 respectively, one would argue that those sampled in Tanzania have relatively deteriorated storage facilities, older or damaged components than those in Ug and thus the cause for the blackouts. By and large, challenges related to power blackouts and poor power quality can be addressed by operators from the generation and distribution subsystems of a microgrid. Therefore; knowledge and skills aimed at reducing or eliminating blackouts, for example ensuring load balancing ought to be imparted to BSc Elec Eng students and technicians. To minimise outages at a consumer's premises, consumers can be skilled to carry out simple maintenance tasks and ensure the safety of selected components. Avoidance of illegal connections, the connection of acceptable electrical loads to the network and proper efficient utilisation of the electrical energy by consumers can minimise power outages.

High cost of electricity – Apart from consumers connected to the microgrid in central Tz who pay a flat monthly fee of Tzs 3,000 (approx. €1.14), the majority of consumers connected to other microgrids find the electricity cost high. In northeastern Tz, consumers indicated that the monthly cost of Tzs 11,000 (approx. € 4.18) for tier T01 is high. The majority of the consumers subscribe to the cheapest tier T01 and are restricted to use up to a maximum of 275 Wh per day dubbed energy daily allowance (EDA). In Uganda, consumers complain that the per-unit cost of UgX 1,240 (approx. € 0.31) is high compared to the national grid charge of Ugx 250 – 747.5 (€ 0.06 – 0.19). In addition to a high per unit cost, they are charged a monthly service fee of UgX 3,000 (approx. € 0.75) and 18% of the total amount as value-added tax (VAT). Worse still is that the service fee and VAT were not being charged initially and that there was no consumer sensitisation when the two charge categories were introduced. On another note; as shown in Fig. 23, it is common to find lights on during daytime. Keeping lights on during the daytime coupled with the use of high-rating electric bulbs also contribute to the high electricity costs.

Fig. 23: Lights kept on during daytime – many were observed during data collection.

This suggests that electrical energy consumers need to be sensitised and skilled on how to: (1) strategise and generate income from electrical energy consumption and (2) utilise electrical energy efficiently to minimise consumption and avoid high bills. To this end, electrical energy consumers need knowledge and skills in productive use of energy (PUE), entrepreneurship, and efficient utilisation of energy among others.

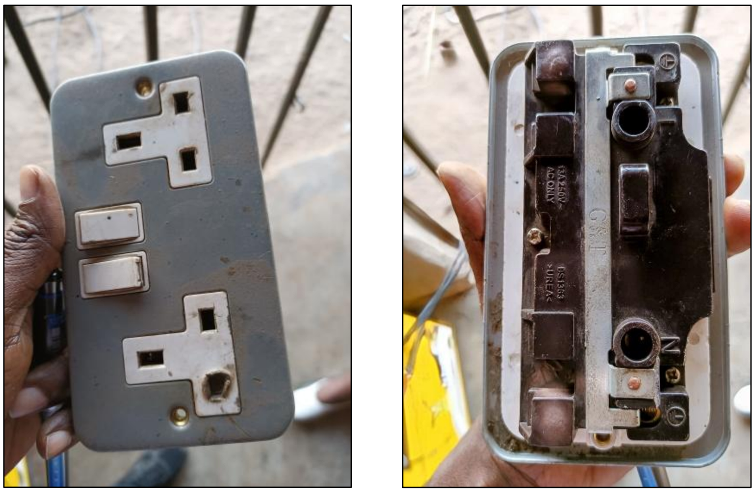
Un-transparent payment system – Following challenges associated with high electricity costs, further examination revealed complaints such as paying for EDA instead of consumed kWh units. Consumers in northeastern Tz claim that EDAs get used up even when one has not consumed the power and that EDAs are not compensated during periods of power blackouts and/or days of non-utilisation. In the same way; that the mode of payment by cash at the office is an inconvenience since no payments are possible at night and during weekends. Consumers in central Tz also indicated that the payment system used is not good. This is because the people who move around and collect the money, in cash, do not write correct records – "they will say one is 3 months in arrears yet the consumer knows it is only one month". Consumers thus suggest that a transparent payment system be introduced.

Some consumers in Uganda say that the payment system delays, sometimes in getting their electricity accounts credited following payments and that at times money never gets credited. This was confirmed by the customer relations officer who said "There are delays sometimes in transferring money to our company account by the bank. From a customer's mobile money account, money is paid to the bank then the bank transfers the money to our account. When money is received in our company account, then a second message is sent to the consumer". One consumer said that "at the end of every month we get disconnected when we have units but we still pay to restore power". Some consumers cannot pay for power off their mobile money phone accounts – "I don't know how to buy and load electricity tokens, even checking remaining units of electricity is a problem". This is an indicator of the need to train the consumers about the steps taken to pay for electricity and also explain the reasons that cause delays in getting units credited.

Other categories of challenges – The foregoing challenge categories can be minimised, to a great extent, if consumers are appropriately trained. Furthermore, Table 17 contains summarised observations, customer statements and/or excerpts for selected challenge categories.

Table 17: Consumer statements and training justification for selected challenge categories.

S/N	Challenge category	Observations, consumer statements and/or excerpts – as a training needs indicator	Justification for sensitisation/training
1	Damage to appliances & devices	The socket, to which a welding machine is connected, keeps getting burnt and the consumer is not sure which sockets to use.	The problem is socket overload. As indicated in Fig. 24, a higher capacity electric wall socket than a 13 A would be appropriate. Consumers and technicians alike need to know that such installations ought to have the right capacity wall plugs, sockets, cable gauges/sizes, and circuit breakers.
		Electric bulbs fuse due to frequent on-and-off power outages.	It would help if consumers are sensitised to always switch off lights and disconnect all appliances and devices on blackouts.
2	Poor installation workmanship	During earthing, no treatment was done to improve conductivity and the work was done using a steal copper-coated earth rod.	Since the statement is from a consumer, consumers can bring technicians to order if equipped with the essential knowledge.
		The circuit breaker supplying a welding machine trips while doing heavy-duty work (drawing a lot of current).	On examination of the circuit; it was revealed that within a distribution board (DB), the welding machine was connected to a 16 A circuit breaker through a 63 A miniature circuit breaker (MCB) shown in Fig. 25. The 16 A CB keeps tripping! Consumers and technicians alike need the right skill sets.
		As indicated in Fig. 26, circuits for lights and socket outlets are terminated within the same junction box (JB) and use the same cable sizes – 1.5 mm^2.	It is a recommended practice to separate light and socket electric circuits. If consumers are sensitised or equipped with basic domestic electrical installation skills, they would question electricians' actions and ensure that installations are properly done and with the right cable sizes.
3	Technical HR-related challenges	Statements like "we do not have a technician in the village", "technicians are few and too busy making any electrical problem escalate for too long", "expensive cost needed to pay transport for technicians to come …", "technicians are far, recruit more workers to support" are uttered by consumers.	Evidently, there is a need to train. The author urges that equipping consumers with the right skill sets would greatly reduce such complaints.
4	Unfair operator business model	"Everything has to be obtained from [or supplied by] the operator *yet some of the supplies are counterfeit* e.g. electric bulbs yet they are sold expensively".	
5	Poor customer care	Some customers are not happy with the way they are treated by the operators' technical teams.	Non-technical skills are equally vital. Therefore, microgrids technical employees ought to have soft skills.



a) Front side. b) Rear side.

Fig. 24: Illustration of damage to accessories, appliances & devices: Burnt socket outlet.

Fig. 25: Poor installation workmanship: A welding machine connected to a *16 A circuit breaker (in a DB)* through a 63 A MCB.

Fig. 26: Light and socket circuits combined, terminated in the JB and using the same cable size – 1.5 mm^2.

The foregoing discussion suggests that many of the challenges faced need sensitisation/teaching/training of consumers. Consumers need to be equipped with appropriate skill sets. To this end, consumers are asked if they would be interested in being trained. The closed-ended dichotomous and contingency questions appear in Appendix E and the responses are indicated in Fig. 27. Reasons for consumers who answered no to the dichotomous question include: Sickness associated with old age, not being able to read and write, fear of being electrocuted, that operators prohibit consumers from outsourcing labour apart from using operators’ appointed technicians so, some consumers fear that the skills might not be put to use!

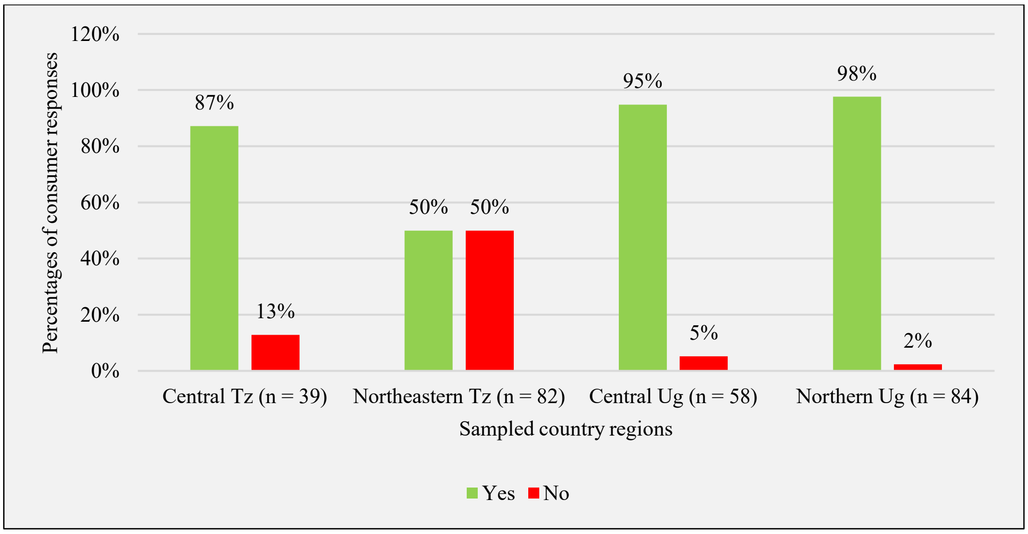


Fig. 27: Consumers’ responses regarding training interests.

On the other hand, consumers who answered in the affirmative to the dichotomous question are asked why they are interested in being trained. The recorded responses to the contingency question are examined and categorised under the themes indicated in Fig. 28.

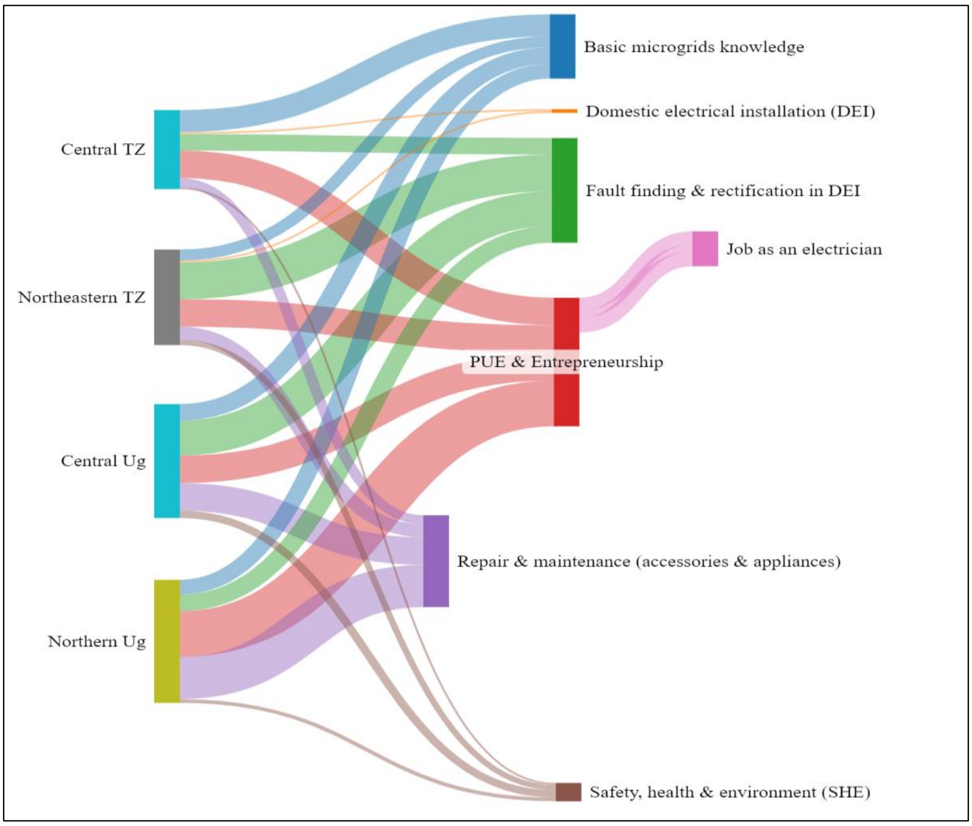


Fig. 28: Categories of electrical energy consumers’ (n = 263) training interests.

It is worth noting that within the PUE and entrepreneurship category, 19 customers expressed interest in working as electricians. This should be of interest to microgrid owners, HEIs, and all stakeholders involved in skilling consumers for microgrids sustainability.

To ensure that adequate skill sets are prepared for electrical energy consumers to support microgrids sustainability, other open-ended questions are asked to the consumers during data collection. The questions for this purpose, as the questionnaire in Appendix E indicates, include 4a, 4b, 5, and question 7. Responses to the questions respectively provide insights into consumers' training needs 1, transferable skills – the ability to apply knowledge and skills acquired from previous pieces of training, training needs 2, and the required skills for repair and maintenance services. The responses are examined and appropriate knowledge and skill categories to meet consumers' training interests and needs are mapped as indicated in Fig. 29.

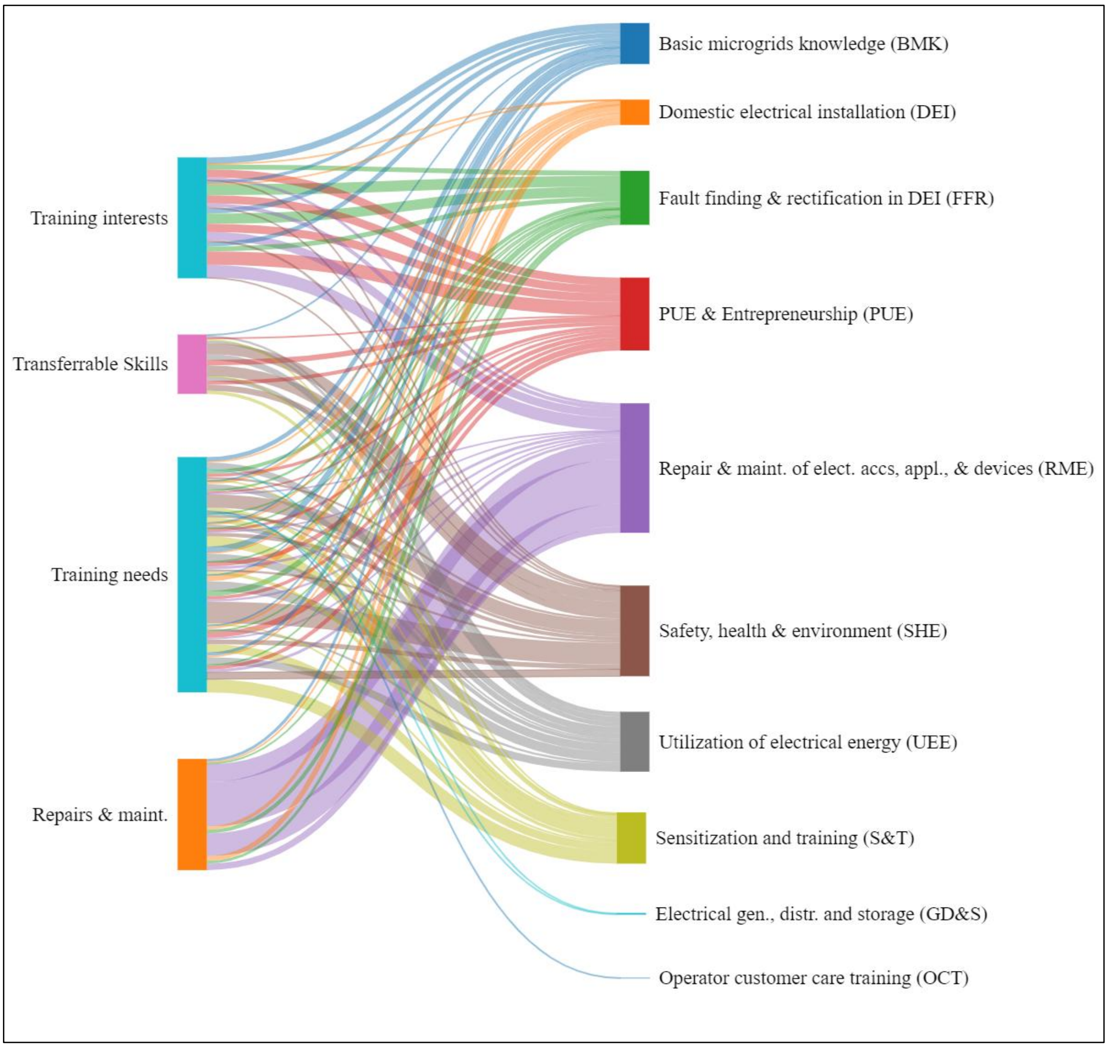


Fig. 29: Mapping of consumers' (n = 263) training interests, transferrable skills, and skills for repair and maintenance needs to knowledge and skills categories.

The knowledge and skills in Fig. 29 are envisaged as solutions to the challenges in Fig. 22. To this end, the challenges are mapped to the appropriate skills as indicated in Fig. 30 skill-challenge solution matrix.

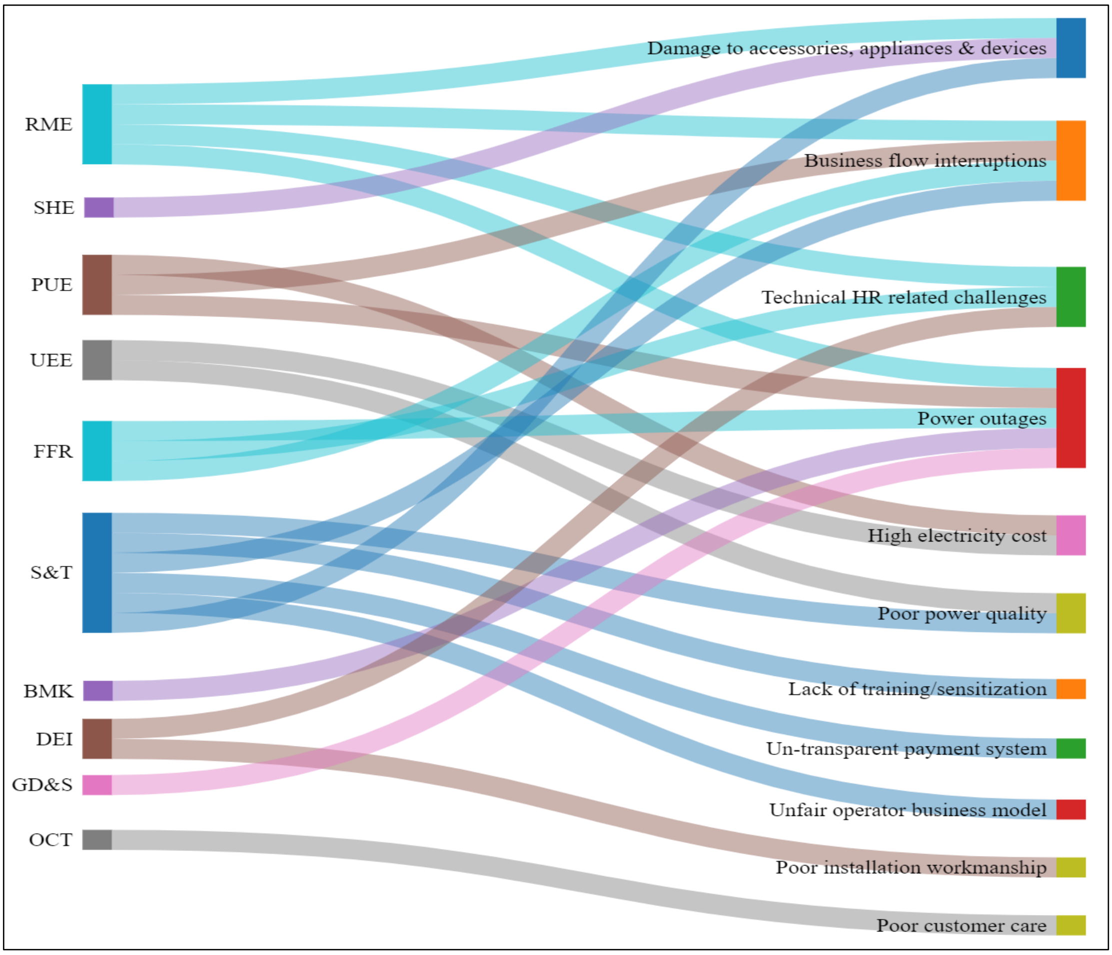


Fig. 30: Mapping of consumers' assessed needs, skill categories, and challenges – a skill-challenge solution matrix.

To realise the solution in Fig. 30, consumers need to be skilled to acquire the relevant competencies. Invoking Bloom's taxonomy as revised in [137], therefore, relevant competencies are expressed as the training objectives in Appendix G. The training objectives characterised by the ILOs form the skill sets envisaged to enable electrical energy consumers to acquire the relevant competencies to support microgrids sustainability and hence sustainable electrical energy. Therefore; skill sets for electrical energy consumers include, but are not limited, to the following:

Skill set 1 – Demonstrate relevant microgrids knowledge and skills. For the consumers to develop this competence, they should be able to perform certain functions or acquire skills expressed as the ILOs in the designed training course of Appendix G. That is to say, consumers should be able to:

- Identify the main components of microgrid systems.
- Discuss the advantages of microgrids with specific social, economic, health, and education examples.

- Support microgrid projects, throughout a project lifecycle, in their respective communities.
- Carry out simple maintenance tasks of selected components in a microgrid ecosystem while ensuring their safety to avoid power outages.

Skill set 2 – Adapt efficient and cost-effective electrical energy utilisation approaches. Some of the ILOs that characterise this competence and form part of this skill set are that a consumer should be able to:

- Discuss applications of electrical energy.
- Determine the per month electrical energy cost.
- Implement efficient electrical energy utilisation approaches.
- Choose appropriate appliances for efficient and cost-effective energy utilisation.

Skill set 3 – Perform simple electrical installations for microgrids sustainability in communities. Some ILOs that characterise this competence are that a consumer should be able to:

- Identify electrical accessories necessary for electrical installations.
- Perform electrical installations of basic households.
- Apply fault-finding & rectification procedures in electrical installations.
- Perform repairs & maintenance of accessories and selected devices in electrical installations.

Skill set 4 – Acquire entrepreneurship knowledge and skills for income generation while consuming electrical energy on one hand and solving local problems on the other. This maximises electrical energy utilisation potential, improves consumers' livelihood, contributes to their well-being and hence, a sustainable development approach. The ILOs that characterise this competence and form part of this skill set are that a consumer should be able to:

- Discuss local challenges that are potential entrepreneurial opportunities.
- Set-up income-generating businesses that solve local challenges.
- Keep financial records for a business of their choice.
- Perform repairs and maintenance of selected electrical appliances and devices based on envisaged business ideas.

Skill set 5 – Adhere to electrical health and safety rules in electrical-related undertakings cognisant of environmental concerns. This is a cross-cutting objective and ought to be incorporated into all topics, as appropriate.

Skill set 6 – Participate in microgrid projects' lifecycle, in their respective communities, for microgrids sustainability. In addition to other ILOs, the ILOs in the "Microgrid operator-specific business model" topic feed into this objective.

Based on Ralph Tyler's suggestion reported and emphasised by [137, p. 12]; the objectives' verbs on one part reveal the required behaviour change or skill development (cognitive process) and the nouns, on the second part; reveal the knowledge content consumers are expected to construct. The skill sets and the ILOs then inform the revised training content development, which appears in Appendix G, for electrical energy consumers. Noting that the developed content should enable consumers to acquire appropriate skills to contribute to microgrids sustainability; it is deserving to establish what consumers envisage as sustainable microgrids. Electrical energy consumers in rural EA communities were asked "What would you say a sustainable microgrid is?". Analysis of the responses to that open-ended question in Appendix E yielded categories in Fig. 31 that represent microgrids sustainability views of electrical energy consumers in selected rural EA communities.

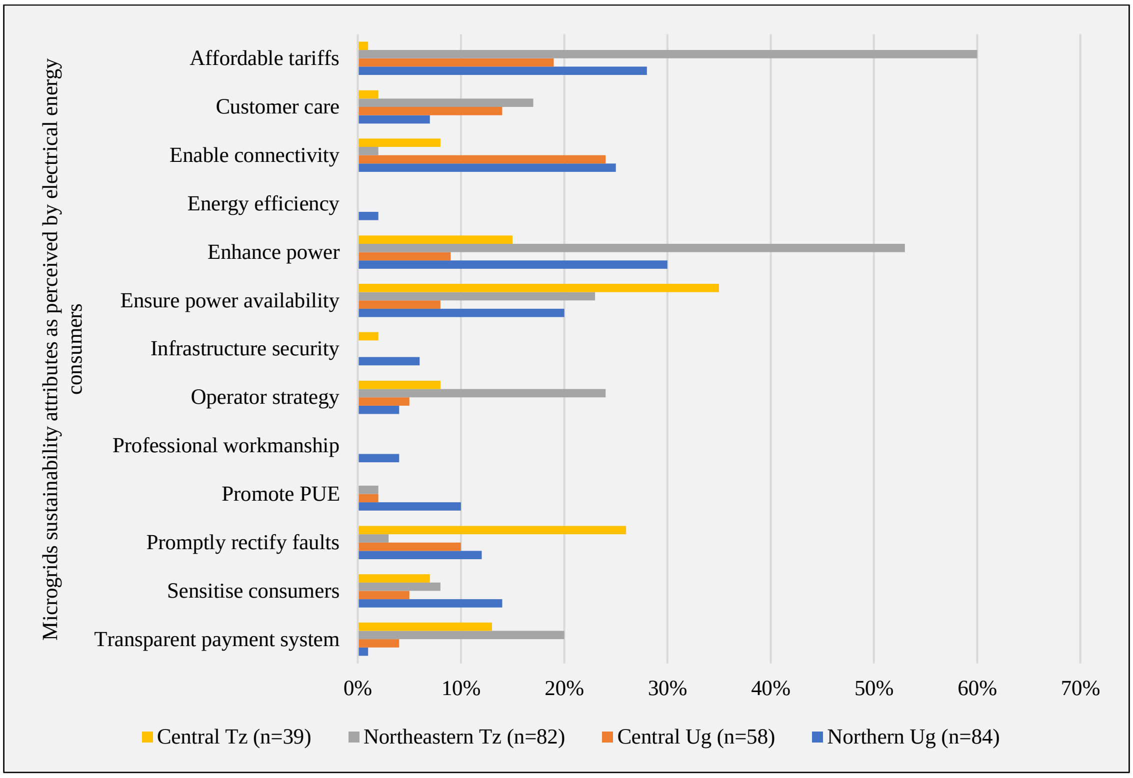


Fig. 31: Categories of microgrids sustainability attributes as perceived by electrical energy consumers.

Consumers' views are vital for the consumption of other stakeholders, such as microgrids operators, interested in microgrids sustainability. With the results in Fig. 31, microgrid operators are better informed about what they have to do to meet microgrids electrical energy sustainability expectations of consumers. One of the many noticeable attributes is the cost. Consumers urge microgrid operators to make tariffs affordable and ensure transparent payment systems. Other attributes mentioned by consumers to ensure the sustainability of microgrids include connection of other consumers to the microgrid network, consumer sensitisation, availability of power since consumers experience blackouts as indicated in Fig. 22, prompt rectification of faults, enhancement of power to ensure that welding machines and three-phase electrical loads can be powered, and promotion of PUE and entrepreneurship among others.

One of the avenues that electrical energy consumers mentioned for promoting PUE is the instalment plan or hire purchase of electrical appliances, devices, and machines. With this arrangement, the operator supplies items such as fridges, welding machines and others and a consumer pays an initial installment. The balance, including an accrued interest where applicable, is paid over an agreed period. This arrangement enables consumers to acquire assets for purposes of generating income while consuming electricity. As one consumer reiterated "Operators should fulfill their promises - they promised people fridges but they never delivered". To this end; the skill sets to enable secondary school learners to contribute to microgrids sustainability, and the process leading to the skill sets, are highlighted in subsection 4.2.3 that follows.

4.2.3 Skill Sets for Secondary School Learners

In the effort to characterise skill sets for appropriate microgrids-related knowledge transfer to secondary school learners, a microgrids course is developed. The author contends that microgrids knowledge transfer through training and equipping secondary school learners aged 14 – 18 with microgrids-related knowledge and skills is a microgrids sustainability strategy. This is because, certainly, on the acquisition of microgrids-related knowledge and skills secondary school learners return to their homes and apply the skills thereby enabling the communities to benefit from their competencies. Fig. 11 in subsection 3.1.3 illustrates the application of DBR in the development of a microgrids course content and materials for microgrids knowledge transfer to secondary school learners.

To characterise the secondary school learners' skill sets, the beginning point is the analysis of the lower secondary schools' physics syllabi for Kenya, Tanzania, and Uganda. Following the syllabi analysis, a microgrids course content is designed. In other words, the course content is developed based on the secondary schools' physics syllabi from the selected EA countries. The developed course content, the corresponding objectives and ILOs appear in Appendix H.

Following the development of the course content, evaluation is done and course materials are developed, implemented and evaluated by [138] in a secondary school in Kenya. During the overall evaluation of the course, trained learners performed a self-assessment to indicate achieved competencies: 82% agreed that they are able to demonstrate microgrids knowledge, that 64% are able to provide recommendations for suitable household appliances, 64% to perform basic domestic electrical installations, and 79% agreed that they can adhere to electrical safety and health rules [138, p. 90]. However, only 3% of the students indicated inability to recommend appropriate appliances [138, p. 90]. This could be because the demand-side management topic in Appendix H was not adequately addressed by [138] during implementation. Therefore, relevant ILOs and content from the demand-side management topic in Appendix H are included in the uses of electrical energy topic in Appendix I. Based on the results and recommendations in [138], the course content is redesigned and indicated in Appendix I.

It is envisaged that through training, secondary school learners can acquire appropriate basic microgrids knowledge and skills to the benefit of local communities. Secondly, the learners are inspired to pursue and join a career in STEM-related disciplines or Elec Eng in particular. With the right microgrids skill sets, secondary school learners are expected to benefit their respective

communities. Therefore, the skill sets to enable secondary school learners to support microgrids sustainability and hence sustainable electrical energy include the following:
Skill set 1 – To demonstrate microgrids knowledge and skills, the learner should be able to:

- Perform simple photoelectric effect experiments.
- Explain the operation of a microgrid.
- Discuss the advantages of microgrids giving specific examples from rural communities.
- Manipulate solar PV module connections (*series* and *parallel*) for a desired system output.
- Design a basic solar home system – taking the respective learner's home as a case study.

Skill set 2 – To provide recommendations for suitable household accessories and appliances for efficient and economical electrical energy utilisation, the learner should be able to:

- Identify devices in which the electric current heating effect is applied.
- Perform simple electric current effect experiments.
- Solve electrical energy and electrical power numerical problems.
- Solve electrical energy consumption and cost numerical problems.
- Determine the per month electrical power cost for their respective homes – as a case study.

Skill set 3 – To perform basic domestic electrical installations and troubleshooting, the learner should be able to:

- Produce simple electric circuits.
- Identify accessories used in domestic electrical installation.
- Use a multimeter for current and voltage measurements in electric circuits.
- Perform, practically, basic installation of electrical circuits on soft boards.
- Apply fault finding and rectification procedures to electrical wiring circuits.

It should be noted that safety, health, and environment (SHE) is vital and crosscutting. As such; SHE is considered an integral aspect, appropriately contextualised, across each of the aforementioned skill sets. In addition, secondary school learners equally need nontechnical professional skills such as interpersonal and effective communication. These are instilled through enabling students to work in groups and make presentations to their peers. In summary, Fig. 32 shows skill sets for all the stakeholders at a glance.

Of all the symbols used in Fig. 32, the bicycle for learners seems misplaced! The choice of the bicycle is to indicate the mode of transport used by some learners to commute to school from their homes in communities. The symbol also reveals that upon acquisition of microgrids-related knowledge, from schools; the learners return to their communities where they are expected to transfer such knowledge to their parents, peers, and other community members at large.

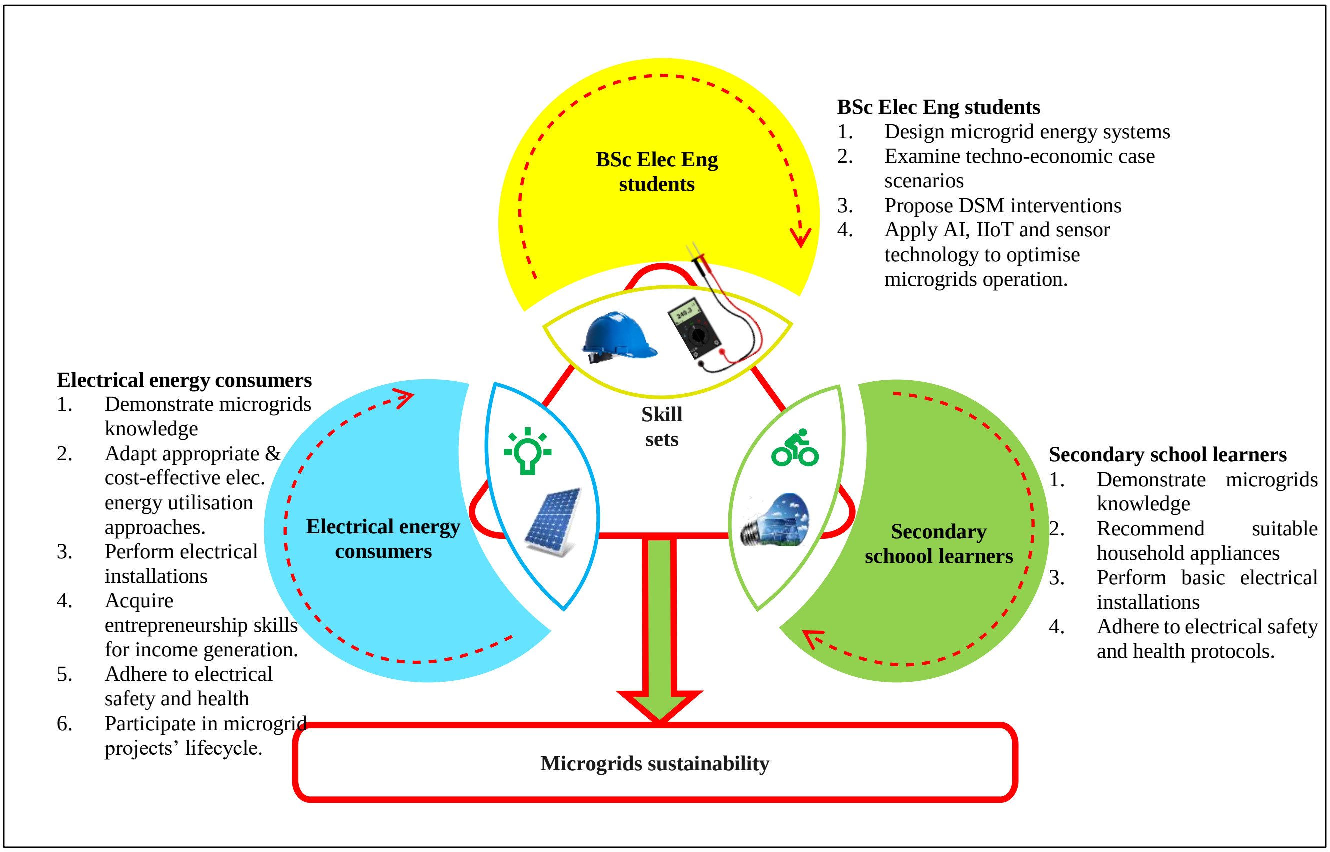


Fig. 32: A summary of stakeholder skill sets for microgrids sustainability.

4.3 Evaluation of the Developed Content

Evaluation of the developed training content and hence the envisaged skills that stakeholders should acquire is vital in ascertaining that: (1) indeed the intended objectives and the goals shall be achieved once the content is administered, (2) the content resonates with local challenges and training needs. Evaluation can also be performed for purposes of validation of either research tools or results. Evaluation for validation in [139], [140], [141], [142] is done by experts and students. For the electrical energy consumers, the developed content in Appendix G is evaluated by experts including a technician, three microgrid operator village representatives, an electrical project engineer, a commercial manager, and an expert in conducting consumer-related training in rural communities. In addition, 12 consumers also evaluated the developed content. On the other hand, the content for secondary school learners is evaluated in [138], [143] as summarised in subsection 4.2.3. In addition, an interview was held with a physics teacher to evaluate and gather feedback regarding the developed secondary school course content and materials. Finally, the BSc Elec Eng content is evaluated by lecturers of power-related courses plus the junior and senior BSc Elec Eng students.

For consumers, content evaluation started with the development of the tool. The tool used for evaluation is indicated in Appendix J. It is a 4-point Likert scale with a degree of assessor's agreement to the content item statement ranging from excellent to poor. Assessors' guidance regarding the language, duration, day, and time the training ought to be conducted is also sought. The tool development is then followed by deciding who the evaluators should be. Table 18 presents a description of evaluators for the electrical energy consumers' content.

Table 18: Description of experts and the consumers who evaluated the consumers' developed training content.

Country	Content Evaluator (CE)	Gender	Age (Years)	Highest education level	Consumer		Expert Designation	Work experience/duration as a consumer (Years)
					Category	Other responsibility		
Tanzania	CE1	Male	49	PSLE*	Domestic consumer	Sub village Chairperson		7
	CE2	Male	43	PSLE	Domestic consumer	Sub village Chairperson		7
	CE3	Male	73	PSLE	Domestic consumer	Sub village Chairperson		7
	CE4	Male	56	PSLE	Domestic consumer	Sub village Chairperson		7
	CE5	Male	68	PSLE	Domestic consumer	VEC** Secretary		7
	CE6	Male	61	PSLE	Domestic consumer	VEC Chairperson		7
	CE7	Male	51	PSLE	Domestic consumer	Village Chairperson		7
Uganda	CE8	Male	29	Diploma in Elec. Eng. & Networking			Technician – doubles as a consumer training facilitator.	2
	CE9	Male		Bachelor of Public Administration			Community Development Officer	3
	CE10	Male	27	Uganda Advanced Certificate of Education	Domestic consumer			2
	CE11	Male	25	Ordinary Certificate of Education	Domestic consumer			1
	CE12	Male	32	Uganda Advanced Certificate of Education			Village Representative	2
	CE13	Male	25	Craft Certificate in Automotive Mechanics			Village Representative	1
	CE14	Female		Ordinary Certificate of Education	Commercial consumer (Selling cold drinks)			2
	CE15	Female		Ordinary Certificate of Education			Village Representative	2
	CE16	Male	30	Diploma in Elec Eng	Commercial consumer (Milling machine)			2
	CE17	Male	31	Ordinary Certificate of Education	Commercial consumer (Welding machine)			3

	CE18	Male		BSc Elec Eng			Commercial Manager	5
	CE19	Male	28	Diploma in Elec Eng			Electrical Project Engineer	5
	CE20	Male	32				Programme Officer (Also facilitates training)	6

*PSLE – Primary School Leaving Examinations VEC** – Village Energy Committee

Content evaluation, for every assessor, started with an explanation of the entire content from the goal, objectives, and each of the topic’s ILOs and content. The explanation is aimed at ensuring that the evaluator and the content author understand and perceive the entire content on an almost equal footing. The evaluator then assesses the content using the tool in Appendix J. Based on the assessors’ evaluation responses, the content validity index (CVI), as applied in [140, p. 3], [144, p. 34], [145], is determined. Although CVI is primarily applied to validate questionnaires and survey instruments, it can be adapted to validate courses. CVI is applied in [140] to validate the developed content for a nursing care course in mental health and in [145], CVI is used to determine vocational knowledge and skills of an electrical technology course. In this monograph, CVI is used to validate the developed content for consumers based on the content objectives, relevance to the target audience, structure and ILOs as evaluated by the assessors in Table 18. Evaluation results are presented in Table 19.

Table 19: CVI for the developed consumers training content based on the assessors’ (n = 20) responses.

CONTENT ITEM STATEMENT	Excellent (4)	Good (3)	Fair (2)	Poor (1)	I-CVI $(n_e/n)^*$	S-CVI
Objectives						
The objectives are clearly defined	16	4	0	0	1	
The objectives align with the overall goal	14	5	1	0	0.95	**0.98**
Target audience						
The target audience is clearly identified	14	6	0	0	1	
The content complexity is appropriate to the level of the audience	13	7	0	0	1	
The content aligns with the challenges of the target audience and is thus suitable to provide solutions after the training is conducted.	14	5	0	1	0.95	
The content is suitable to the needs of the target audience	10	10	0	0	1	
The content is suitable to the interests of the target audience	8	10	1	1	0.90	**0.97**
Content structure and intended learning outcomes (ILOs)						
The content is broken down into themes	16	4	0	0	1	
The themes are clearly defined	20	0	0	0	1	
The ILOs are clearly defined to communicate what will be learnt	19	1	0	0	1	
The ILOs align with the objectives	17	3	0	0	1	
The ILOs are achievable	15	4	1	0	0.95	
The themes are logically and sequentially organised	15	5	0	0	1	
The content workload is manageable	13	7	0	0	1	
The content is factually correct and up-to-date	15	5	0	0	1	**0.99**
Overall S-CVI						**0.98**

$^*n_e$ is the total number of assessors who evaluated a content item statement as either excellent or good and n is the total number of assessors.

Basing on each item CVI (I-CVI) as evidenced in Table 19, all content item statements are accepted by the evaluators. This is based on the fact that the minimum I-CVI of 0.90 is greater than the recommended minimum CVI values of 0.78 in [144, p. 33] and 0.80 in [140, p. 3], [145, p. 1532]. Acceptability of the statements, therefore, explains the lack of need to eliminate or review but rather retain the consumers’ developed content in Appendix G. To confirm the overall content validity, the scale level CVI (S-CVI) is determined by aggregating I-CVIs divided by the number of items. Referring to Table 19; the objective, target audience, content structure and ILOs, and the overall S-CVI respective values of 0.98, 0.97, 0.99, and 0.98 are all above the minimum CVI values of either 0.78 or 0.80. Therefore, all evaluators approve that the objectives are well defined and aligned to the goal, the content is appropriate, can provide solutions to the challenges of the consumers, and suits the needs and interests of the consumers.

In addition to the quantitative evaluation, assessors were encouraged to indicate any descriptive evaluation under the remarks column of the tool in Appendix J. Evaluator CE16 indicated that “consumers need a reduction in the cost of an electrical power unit”. This statement also validates the results in Fig. 22 in which high electricity cost is indicated as a challenge. Evaluator CE15 suggested that the safety, health, and environment topic be made the 3rd topic as opposed to being the final topic number seven of the content. The suggestion is logical since consumers are then introduced to the electrical-related health and safety concerns before the electrical energy utilisation and installation topics. The suggestion is implemented in the content that appears in Appendix G. Evaluator CE6 indicated that training of consumers ought to be done as soon as possible given that there are plans to have the microgrid taken over by the Tanzania Electricity Supply Company (TANESCO) Limited. The suspected takeover of the microgrid by TANESCO is probably the reason why the microgrid developer never showed interest in the feedback session that was proposed by the author of this monograph.

Regarding the language, in response to an open-ended question “What language should be used by the trainers?” that appears in Appendix J; all assessors from Tz indicated that the training should be conducted in Kiswahili. This is reasonable since Kiswahili is one of the two official languages in Tz alongside English. In northern Ug, assessors indicated that English and Acholi (Luo) should be used. In central Ug, on the other hand, 37% of the assessors (n = 8) indicated only Luganda whereas 63% indicated that the training should be conducted in English and Luganda. Assessors’ guidance regarding the training duration, day of the week, and the start and end times the training ought to be conducted is also sought. Responses are indicated in Fig. 33.

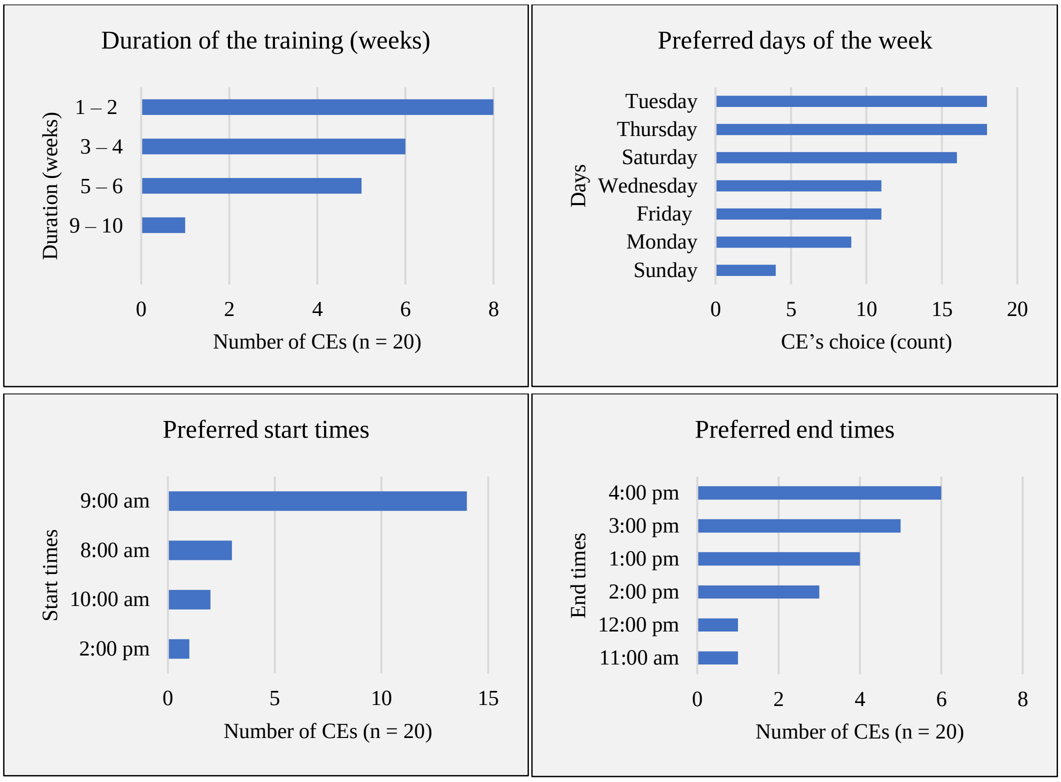


Fig. 33: Assessors' (n = 20) responses regarding duration, preferred days of the week, start and end times of the training.

As indicated in Fig. 33; a total of 8 assessors suggested that the training should be conducted for 1 – 2 weeks whereas 6 indicated 3 – 4 weeks. For the preferred days of the week, assessors would choose any number of days in a week. Tuesday, Thursday, and Saturday are the most preferred days. A significant number of assessors also prefer Monday, Wednesday, and Friday. Concerning the preferred start time, fourteen assessors prefer 9:00 am whereas 3 prefer 8:00 am. About the end time; 6 assessors prefer 4:00 pm whereas 5 prefer 3:00 pm. These preferences can guide the scheduling of microgrids-related knowledge transfer sessions to maximise the participation of electrical energy consumers and the effectiveness of the training.

For secondary school learners, on the other hand, predictive and retrospective evaluation of the microgrids course content is done in [138], [143]. Following the course implementation, another evaluation interview was held with a physics teacher to evaluate the course materials. According to the teacher, the materials are suitable to the age of the learners, are based on the physics syllabus and comply with the new CBC. The workload is manageable except that it requires a bit more time. "I would recommend that it can be done for the entire term." The teacher recommends that the course be taught during term two of Form 4. Since there are five physics lessons per week, the teacher recommends three lessons per week for the microgrids course. The teacher further mentions that the materials are problem-oriented, that is, taught through problem-solving and they are student-centred given that students were actively engaged with the material during learning. The teaching approach, through the use of practicals, made physics seem simple, not abstract and that physics has meaning. That the course motivated students to learn physics more than before and that with the more Elec Eng-oriented practical assignments offered, some students are likely to pursue Elec Eng courses.

The teacher, however, indicated that more practical exercises are required and recommends a theory-practical ratio of 1: 2. The ratio translates into approximately 33% theory and 67% practical sessions. It should be noted that the issue of more time for the course including that for practical assignments was also mentioned by students during the course evaluation as reported in [138], [143].

The teacher's recommended media that can be used for teaching the content include hands-on practicals, animated videos, projections of PowerPoint presentations, excursions, and the use of smart TVs to screen videos. The teacher also mentioned that he supervised the implementation of the course content in the classroom and that the content is sufficient to enable achievement of the set goal, objectives, and ILOs. The teacher mentions that during the implementation of the course, he would assist, especially in making connections and during course material evaluation by learners. The 13-year experience physics teacher who, over the years, has taught physics in all secondary school classes says "… I wish that the teachers may also be able to receive the same training". The teacher recommends training the trainers, the physics teachers, by subjecting them to the same microgrids course content. The teacher's recommendation is a strategy aimed at equipping the trainers with the necessary instruction competencies to conduct the secondary school microgrids course. Engaging the physics teacher in the interview enabled feedback to be gathered on the effectiveness, relevance, and quality of the developed secondary school microgrids course content and materials.

Evaluation of the content for BSc Elec Eng students is done based on feedback written on printed DEES course content materials. Evaluators were asked to point out DEES content that appears in the BSc Elec Eng curricula at the time of evaluation and suggest: (1) a suitable time for the administration of the DEES course in the four-year duration of the BSc Elec Eng programme, (2) DEES course content for removal and for addition. About the suitable time to administer the DEES course, as indicated in Fig. 34, only one senior student from Uni B suggested that the course be taught in the third year semester 1. All other Uni B students did not comment on the suitable time to administer the course. For Uni A, one junior student suggested that "the course content basics (introductory part) should be taught in 2^{nd} year to introduce a student to the actual issues out there and then the advanced part (designing, operation, and practical part) in 3^{rd} year for thorough understanding". The student did not specify the semester in each of the years stated. Three junior and two senior students, on the other hand, indicated that the course be administered during the third-year semester 2.

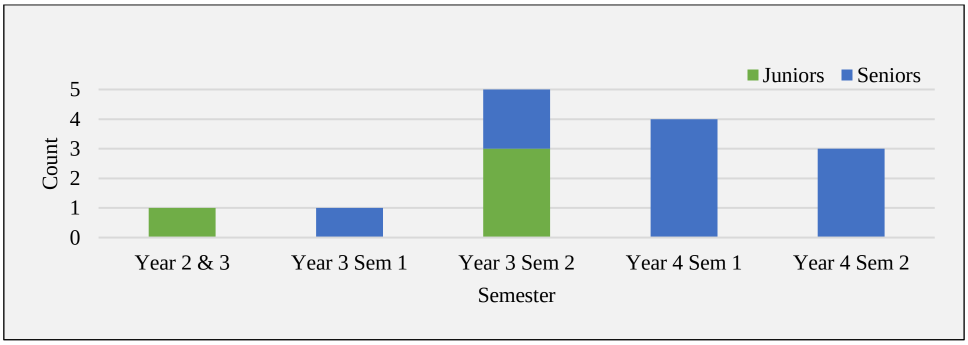


Fig. 34: Suitable time to administer the DEES course as suggested by BSc Elec Eng students (n = 39).

Relatedly; four and three seniors of Uni A respectively indicated that the course be administered during year 4 semester 1 and year 4 semester 2. Basing on the foregoing results, the author of this monograph proposes that the DEES course be administered during year 3 semester 2 as suggested by some junior and senior students. The suggested slot is a suitable semester because: (1) Students have then covered several basics in other courses in year one through to year 3 semester 1. (2) The timing enables students to acquire relevant advanced knowledge and hands-on skills to prepare them to undertake internship at the end of year 3 semester 2. (3) Those interested in pursuing a career in microgrids, once secure internship placement in a microgrids related firm, can identify a challenge and develop a final year research topic to address the problem. This cannot be possible if the course is done in the final year of study.

About content for removal; students indicated some (content) topics that appear in the curricula at the time of this evaluation. Some content, however, is actually not in the curricula as students indicated. For example, the topic about the sizing of solar systems which is reported to appear in Electrical Power Systems of Uni A is actually not in the analysed curricula. This confirms the information that lecturers teach up-to-date topics that are not in the curricula though students perceive it to the contrary. Students further indicated that content that appears in the developed DEES course and was covered in the course of their studies, should not be removed but rather ensure that the entire DEES course is more of a practical course. One of the senior students indicated that the "course unit be made more practical than theoretical since most of the theory would be covered in other course units in the lower level of studies". Students advocated for a practical course with another student indicating that "if 60% is practical and 40% theory, it will be a good course unit". Another student indicated that the course "needs to be taught as an applied course unit because the basics are taught in year 2 in electrical energy systems". To this end, all courses where some mentioned content seemingly appears should be made prerequisites to the DEES course at the prerogative of the respective universities. Such courses include ME322 Renewable Energy Technologies, EE323 Electrical Power Utilisation, EE 314 Power Electronics II for Uni A and ELE 2212 Electrical Energy Systems, and ELE 3216 Energy Conversion and Generation for Uni B, among others.

About content for addition; students indicated the need to include other renewable energy sources like biomass, geothermal, hydro, and wind. It is noted however that these sources appear in courses such as ELE 2212 Electrical Energy Systems and ELE 3216 Energy Conversion and Generation of Uni B and EE 421 Electrical Power Plants for Uni A. Since there are no compelling admissible reasons presented, other renewable energy sources are not included. Other content suggested to be added include the use of AI for monitoring microgrids and other functionalities, IoT basics, the use of IoT in forecasting load and supply, design of battery energy storage, and application of software tools in microgrids design among others. Consequently; topics such as AI, Energy storage systems, IIoT and embedded sensors are added to the DEES content. Following the inclusion of content and other suggestions, the content for the proposed DEES course was peer-reviewed. The peer reviewer's recommendations were all attended to save one that topics nine and ten be an independent course from DEES. The recommendation is not implemented given that the ILOs in the two topics are insufficient to make a course. Secondly, the topics complement each other with topic 10 being more practical than nine. To this end, Chapter 4 summary is presented in section 4.4.

4.4 Chapter Summary

This chapter reports the research analysis and discussion of results leading to stakeholder-specific content development and skill sets necessary for local capacity building in the EA region to contribute to sustainable microgrids in rural communities. The chapter begins with the current and future skills for microgrid sustainability and the use of AI, IIoT and sensor technology in the renewable energy value chain is highlighted. The BSc Elec Eng curricula from Uni A and Uni B in EA are analysed, revealing a lack of microgrids-specific knowledge and identifying skill-based competencies derived from the curricula. BSc Elec Eng junior and senior students, lecturers of power-related courses, and microgrid operators highlight the BSc Elec Eng microgrids career required skills. The derived competencies are compared with microgrids career required skills as perceived by BSc Elec Eng students, lecturers and microgrid operators and a skills gap is identified. Hence, laying a foundation for establishing microgrids career-related competence gaps in BSc Elec Eng graduates. Further; the skills for the day-to-day operation of microgrids, skills microgrid operators lack and microgrids-related employability skills HEIs should consider instilling in BSc Elec Eng are determined through analysis of the collected data. All the results plus workplace-required competencies derived from job descriptions of selected positions guide the development of BSc Elec Eng content and consequently, the skill sets are characterised.

The discussion extends to the essential skills for electrical energy consumers, detailing the content development process. The content to facilitate skills acquisition is developed based on the consumers' challenges, training interests, transferable skills, training needs, and repair and maintenance needs. Skill sets to enable consumers to solve their electrical utilisation challenges and contribute to microgrids sustainability are then characterised. Further, the lower secondary school physics syllabi from three EA countries are analysed and the analysis guides the microgrids course content development process. Course materials are developed, implemented, and evaluated, and the course is re-designed. Skill sets for secondary school learners are characterised based on the re-designed course content. The developed training course contents for all the stakeholders are evaluated to ascertain that the skill sets shall enable achievement of the intended objectives and goals. Taking the example of the consumers, evaluation is based on CVI and all evaluators approve that the objectives are well-defined and aligned to the goal. Most important to note is that the content can provide solutions to the challenges, and suits the needs and interests of the consumers. To this end, the microgrids-related knowledge content development processes are summarised in section 5.1 of Chapter 5 and evolve into a didactic architectural model.

5 Didactic Architectural Model and Curriculum Development Processes

This chapter is organised in three sections and presents the microgrids-related knowledge transfer didactic architectural model and curriculum development processes. Section 5.1 summarises the content development process into a microgrids knowledge transfer didactic architectural model. The BSc Elec Eng curriculum design processes, on the other hand, are investigated in section 5.2. The chapter concludes with a summary in section 5.3.

5.1 Microgrids Knowledge Transfer Didactic Architectural Model

In this section; a microgrids knowledge transfer didactic architectural model, for microgrids sustainability, is presented. This section recaps the content development process, from stakeholder identification through to a trained stakeholder, into a didactic architectural model. In addition to DBR's ADE model, the tools employed during the content development process include the revised Bloom's taxonomy, the constructive alignment (CA) concept described in subsection 6.2.3, and the Accreditation Board for Engineering and Technology (ABET)'s Engineering Criteria 2000 (EC2000) set of standards. As a didactics of technology discipline, the aforementioned tools are employed to design social-technical strategies for microgrids sustainability. To this end, content for EA community training programmes that are locally relevant are developed cf. [24, p. 1].

To enable benchmarking and support replication of the knowledge content for such training programmes, the approaches and tools, didactic concepts and the instructional design/strategy for microgrids knowledge transfer are summarised into a didactic architectural model. The didactic architectural model, therefore, summarises the didactic concepts and/or methods of training microgrids-related knowledge to secondary school learners aged 14 – 18 cf. [36, p. 1874], BSc Elec Eng students, and consumers of electrical energy [37, pp. 1859–1860], [38, p. 7], [39, p. 1]. The training aims to empower the mentioned stakeholder categories to contribute to microgrids sustainability.

5.1.1 Didactic Concepts

Didactic concepts, frameworks and standards applied in the development of the content include the revised Bloom's taxonomy [137], [146], [147], ABET's engineering criteria 2000 (EC2000) [134], and the CA concept [148, p. 7] among others. It is interesting to note that EC2000 focuses on learners' achievements, that is, learned (outputs) rather than taught (inputs). The criteria emphasise assessment and demonstration of learning outcomes from 11 areas including but not limited to technical knowledge, effective communication, teamwork, engineering ethical and circumstantial matters [134, p. 1]. Therefore, the interplay between the revised Bloom's taxonomy, the EC2000, and the CA concept is vital in: (1) proposing ILOs, teaching-learning activities, and assessment methods that emphasise the practical relevance of microgrid-related skills. (2) skills classification into factual, conceptual, procedural, and metacognitive knowledge dimensions. (3) skills categorisation into cognitive, affective, and psychomotor knowledge domains.

Bloom's taxonomy framework enables instructors to classify educational objectives hierarchically following the stages of a particular knowledge domain [146, p. 212]. For clarity, knowledge domains are cognitive, affective, and psychomotor. In the classification of educational objectives and/or ILOs, and hence the acquired skills; a taxonomy table is an important tool. A taxonomy table is a matrix of knowledge dimensions as rows and the knowledge/skills acquisition processes as columns. The knowledge dimensions vary from factual to metacognitive as indicated in Table 20 and the cognitive processes, taking an example of the cognitive knowledge domain, are classified as illustrated in Table 21. A taxonomy table reveals the knowledge scope or breadth based on knowledge dimension and cognitive process as involved during objectives setting.

Table 20: Knowledge dimension structure, adopted from [146, p. 214].

Knowledge Dimension	Description
Metacognitive	Knowledge of overall cognition and self-awareness of one's cognitive processes.
Procedural	The approach to accomplishing tasks; applied methods of analysis, the standards for applying skills, algorithms, techniques, and procedures.
Conceptual	The inter-relationships between fundamental elements that enable a larger structure to function together.
Factual	Refers to terminologies, specific and basic details of a specialised discipline that trainees should be conversant with.

Table 21: The cognitive domain knowledge levels, adopted from [146, p. 215].

Cognitive Domain level			Description
Cognitive learning process →	6	Create	Putting parts together to form an original product or knowledge
	5	Evaluate	Making decisions grounded on procedure and standards.
	4	Analyse	Using one's faculty of reason to critique what is learnt or disintegrate material into constituent parts and draw inferences.
	3	Apply	Using learned material to execute tasks or follow a required procedure in a given situation.
	2	Understand	Constructing meaning out of the knowledge previously learned or out of instructional messages.
	1	Remember	Retrieving knowledge from memory.

A taxonomy table in the same way enables the revelation of the degree to which the ILOs, learning activities, and assessment methods are aligned [137, pp. 102–104]. The alignment, however, is guided by the CA concept illustrated in Fig. 46 of subsection 6.2.3. According to [148, p. 5], CA is a form of outcomes-based education (OBE). Further, CA derives the word "constructive" from the constructivism theory on which the teaching-learning and assessment design, and hence knowledge acquisition is centred [148, p. 52].

Primarily, the original Bloom's taxonomy framework considered only the cognitive domain [149]. The five-level affective domain of learning in Bloom's taxonomy was developed later [150]. The psychomotor domain, on the other hand, was never developed initially [137], [151]. Nevertheless, as reported in [151, pp. 166–168]; various psychomotor domain models exist. These include Simpson's seven-level model, Dave's five-level model, and Harrow's six-level model of psychomotor domain among others. Based on simplicity, coupled with attribution to Bloom's taxonomy and the fact that it is more recent compared to the aforementioned models, the five-level psychomotor domain model indicated in Table 22, is considered in the classification of ILOs in this monograph.

Table 22: Description of Psychomotor domain in Bloom's Taxonomy, adopted from [151, p. 166], [152, p. 29].

Domain level			Description
Learning process →	5	Mastery	Expertise exhibited by involuntary actions.
	4	Conscious control	Competence exhibited through rigorous effort.
	3	Coordinated performance	Blending solutions of executed individual tasks – that require a psychomotor skill.
	2	Partial performance	Execution of individual tasks that require a psychomotor skill.
	1	Procedural task knowledge	Follow instructions, procedures and/or list sequence of actions

5.1.2 Instructional Strategy

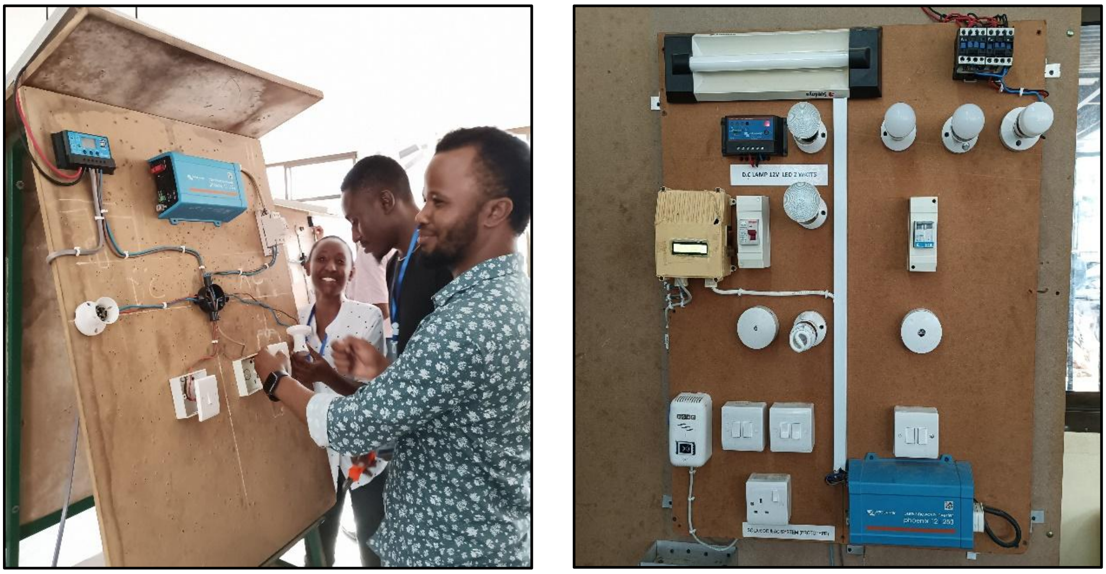
As indicated in [153, p. 2], the phrase instructional strategy or instructional design refers to teaching-learning didactic patterns, activities, or methods. The microgrids-related knowledge instruction strategy is for the BSc Elec Eng students, secondary school learners, and electrical energy consumers. The instruction of microgrids-related knowledge to BSc Elec Eng students, secondary school learners, and consumers can take place in formal and informal settings employing various learning activities, tools and media. According to [154, p. 31]; media refers to material artefacts and people that "produce and/or transfer information on socio-technological change". Such activities, tools and media include excursions to microgrids, microgrid model demonstrations, hands-on practical experiments, online platforms, remote laboratories, and virtual laboratories among others. Excursions, demonstrations, and hands-on experiments are experiential learning activities during which participants may record videos or take photos. The recorded videos and photographs then become (audio)visual media. Online platforms such as the designed VIMLE in this study, remote laboratories, and virtual laboratories employ various interactive tools to facilitate learning through (audio)visual, verbal, non-verbal, hybrid, and verbal-visual media.

To this end, the instructional strategy for secondary school learners is that teaching is done through the traditional education school system of classroom-based instruction. Teaching-learning, and thus the implementation of the developed secondary school microgrids course content, takes place in formal secondary schools. Traditional verbal lessons, microgrids demonstrations, excursions to live microgrids, video shows, printed and digital didactic lesson materials are employed in the instruction. Practical hand-on training sessions that use real microgrid lab components are also conducted thereby imparting psychomotor-related skills to the learners. Convergence of the aforementioned learning activities, tools and media are an envisaged strategy to provide rich multimedia-based microgrids learning experiences to secondary school learners.

For BSc Elec Eng students, the developed microgrids-related course content is suggested for inclusion in BSc Elec Eng curricula. Thus; the teaching ought to be regulated by the university guidelines in the Elec Eng degree study programme. Furthermore, the content can be utilised for skilling graduates and re-skilling microgrid operators in continuous professional development (CPD) seminars. The conventional lecture presentations, a didactic approach, remain a vital medium that offers microgrid learning opportunities to adults such as BSc Elec Eng students and electrical energy consumers. Materials to convey new microgrids-related ideas, products or power supply solutions are prepared for delivering presentations in line with the developed content. Materials are, in most cases, shared with participants after the presentations to facilitate further learning. In addition to lectures, conference presentations are other verbal media. Non-verbal and hybrid media on the other hand include peer-reviewed publications such as textbooks, conference papers, journal papers, and poster presentations. Peer-reviewed publications support instruction in various ways. They offer microgrids-related information that BSc Elec Eng students can benefit from. Peer-reviewed publications are for formal settings and, might not benefit majority of the electrical energy consumers in rural communities. However, Peer-reviewed publications can benefit an interdisciplinary spectrum including but not limited to BSc Elec Eng students, researchers, academic instructors, practising electrical engineers, vendors, developers, and service providers of microgrid solutions.

For electrical energy consumers; verbal microgrid skills training programme is envisaged to take place in known accessible community centres with an emphasis on practical hands-on. To eliminate learning by rote; active real microgrids and/or live laboratories are instrumental as emphasised in [155, p. 3]. Study excursions to real microgrids such as the one at Lwak can, therefore, facilitate learning for all the three stakeholder categories. The mentioned media, as stated by [67, p. 8156], facilitate knowledge transfer through "observation and doing". The VIMLE online platform designed in this study and the associated VIMLE laboratories (V-Labs) that appear in [156, pp. 675–677] are other media that complement microgrids-related knowledge transfer. Relatedly as [35, p. 20] intuitively implies; microgrid demonstrations, promotional or rather didactic materials on posters and leaflets, and radio and television programmes are applicable knowledge transfer approaches. For sensitisation purposes, roadside video shows and microgrid demonstrations in markets, schools and other public places are equally applicable [35, p. 22]. Other methods noted during data collection include radio talk shows and outdoor community radios.

Relatedly; CPD workshops and seminars are other strategies to transfer microgrids-related knowledge. As an example, GT was employed during the operational period of the A:RT-D Grids project to disseminate renewable energy and microgrids-related knowledge in particular to researchers and other stakeholders majorly in EA. Fig. 35 a) shows participants at Don Bosco Oysterbay Vocational Training College (VTC) in Dar es Salaam, during one of the 3rd GT workshops, executing a task to design a microgrid model. Fig. 35 further reveals that microgrids-related training is integrated into the EA education system at the vocational level. Fig. 35 b) shows several appliances and components that can facilitate microgrids-related training.



a) GT participants during a microgrids workshop. b) Assorted appliances for microgrids training.

Fig. 35: Appliances and components for microgrids-related training at Don Bosco Oysterbay VTC in Dar es Salaam, Tanzania.

On a lighter note; instruction (teaching and learning) is a knowledge transfer strategy. The instructional strategy explained in the foregoing paragraphs should therefore be complemented by training the trainers. Training the trainers is aimed at equipping probable microgrids-related content trainers with the requisite minimum pedagogical skills to ensure that the developed content achieves the ILOs, the objectives, and the goals for which it was developed. Further, the training of trainers is aimed at enhancing the capacity of the trainers [157], [158]. To this end, physics secondary school teachers, technical teachers, community leaders, energy committee members (ECM), and village representatives are trained.

5.1.3 The Didactic Architectural Model Development

The development of a microgrids knowledge transfer didactic architectural model follows an architectural model design structure that has three stages of input, process, and output as indicated in [159, p. 1]. For the three stakeholder categories of secondary school learners, BSc Elec Eng students, and electrical energy consumers, the input is a context training needs assessment as particularised in Fig. 36. The input is analogous to the analysis stage for the first meso-cycle iteration of the ADE model in Fig. 9, Fig. 10, and Fig. 11 of the three stakeholder categories. The process stage in Fig. 36 employs the revised Bloom's taxonomy, the ADE model reiterations, and the CA concept. The output stage provides a stakeholder-specific training programme content.

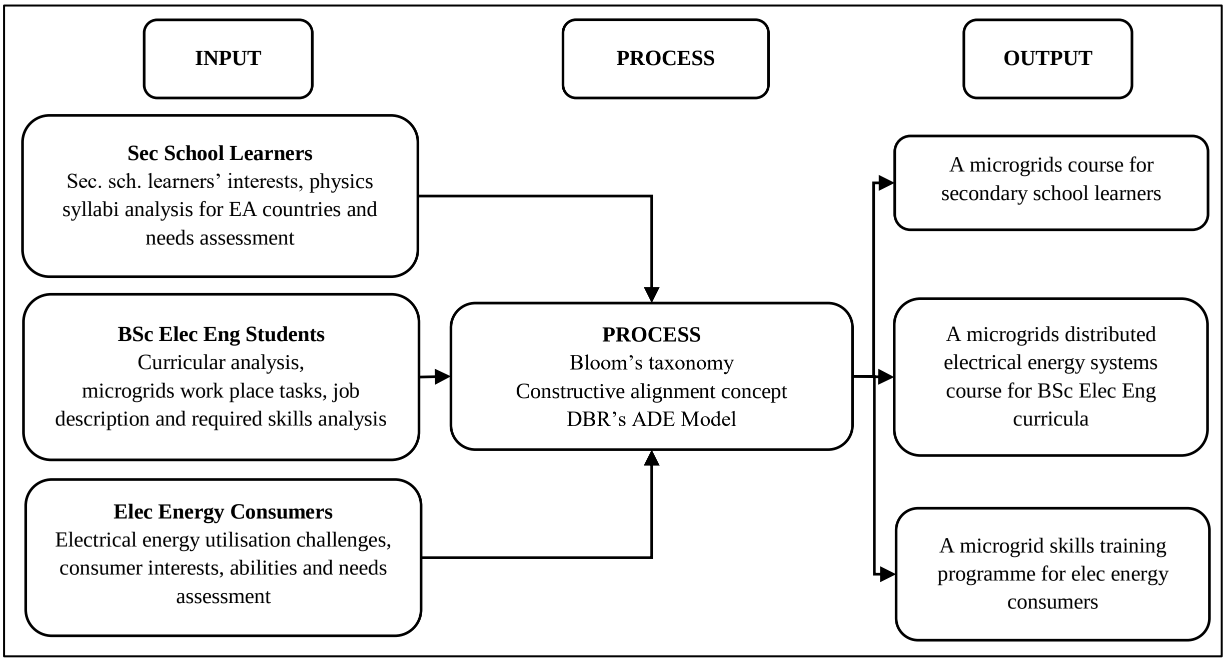


Fig. 36: The didactic architectural model design structure for microgrids knowledge content development, adapted from [159, p. 1], [160, p. 2].

Since the input stage in Fig. 36 corresponds to the analysis stage of the ADE model; there is an overlap between the input and the process stages of the design structure. In the same way; evaluation is performed on the training programme content, and the output hence, resulting in an overlap between the process and output stages of the design structure. Generally; the ADE model is employed and iterations are performed to obtain the stakeholder-specific microgrids knowledge content in Appendix C for BSc Elec Eng students, Appendix G for electrical energy consumers, and Appendix I for secondary school learners. For selected themes; a summary of objectives, topics, ILOs and Bloom's taxonomy levels for each ILO is presented. The presentation intuitively classifies skills, based on ILOs, into cognitive, affective, and psychomotor knowledge domains. The classification summary based on distributed energy systems, microgrids knowledge, and AI themes for BSc Elec Eng students is presented in Table 23.

Table 23: Classification of BSc Elec Eng course ILOs into cognitive, affective, and psychomotor knowledge domains for selected themes.

Theme	Objective	Topic	Intended Learning Outcomes (ILOs)		Bloom's Taxonomy*		
	Upon completion, the engineering student shall be able to:		By the end of the topic, the student should be able to:		Hierarchical level 1 Low – 6** High	Level category	Domain
Distributed energy systems	Design microgrid energy systems in the range of, at least, 10 – 20 kWp capacity cognisant of a	(T1) Distributed Energy Systems	ILO i	Explain the role of distributed energy resources (DERs) in the modern electrical grid.	2	Understand	Cognitive
			ILO ii	Classify distributed energy systems according to their generation technologies, sizes, and applications.	4	Analyse	Cognitive
			ILO iii	Assess the economic, environmental, and social impacts of distributed energy systems on local communities.	5	Evaluate	Cognitive

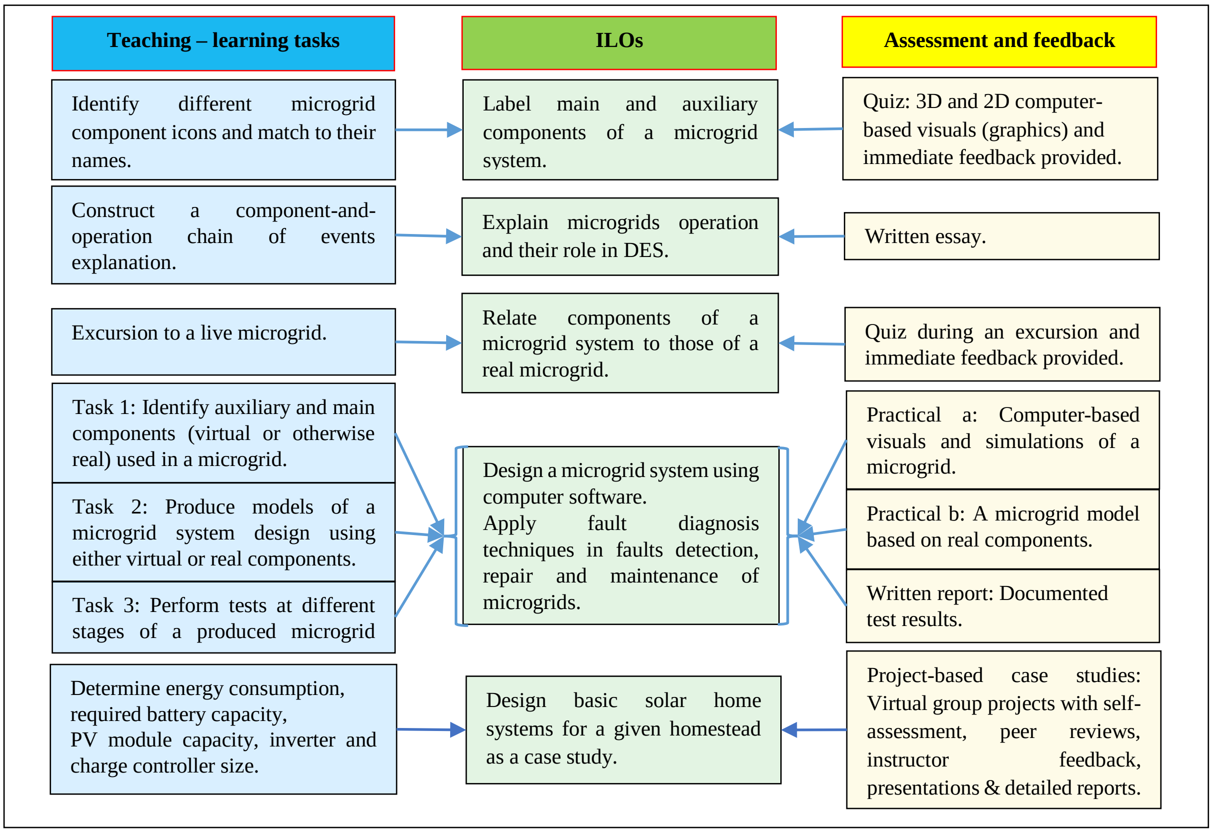
	community's electrical energy requirements		ILO iv	Perform technical evaluations and feasibility studies for implementation of distributed energy projects.	3 | 4	Apply | Conscious control	Cognitive | Psychomotor
Microgrids knowledge		(T2) Microgrids introduction	ILO i	Label auxiliary and main components of a microgrid system.	1	Remember	Cognitive
			ILO ii	Explain microgrids operation/functionality and their role in DES.	2	Understand	Cognitive
			ILO iii	Relate components of a microgrid system to those of a real microgrid.	2 | 4	Understand | Organisation	Cognitive | Affective
			ILO iv	Produce models of a microgrid system using physical laboratory components to represent a real microgrid.	3 | 5	Apply | Mastery	Cognitive | Psychomotor
			ILO v	Debate microgrids technical concepts effectively with peers, consumers of electrical energy services, and local leaders in communities.	4 | 3	Analyse | Valuing	Cognitive | Affective
			ILO vi	Discuss the pros and cons of a career in microgrids-related environments.	2	Understand	Cognitive
			ILO vii	Choose whether to pursue a career in microgrids-related environments given that microgrids are mostly installed in remote communities.	2 | 1	Understand | Receiving	Cognitive | Affective
		(T3) Solar cells and PV modules	ILO i	Explain the principle of operation of a solar cell.	2	Understand	Cognitive
			ILO ii	Construct solar cells to achieve a desired level of output.	3 | 5	Apply | Mastery	Cognitive | Psychomotor
			ILO iii	Produce I-V characteristic curves of ohmic resistance.	3 | 5	Apply | Mastery	Cognitive | Psychomotor
			ILO iv	Categorise elements/devices based on their I-V characteristic curves.	4	Analyse	Cognitive
			ILO v	Assemble solar cells into PV modules.	6 | 5	Create | Mastery	Cognitive | Psychomotor
			ILO vi	Produce I-V characteristic curves of PV modules in ILO v above.	3 | 5	Apply | Mastery	Cognitive | Psychomotor
			ILO vii	Determine the capacity of solar PV modules in ILO vi above.	5 | 3	Evaluate | Coordinated performance	Cognitive | Psychomotor
			ILO viii	Discuss the terms string and array concerning solar PV modules.	2	Understand	Cognitive
			ILO ix	Construct series-connected and parallel configurations of solar PV modules for a required system output.	6 | 5	Create | Mastery	Cognitive | Psychomotor
			ILO x	Determine appropriate inverter and controller component sizes of a solar PV system through measurements and calculations.	5 | 4	Evaluate | Conscious control	Cognitive | Psychomotor
		(T4) Microgrids maturation	ILO i	Analyse electrical energy needs for a given community.	4	Analyse	Cognitive
			ILO ii	Predict electrical energy demand for a microgrid project in a given community.	4	Analyse	Cognitive
			ILO iii	Discuss technical details of microgrids' auxiliary and main components.	5	Evaluate	Cognitive
			ILO iv	Discuss primary engineering considerations in microgrid designs.	5	Evaluate	Cognitive
			ILO v	Design a microgrid system, for a specified load/predicted demand, using AutoCAD or any other up-to-date computer software.	6	Create	Cognitive
			ILO vi	Construct microgrids from installation, testing for commissioning, through to operation.	6 | 5	Create | Mastery	Cognitive | Psychomotor
			ILO vii	Apply fault diagnosis techniques in fault detection, repair and maintenance of microgrids.	3 | 4	Apply | Conscious control	Cognitive | Psychomotor

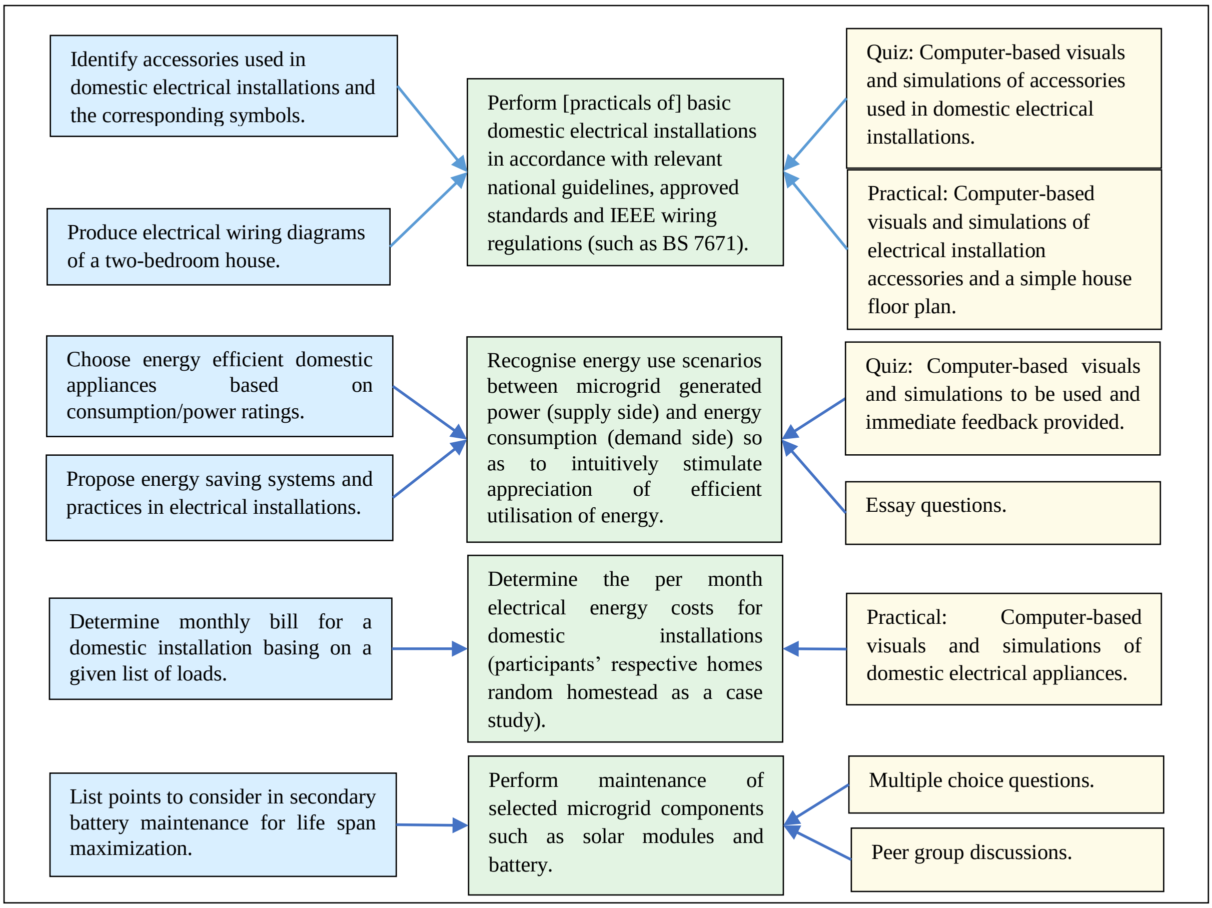
			ILO viii	Implement control strategies for managing microgrids - monitoring and control; optimisation of resources for optimised and cost-effective performance.	3 | 4	Apply | Conscious control	Cognitive | Psychomotor
			ILO ix	Explain microgrids interconnection basics and the associated limitations.	2	Understand	Cognitive
			ILO x	Define grid code parameters for safe, reliable, and cost-effective microgrid functioning.	1	Remember	Cognitive
			ILOs for TOPICS 5 – 8, and 10 are intentionally not included in this table.				
Artificial Intelligence	Apply Artificial Intelligence (AI) in the enhancement of microgrids operation and reliability.	(T9) Artificial Intelligence	ILO i	Write AI algorithms to analyse sensor data and predict components failure.	6	Create	Cognitive
			ILO ii	Apply AI algorithms to optimise microgrids performance, monitoring, and control.	3	Apply	Cognitive
			ILO iii	Design AI-based solutions for energy management - demand prediction versus (re)sources mix and hence;	6 | 5	Create | Mastery	Cognitive | Psychomotor
			ILO iv	Implement AI-based solutions that enhance microgrids reliability.	3 | 4	Apply | Conscious control	Cognitive | Psychomotor

*The domain categorisation of ILOs is based on the revised Bloom's taxonomy in [137], [161], [162], [163]. **5 levels for affective, 6 for cognitive and 5 for psychomotor.

The CA concept illustrated in Fig. 46 is then applied to align selected ILOs to teaching-learning tasks and envisaged assessment methods. Consequently, a CA frame for selected ILOs is obtained as illustrated in Table 24. It should be noted that in addition to selected ILOs for BSc Elec Eng from Table 23, the CA frame in Table 24 includes selected ILOs from Appendix G for electrical energy consumers and Appendix I for secondary school learners as well.

Table 24: A constructive alignment frame indicating selected ILOs from the BSc Elec Eng students', electrical energy consumers', and secondary school learners' developed course content, adapted from [156, p. 676].





It is vital to estimate the scope of knowledge that those expected to be trained using the developed DEES course content, proposed for inclusion in the BSc Elec Eng analysed curricula, will acquire. For this purpose, the taxonomy table is practically useful and convenient since it enables the knowledge breadth to be envisaged. Considering Table 23, the ILOs for the cognitive domain are classified to reveal the knowledge breadth for developed BSc Elec Eng content as indicated in the taxonomy table of Table 25. ILOs for psychomotor and affective learning domains are ignored. This is because, intuitively, the execution of the psychomotor tasks and thus the psychomotor learning processes require and involve cognitive abilities. Therefore, the estimation of knowledge scope based on the cognitive learning processes is sufficient. Relatedly, this line of thought is equally held by [151, p. 165] who states that most ILO verbs for the affective domain portray cognitive learning and that "some have psychomotor dimensions". Further; [137, p. 258] states that "… nearly every cognitive objective has an affective component". To this end, considering only the cognitive learning domain from this point onwards is intentional and informed by the foregoing discussion.

Considering the distribution of the ILOs in Table 25, some cells are empty which signifies the lack of a cognitive process category and knowledge dimension combination for cells marked with X. However, microgrids knowledge transfer can be achieved by the developed content given the ILOs distribution in other cells. This is supported by [137, p. 66] who states that the five highest cognitive learning processes of the revised Bloom's taxonomy, that is; understand, apply, analyse, evaluate, and create are closely related to knowledge transfer in increasing order of hierarchy from simple or low-order thinking to complex or higher-order thinking. The fact that ILOs are spread throughout all the levels from remember to create suggests breadth whereas the high concentration of ILOs in cells, for example, C3 and D6 suggests depth.

Table 25: Classification of the BSc Elec Eng proposed DEES course's ILOs into knowledge dimensions.

The knowledge dimension – informed by the ILO noun phrase.	**The cognitive learning process category – informed by the ILO action verb**					
	1. Remember	2. Understand	3. Apply	4. Analyse	5. Evaluate	6. Create
A. Factual	ILO i T2 ILO x T4	ILO vi T2 ILO i T3 ILO viii T3 ILO ix T4 ILO i T10	X	ILO ii T5	X	X
B. Conceptual	X	ILO i T1 ILO ii T1 ILO ii T2 ILO iii T2 ILO i T5 ILO i T7 ILO i T8 ILO ii T8 ILO ii T10	ILO ii T6	ILO iv T3 ILO iv T8	ILO ii T7	ILO iii T5
C. Procedural	X	ILO iii T8	ILO iv T1 ILO iv T2 ILO ii T3 ILO iii T3 ILO v T3 ILO vi T3 ILO ix T3 ILO vi T4 ILO vii T4 ILO viii T4 ILO iii T5 ILO iv T5 ILO i T6 ILO iv T6 ILO ii T9 ILO iv T9 ILO iv T10 ILO vi T10	ILO i T4 ILO ii T4	ILO vii T3 ILO x T3	ILO v T3 ILO ix T3 ILO v T6
D. Metacognitive	X	X	X	ILO v T2 ILO i T4 ILO ii T4 ILO iii T6 ILO v T10	ILO iii T1 ILO iii T4 ILO iv T4 ILO iii T10	ILO ii T3 ILO ix T3 ILO v T4 ILO vi T4 ILO iii T5 ILO v T6 ILO iii T7 ILO iv T7 ILO i T9 ILO iii T9 ILO iv T9 ILO iv T10 ILO vi T10

Although not indicated in this monograph, the classification of teaching-learning tasks and the assessment methods in Table 24 can also be done on a taxonomy table to establish the degree of alignment [137, pp. 95–97]. The taxonomy table, therefore, is not used to answer the alignment or assessment questions in this monograph but rather, the learning and instruction questions [137, p. 95]. Referring to cell C3 of Table 25, BSc Elec Eng students trained using the DEES proposed content shall learn to apply procedural knowledge which is representative of practical skills. The ability to apply procedural knowledge is an answer to a call from interviewed stakeholders, BSc Elec Eng and microgrid operators, to ensure that students who undertake the DEES course are subjected to practical work. Another cell with a high concentration of ILOs is D6 and represents the create metacognitive knowledge that reveals problem-solving, creative and innovative skills. The aforementioned skills are vital in the world of work and the high concentration of ILOs in D6 reveals that the developed content not only contributes to an innovative workforce but a workforce that is both creative and solves societal problems.

Another vital aspect to note is that some ILOs are a combination of more than one knowledge dimension and domain process [137, p. 66]. The reason is that during instruction; such ILOs decompose, guided by the instructional activities, into other knowledge dimensions and domains. Take an example of ILO ix T3. It is mandatory that for students to construct, which is a "create" cognitive process category, the series-connected and parallel configurations of solar PV modules; they apply a criterion of procedures (approaches and techniques) cf. [137, p. 99], cf. [161]. Based on the foregoing sentence, it is instructive that the ILO ix T3 is placed in cells C6 and C3. Further; during configuring and basing on ILO ix T3 noun phrase "… for a required system output", it is necessary that students are creative and thus learn to create meta knowledge hence placing the ILO in cell D6. The classification shows a systematic learners' acquisition of skills from simple to complex.

Repeating the same procedure, the classification of ILOs for electrical energy consumers and secondary school learners is done. For consumers, the classification in Table 26 is based on ILOs in Appendix G.

Table 26: Classification of the ILOs for skilling electrical energy consumers.

The knowledge dimension – informed by the ILO noun phrase.	**The cognitive learning process category – informed by the ILO action verb**					
	1. Remember	2. Understand	3. Apply	4. Analyse	5. Evaluate	6. Create
A. Factual	X	ILO i T1 ILO ii T1 ILO i T2 ILO vi T4 ILO i T5 ILO i T6 ILO i T7	X	X	X	X
B. Conceptual	X	ILO ii T2 ILO i T4 ILO ii T6	X	X	X	X
C. Procedural	X	ILO iii T2	ILO iv T1 ILO i T3 ILO ii T3 ILO ii T4 ILO iv T4 ILO v T4 ILO ii T5 ILO iii T5 ILO iv T5 ILO vi T5 ILO iii T6 ILO v T7	X	ILO iii T1 ILO iii T4	ILO iv T7
D. Metacognitive	X	ILO iv T2	X	X	ILO v T5	ILO ii T7 ILO iii T7

Referring to Table 26, there are no ILOs in the remember and analyse learning process categories for all the knowledge dimensions! The lack of ILOs in the former category reveals a lack of emphasis on memorising, no need to remember but rather to understand. The electrical energy consumers need to understand and be able to apply the knowledge thus; the high concentration of ILOs in cells A2 and C3 suffices.

With the "understand factual" knowledge represented by ILOs in cell A2, electrical energy consumers shall understand the basics of a microgrid including some terminologies like solar PV modules as components of a microgrid and specific details like advantages of microgrids to their communities as per the proposed content. With the "understand conceptual" knowledge in cell B2, consumers shall understand microgrid components and subsystems inter-relationships such as generation, distribution, and demand side subsystems. Most important to note is that all these are in response to consumers' training needs as established during data collection. The "understand" cognitive learning process is supplemented by the "apply procedural" knowledge as revealed by the high concentration of ILOs in cell C3. For example; consumers shall be able to carry out simple maintenance tasks of selected microgrid components, apply fault-finding procedures in electrical installations, and perform repairs of selected electrical utilisation appliances. All the aforementioned shall enable consumers to acquire practical skills that not only enable them to understand basics but also solve challenges they face in rural communities.

On the other side, it is vital to note that ILO iv T7 is more of an affective domain than a cognitive one. However, before records are kept, they have to be written following financial records and bookkeeping procedures. Hence, the categorisation under "create procedural" in the cognitive domain. Lastly, ILO ii T7 under "create metacognitive" is vital in enabling consumers to come up with innovative business ideas. This is vital because it feeds into affordability in the sense that on implementation of such business ideas, it is probable that community challenges are solved and business owners get a source of income that improves their livelihood on the one hand while consuming electricity on the other. With a source of income, community inhabitants can pay electricity bills. This, consequently, feeds into affordability, and indirectly into microgrids sustainability.

For secondary school learners, the classification of ILOs in Table 27 is based on the ILOs in Appendix I.

Table 27: Classification of the ILOs for training secondary school learners.

The knowledge dimension – informed by the ILO noun phrase.	**The cognitive learning process category – informed by the ILO action verb**					
	1. Remember	2. Understand	3. Apply	4. Analyse	5. Evaluate	6. Create
A. Factual	ILO i T2 ILO i T5	ILO ii T1 ILO iii T1 ILO iv T1 ILO ii T2 ILO v T2 ILO i T3 ILO i T4 ILO iv T4 ILO ii T5	X	X	X	X

		ILO iv T5				
B. Conceptual	ILO i T1	ILO vii T1 ILO vii T2 ILO ix T3 ILO ii T4	ILO v T1 ILO vi T1 ILO v T4 ILO vi T4	X	X	X
C. Procedural	X	X	ILO iii T2 ILO iv T2 ILO vi T2 ILO ii T3 ILO iii T3 ILO vi T3 ILO vii T3 ILO viii T3 ILO iii T4 ILO vii T4 ILO viii T4 ILO ix T4 ILO iii T5 ILO v T5 ILO vi T5 ILO vii T5	X	ILO iv T3 ILO viii T5	X
D. Metacognitive	X	X	ILO vi T3	X	ILO vii T5 ILO ix T5	ILO vii T3

Referring to Table 27, cells A2 and C3 have the highest concentration of ILOs. Cell A2, “understand factual” represents the foundation for secondary school learners to understand concepts such as basic information and specific details of microgrids. It is essential that learners are well equipped with the fundamental elements and thus have a solid understating of the microgrids concepts, basic information and specific details. This builds a strong foundation for the learners to benefit from the practical related ILOs, the apply procedural knowledge, in cell C3.

5.1.4 The Didactic Architectural Model

Finally, the microgrids knowledge transfer didactic architectural model is presented in Fig. 37. The architectural model summarises various stages of microgrids knowledge content development, classification of ILOs and hence the skills that trained stakeholders are expected to be competently equipped with.

The aim is to transfer technical and soft skills with practical knowledge and professional competencies required in the world of work for microgrids sustainability. The acquisition of professional competence is supported by internship training, laboratories at universities, live microgrids as demonstrations and test beds. Problem-based learning through real-life problems is equally a vital concept/practice for the world of work-required knowledge and competence acquisition.

The didactic architectural model is for purposes of microgrids knowledge transfer so as to build the local capacity comprising secondary school learners, BSc Elec Eng students, and consumers of electrical energy services. It is envisaged that with local capacity built through microgrids knowledge transfer, the mentioned stakeholders shall contribute to the sustainability of microgrids. The didactic concepts, the knowledge transfer strategy that includes the “train the trainer”, and the instructional (teaching and learning) strategy are highlighted in the architectural model of Fig. 37. The classification of ILOs is done to enable visualisation and reflection on the contextual relevance of the content for microgrids sustainability. The didactic architectural model is therefore a good reference tool for academics and researchers who are desirous of developing related training content for microgrids and other specialisations.

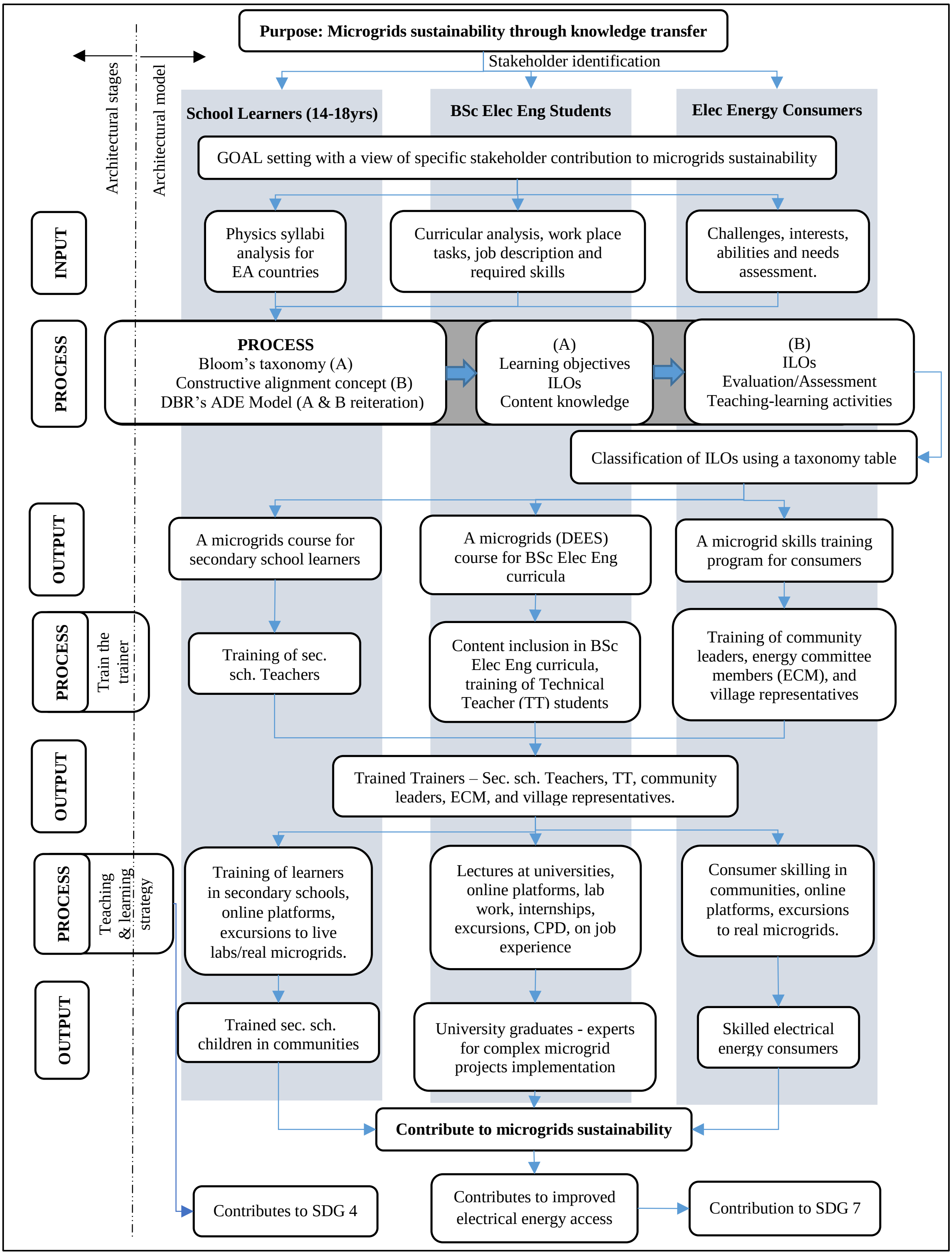


Fig. 37: The microgrids knowledge transfer didactic architectural model for microgrids sustainability, adapted from [160, p. 5].

In conclusion; given that the proposed DEES course for BSc Elec Eng students ought to be included in the respective university curricula, an inquiry into the BSc Elec Eng curriculum development, review, and implementation processes must be performed. Therefore, curriculum design processes and associated challenges are explored in section 5.2.

5.2 Curriculum Design Processes and Associated Challenges

This section presents the BSc Elec Eng curriculum development and review processes in subsection 5.2.1. Challenges that affect curriculum review and implementation processes are illuminated in subsection 5.2.2. Although the curriculum design processes and the associated challenges relate to the BSc Elec Eng study programme, they generally apply to other programmes offered by the respective universities.

5.2.1 Curriculum Development and Review Processes

Using the interview guide in Appendix K; the two Heads of Department (HoDs) from Uni A and Uni B were asked, "What is the process like for curriculum review from the department through to approval and accreditation?". The respective HoDs then provided a detailed description of the process.

As a disclaimer; one HoD mentioned that he could not give a step-by-step process but that documented guidelines exist [a statutory system] according to the regulatory body of [the country's] universities. The HoD mentioned that first; the need for [or review of] the curriculum is established with the help of tracer studies. After that, information captured from stakeholders including staff and prospective employers is accommodated and a draft is prepared. Within the Department, a few members of various specialisations that cover the whole curriculum spectrum [a curriculum sub-committee of the department] convene. Other colleges [and departments] that are closely related to what is being done are also invited. The draft is then reviewed [and discussed] within the department and comments are raised.

A stakeholders meeting is then called. In the [regulator's] guidelines, there are some key stakeholders who should be involved. These include the colleges close to what is being done and the industries. There are proportionality numbers, in the guidelines, of the stakeholders that have to be invited and an almost final draft is presented to them. After that, comments are obtained from about 100 or 50 stakeholder participants. The HoD emphasised that stakeholders' input is extremely crucial in the curriculum development and review process because they give the vital feedback required in the review process. After a stakeholders' engagement; information is compiled in accordance with the regulatory body template, presented and then submitted to the college board. The board checks the submissions to ascertain adherence to the guidelines and accept or disagree with some issues. The college board then passes or fails the curriculum. If failed; the curriculum is returned to the department else, it is forwarded to the university [Senate]. The university [Senate] as the custodian is therefore responsible for sending the curricula to the universities' regulatory body.

The HoD's submission covers steps one through four in [164, p. 2] of the required eight in the process of study programme accreditation. Other steps that are managed by the regulator, on receipt of the programme, are summarised as verification of the minimum requirements based on the 2018 curriculum framework, peer reviews and input from relevant professional bodies. Recommendations of the reviewers and professional bodies are then sent to the university for consideration, the programme is then resubmitted to the regulator and consequently forwarded to the reviewers and professional bodies to verify the incorporation of the recommendations. If the reviewers then recommend that the programme be accredited, the final step is to send the reviewers' report and the revised curriculum to the accreditation committee. The committee pronounces a recommendation and a decision is then made by the regulator [164, pp. 2–3].

The second HoD, on the other hand, mentioned that once the curriculum review is initiated in the department, a curriculum review committee is formed and the HoD or their assignee chairs the committee. The committee solicits input from the different members of staff and students – usually, current students and immediate alumni (those who just graduated). There is also benchmarking with universities of the same or perceived higher standing to check on their current curriculum - what they are teaching that is not taught and what might be new yet probably omitted. Once input is obtained, the committee drafts a working document of what the changes should be – a gap analysis is done because the lecturers who have been teaching know where the gaps are, and the students give feedback about how courses are instructed, what they feel is missing and those from the field give feedback inline with the skills they are missing. So; that kind of gap analysis informs the draft document which is then discussed by the department committee. Once the draft is discussed by the committee; it is then put forward to the entire department for staff members to give comments and their input. Unfortunately, most people do not give comments so, it is in most cases left to the committee.

As changes are being made, some of the committee members are tasked to engage industrial key players asking them how the industry thinks the graduates should be taught, how they find those they recruit, and what skills they think graduates are missing. The draft and the comments are then shared with the stakeholders. Feedback is then obtained from the stakeholders at a workshop which can be a half day but preference is a full-day workshop where part of the morning is the motivation process - what was made and then in the afternoon the nitty-gritties of what should be added are discussed. Thereafter, corrections or modifications are made and responses are given to the stakeholder comments regarding acceptable suggestions and what can not be done. The department takes a stand. The good is incorporated and the bad or ambiguous is left out. A report is then written and the curriculum is presented to the school. The school is a wider entity and views are obtained at that stage of what is expected from the department and general comments on formatting, content, issues to do with ways of assessment, ways of instruction pedagogy, blended learning or in-person teaching. Thereafter, the curriculum is brought back to the department to address comments raised at the school level.

A compliance report is then written and the curriculum is presented to the college. The college board also provides feedback. At this stage, feedback is about quality assurance, that is, ascertaining whether the curriculum meets the university and the regulatory body standards. After that, the college then goes ahead and provides minutes of that meeting. A compliance report regarding how the comments have been addressed is developed and the college submits it to Senate. Curriculum submission to the Senate is done through the Academic Registrar (AR) – submission is not directly to the Senate but to the AR. The AR invites the department to present the curriculum to an academic policies committee of the Senate where the curriculum is thoroughly vetted and suggestions of content in comparison to other universities and colleges are made. At this stage, the policies committee of the Senate ascertains whether the curriculum meets their expectations in line with the university's academic policies. After that, the curriculum is sent back to the department committee to review and make a compliance report and then members of the academic policies of the Senate committee present the curriculum to the Senate. If there are any further issues, they are raised but normally, they are very minimal at that stage. Once the Senate has endorsed it, the curriculum is sent to the quality assurance committee (QAC) of the University Council. The QAC now checks issues to do with similarity with other programmes and the relevancy of the programme to be taught at the university. Once that is done, the [department] committee that drafted the curriculum are asked to develop a compliance report of how they addressed issues raised by the Senate. A table summarising what the curriculum is all about is drafted and the curriculum is presented by the QAC to the University Council. The University Council approves and once the University Council approves, the curriculum is sent to the regulator for vetting. The regulator does the vetting and communicates to the university usually with some comments but in some cases with almost no comments. The communication is through a written approval letter that the curriculum is accredited and that it meets the requirements. However; should the regulator require confirmation of some information such as the levels of staffing, infrastructure, library, laboratories, classrooms, and extra then; they can request to visit the university before they formally write that a study programme is accredited.

It is vital to note that the Tanzania Commission of Universities TCU and the National Council for Higher Education (NCHE) are the statutory bodies mandated to regulate university operations in Tanzania and Uganda respectively. TCU and NCHE respectively derive powers from the *Universities Act, 2005* (Chapter 346 of the Laws of Tanzania) and the Universities and Other Tertiary Institutions Act, 2001 as amended in 2003 and 2006. Among other responsibilities, the respective bodies accredit study programmes (academic and professional) offered by universities within their jurisdiction. As such, the bodies instituted regulatory systems for supporting universities to meet the expected standards and quality of study programmes (curricula) and implementation thereof. The regulatory system in Tanzania is supported by [99], [135], [164], [165] while [100], [166], [167] support the system in Uganda. Curricula development, review thereof, quality assurance and initiation of programmes that are labour market inspired is one of the objectives in [100, p. 2]. As such, guidance and support are provided but most important to note are the programme requirements [100, pp. 19–20]. Related guidance and support for Tanzania universities is provided in [165, p. 1].

5.2.2 Challenges that Affect Curriculum Processes

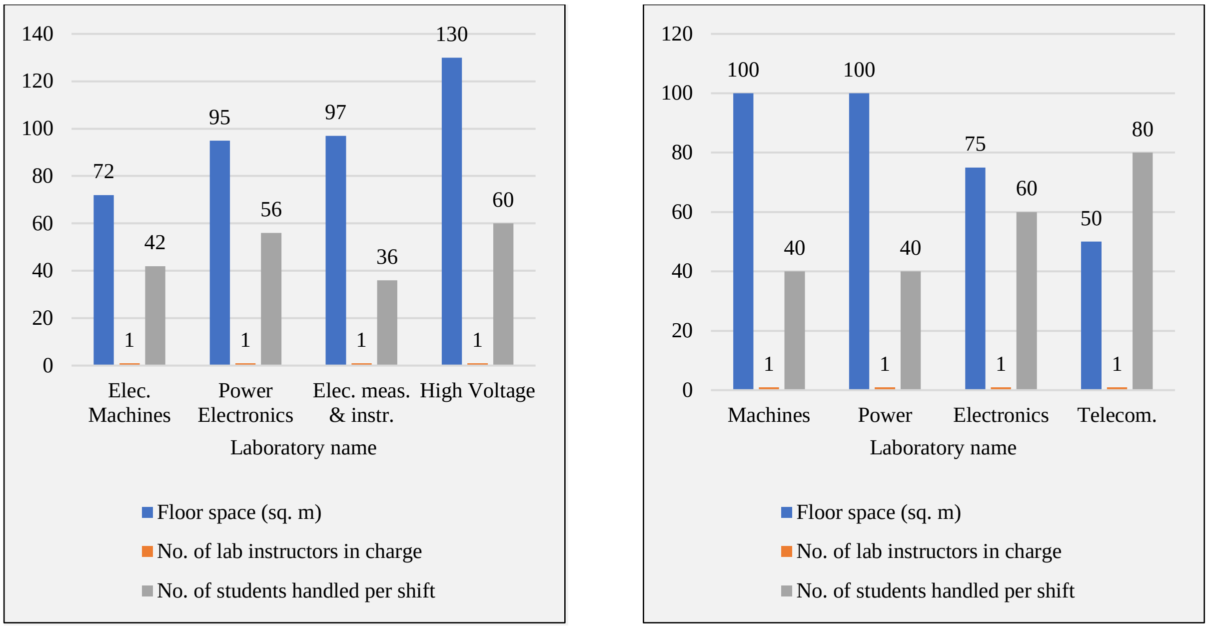
This subsection highlights challenges that surround curriculum development, implementation, and review processes. The challenges include the long duration to review curricula, inadequate human resources, inadequate infrastructure, and inadequate teaching facilities among others as explained in this section.

The long duration taken before curricula are reviewed is one of the challenges. At both Uni A and Uni B, according to the HoDs and the guidelines of the regulatory bodies, the BSc Elec Eng curriculum review is supposed to take place every 4 years; the duration of the study programme. However; it is 11 years for Uni A and 12 years for Uni B, as of October 2022, since the previous review. This implies that curricula have not been reviewed for close to 3 cycles. The review had already kicked off at Uni B and Uni A had plans to start soon.

It should be noted that there exist excellent curriculum development quality control measures at both universities. The curriculum development quality control measures are guided and supported by the TCU and NCHE regulatory systems. The same regulatory systems, however, indirectly influence curriculum development, implementation, and review delays. This is particularly because, in an effort to comply with the quality control guidelines of the regulatory systems, the concerned committees at different levels of the university structure spend a lot of time preparing the relevant documents yet committees take a long time to meet. The low human resources levels in addition to the stringent requirements like the need to have signed minutes and compliance reports equally contribute to the delays.

Lack of finances is another cause of delayed curricula review. According to the HoD of Uni A, money used for curriculum review normally comes from the government, the university budget, and grants. For Uni B, the university budget and grants are the sources of funds for curriculum review. Universities are always financially constrained and thus, pay little or no attention to curriculum review activities. It ought to be the responsibility of the University Council to ensure that a vote for curricula review is included in each financial year's budget.

Inadequate facilities are some of the challenges that affect curricula implementation. During data collection, efforts were made to establish laboratory/workshop facilities that can support microgrids knowledge transfer instruction/teaching of BSc Elec Eng students. Fig. 38 indicates the floor space and capacity of the laboratories at the departments that administer the BSc Elec Eng study programme at Uni A and Uni B. The floor space was measured using a 100 m open reel tape measure and additional information was shared by technicians. One technician from each university, Uni A and Uni B, provided the additional information.



a) b)

Fig. 38: Floor space and capacity of laboratories at Uni A and Uni B departments that administer the BSc Elec Eng study programmes.

Referring to Fig. 38, the ratio of student-to-lab instructor per lab shift is high. The lowest as evident for the electrical measurement and instrumentation laboratory in Fig. 38 a) is 36 to 1. It is noted that: (1) the student numbers indicated in Fig. 38 are the per-shift capacities the laboratories can accommodate. (2) Uni A and Uni B admit 70 and 80 students to the BSc Elec Eng study programme respectively as student quotas. (3) 61 and 68 are the average students enrolled in each BSc Elec Eng class (freshmen to seniors) for academic years 2018/2019 to 2021/2022. (4) the BSc Elec Eng students who graduated from Uni A and Uni B in 2018 are 55 and 59 respectively whereas those who graduated in 2019 are 49 and 95 respectively. The student numbers in (2) through (4) compared to those in Fig. 38 indicate inadequate laboratory facilities due to obsolete and limited laboratory equipment. (5) 83% of the lecturers do not participate in the process of conducting laboratories as evident in Fig. 39 which increases the student-to-lab instructor ratio. The two lab instructors from Uni A and Uni B expect lecturers to be present and offer support during the execution of laboratory experiments under the course units the respective lecturers administer. This information is corroborated by the Uni B Human Resources Manual which allocates some working hours of academic staff to conduct practicals. The respective country regulators of both Uni A and Uni B also allocate time, in their standards and guidelines, for academic staff involvement in practical sessions [135, p. 186].

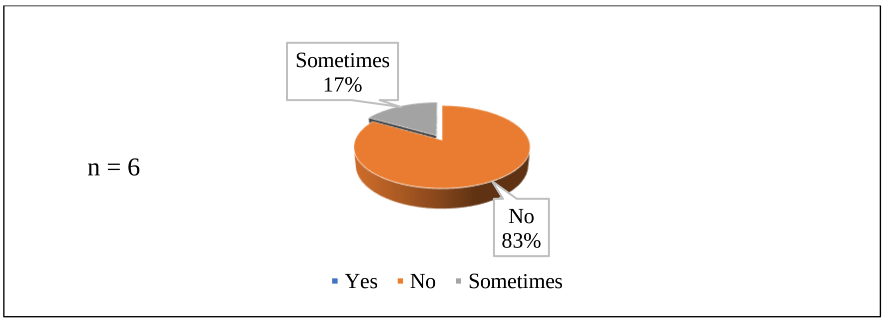


Fig. 39: Lecturers' response to "Do you normally assist lab instructors in the process of conducting laboratories?" in Appendix L.

Challenges notwithstanding, the available laboratories can enable microgrids-related knowledge transfer to BSc Elec Eng students. For example, the power electronics lab for Uni A and the electronics lab for Uni B enable BSc Elec Eng students to acquire energy conversion, control, and stability-related skills which are related to and vital in microgrids. Both labs have control and measurement equipment which enable training of control engineering skills to BSc Elec Eng students. Fig. 40 shows a control trainer in the Uni A power electronics laboratory. The trainer can enable BSc Elec Eng students to design and implement control system strategies; design, implement and analyse thyristor-based converters including AC–DC rectifiers and DC–AC inverters; implement and test protection schemes; and perform network fault analysis. These are vital skills in microgrids design, implementation, operation, monitoring, and control.

Fig. 40: A 3-phase HV thyristor control trainer (model XPO-APPE-1) at Uni A.

Fig. 41 shows a power system and protection-related trainer, that is the advanced double bus bar system, in the Uni B electronics laboratory. The trainer can enable students to acquire skills related to electric power generation, transmission, and distribution, power line protection and control, and programming the logic through a PLC to switch between the double (main and auxiliary) bus bar circuits, among others. Although the mentioned skills in both cases of Uni A and Uni B are taught without making specific reference to microgrids, due to a lack of microgrids-specific knowledge in the curricula; the skills are applicable and transferrable to microgrid work-related environments. In line with the developed content in Appendix C, the trainers in Fig. 40 and Fig. 41 can enable BSc Elec Eng students to be trained so as to implement microgrids control strategies for managing, that is monitoring and control; optimisation of resources for optimised and cost-effective performance.

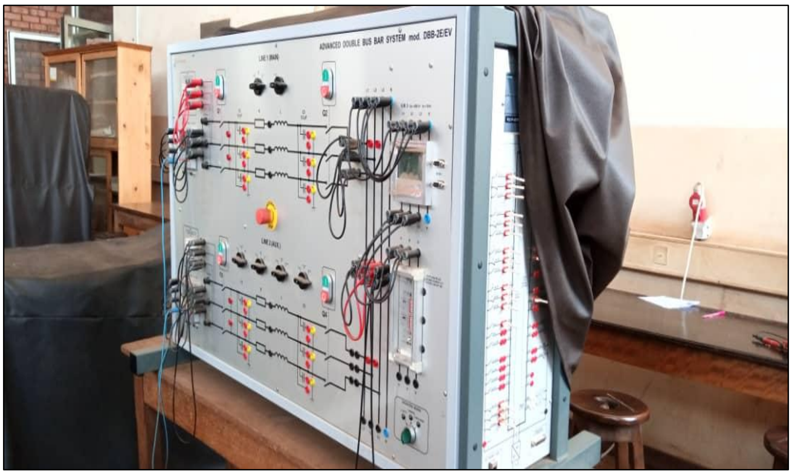


Fig. 41: A double bus bar system trainer (model DBB-2E/EV) at Uni B.

Interestingly, another university in Kenya that started BSc Elec Eng in January 2021 embraced microgrids-specific skills. A course unit Sustainable Energy Systems is included in their curriculum and renewable energy, distributed generation, and microgrid technologies are introduced to the students. As such, laboratories are installed to enable students to acquire microgrids-specific hands-on skills as indicated in Fig. 42. In addition to the university engineering students; the facilities are also used, at a cost, to train other stakeholders such as professionals in the field on a continuous professional development basis; individuals who wish to be licensed, for example as solar technicians, go to be retrained before proceeding to the regulator for examination. Those who wish to be licenced are trained at the University's Energy Research Centre and get a certificate which they present to the regulator. The regulator then examines and issues licenses to those who pass. Other categories of people who normally need the training include renewable energy-related business owners and consultants going into the practice of designing microgrid systems, solar water pumps, and solar cooling systems. Universities, therefore, should invest in such facilities since they are income-generation avenues in addition to meeting their core objectives of training students. Such income-generating initiatives can help universities to solve some financial challenges.

Fig. 42: Selected photos of a microgrid trainer at a University in Kenya.

Low human resources (HR) is another challenge that deserves mention. Both departments of Uni A and Uni B face the challenge of low levels of teaching and non-teaching staff. The filled positions and the corresponding numbers of academic staff are indicated in Fig. 43.

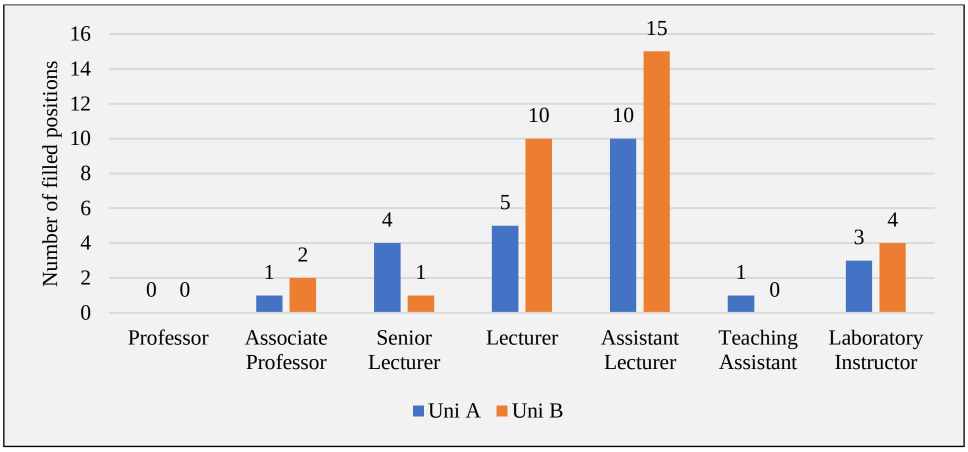


Fig. 43: Academic staff numbers as of June 2024.

In view of the earlier indicated admission student quotas, the total admitted students to the BSc Elec Eng degree at Uni A and Uni B for four years are 280 and 320 respectively. Referring to Fig. 43 and considering the respective admission student quotas, the ideal academic staff-student ratio is 1:12 and 1:10 for Uni A and Uni B respectively. Although the indicated academic staff-to-student ratios meet the recommended ideal numbers [135, p. 36], [167, p. 36], [168], the considered student numbers do not include postgraduate students taught by the same academic staff. If on the other hand; the average class enrollment earlier indicated for 2018/2019 to 2021/2022 is considered, the total enrolled students pursuing the BSc Elec Eng degree at Uni A and Uni B are 244 and 272 respectively. It should be noted that the considered academic years span through the COVID-19 pandemic period which could have affected the enrollment. At the time of data collection, Uni A department that administers the BSc Elec Eng programme had 24 students pursuing three different master programmes and 5 registered doctoral students. In addition to the BSc Elec Eng programme; the Uni B department on the other hand was running two other undergraduate programmes, had 20 students on two master programmes, and runs a doctoral programme. This suggests that considering postgraduate students, other study programmes handled by the same departments and some academic staff who teach courses in other departments and universities; the challenge of low academic staff numbers becomes realistic. One of the causes of low HR numbers is the lack of strategic HR management (HRM) processes. According to [169, p. 122], strategic HRM practices would address challenges such as heavy workload, moonlighting, and high student numbers among others. Another cause of low HR levels is halting recruitment, due to wage bill limitations, yet departments work below their personnel quota commonly known as establishment. With strategic HRM practices, [170, p. 68] argues that employee efficiency can be realised to improve internal revenue collections and decrease university dependence on the government. This would ensure the availability of finances to attract, recruit, reward, train, promote, and maintain academic staff.

In light of the illuminated foregoing challenges, envisaged plausible solutions are proposed. The proposed solutions are placed under the knowledge transfer concepts for microgrids sustainability and presented in section 6.1 of Chapter 6. First, Chapter 5 summary is presented in section 5.3 that follows.

5.3 Chapter Summary

This chapter summarises the microgrids-related knowledge content development process in one part and the curriculum design processes in the second part. Key didactic concepts, frameworks, and standards such as the CA, Bloom’s taxonomy, and ABET’s EC2000 applied in microgrids-related knowledge content development are highlighted. The section on instructional strategy presents various approaches, activities, tools and media aimed at enabling stakeholder-specific microgrids knowledge transfer. Integration of the developed content into the education system at universities and lower secondary schools, excursions to live microgrids, demonstrations, practical hands-on tasks, online learning platforms, remote and virtual laboratories, (audio)visual and verbal media are some of the approaches, activities, techniques and media envisaged to facilitate microgrids knowledge transfer. Training of trainers such as secondary school teachers, technical teachers, community leaders, energy committee members (ECM), and village representatives is another aspect mentioned as a knowledge transfer strategy. Stakeholder-specific microgrids-related knowledge development stages are presented and they evolve into a knowledge transfer didactic architectural model. The model also illustrates how the developed knowledge can be systematically transferred to specific stakeholders and applied within educational contexts so as to contribute to microgrids sustainability.

The second part of the chapter also explores curriculum development and review processes, at a university level, for selected EA countries. The section discusses the stages of curriculum development and review, and the alignment with the universities statutory system. Additionally, challenges in curriculum development are addressed highlighting hindrances such as the long duration to review curricula and limited resources. Limited resources such as finances, laboratories, and HR affect curriculum development, implementation, and review. To minimise the challenges, solutions are proposed in Chapter 6.

6 Knowledge Transfer and Virtual Learning Environments

This chapter is structured in four sections. To minimise challenges that BSc Elec Eng curriculum review and implementation processes encounter, as presented in 5.2.2, knowledge transfer concepts for microgrids sustainability are proposed in section 6.1. Since online learning platforms are part of the proposed concepts, virtual and interactive learning environments are discussed in section 6.2. Consequently, the VIMLE online platform is designed in this research as detailed in section 6.3 highlighting the architectural and system designs. Finally, the chapter is summarised in section 6.4.

6.1 Knowledge Transfer Concepts for Microgrids Sustainability

This section presents concepts as plausible solutions that can contribute to knowledge transfer efforts for microgrids sustainability while at the same time deter challenges that surround curricula development, implementation, and review. The concepts can supplement the teaching-learning processes while instilling the microgrids' world of work essential skills in learners. The proposed solutions are conceptualised into work-based learning, live laboratories, and online learning platforms described in subsections 6.1.1, 6.1.2, and 6.1.3 respectively.

6.1.1 Work-based Learning

In the Work-based learning (WBL) concept, students are deployed to industrial workplaces for a specified period cf. [171, p. 3]. Normally under the supervision of academic and practising personnel; students are subjected to the same policies and/or administrative guidelines that govern other employees of the organisation. The real-life work involvement enables students to correlate academic knowledge, practical sets performed in university laboratories and the world of work-required skills.

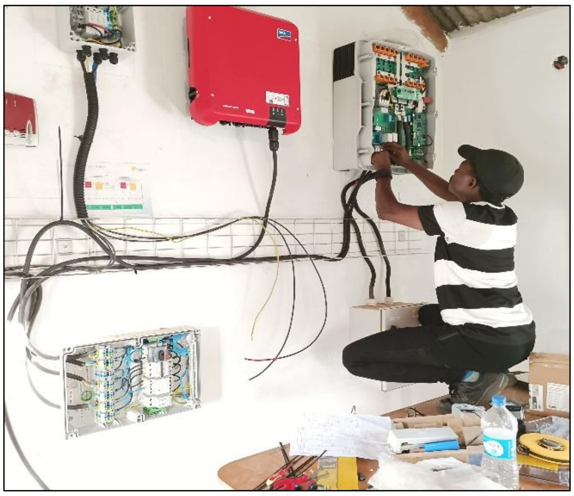
Reference [86, pp. 97–100], examines five theoretical models of WBL and hence didactic skills acquisition for and from the contemporary workplace. One of the five models which supports this monograph author's line of thought in the foregoing paragraph is the competency-based or outcome-based model. It is worth noting that the activity theory, explained in subsection 2.4.3 of this monograph, supports WBL [86, p. 99]. Reference [86, p. 98] maintains that skills acquisition, through the competency-based model, is pedagogical [or didactical] in nature. Through the competency-based model, the following attributes define WBL: (1) learning and hence skills acquisition is facilitated and guided by instructors (teachers/trainers, academic and practising/specialist personnel). (2) Evaluation of a learner's level of skills acquisition is done by instructors. (3) Performance criteria, stipulated by a body of competent authority/standard setting/accreditation, against which competence evaluation is done. (4) List of expected skills and/or competencies to be attained by the learner.

The internship is an indicator of WBL availability in the assessed curricula. Therefore, attributes such as assessment criteria, expected skills and competencies, duration of placement training, assessment templates, and supervision criteria of both academic and field supervisors ought to be well documented and included in the curricula. Before placement, students should be briefed about the general workplace rules expected to govern them during placement.

6.1.2 Live Laboratories

The concept of operational microgrids, or renewable energy systems, at HEIs, is admirable. Microgrids at such HEIs reduce electrical energy costs by providing electrical energy but, most importantly, they can be used as live laboratories cf. [172, pp. 47–48]. The live laboratories enable students to acquire skills required in the world of work and hence, improve graduates' employability. In support, [173] demonstrates the effectiveness of a microgrid in transferring job market skills to undergraduate and graduate engineering students. Further [155] illuminate the importance of microgrids as tools that enhance learning and enable the acquisition of practical skills and knowledge that are truly relevant and applicable to the industry. Specifically, [155, p. 4] reports that using a microgrid as a learning tool has a positive impact on Elec Eng student learning outcomes and industry feedback as well. Live laboratories are handy as testbeds in enabling students to test-run developed prototypes.

The concept of live laboratories is equally embraced by many renewable energy projects, for example, the A:RT-D Grids project. As evidenced in Fig. 44 a), the A:RT-D Grids project installed a 12 kWp microgrid with 12.5 kWh battery storage at Lwak in Kenya. As Fig. 44 b) and Fig. 44 c) confirm, the Lwak microgrid is instrumental in teaching secondary school learners and electrical energy consumers about the basics of microgrids in addition to offering field trips and WBL opportunities to HEIs students in the EA region. Hence building technical local capacity for microgrids sustainability.



a) Part of the live laboratory installation in progress.

b) Training of secondary school learners.

c) Training of Nun Postulants.
Fig. 44: The Lwak A:RT-D Grids project microgrid – a live laboratory.

Microgrid live laboratories ought to have the following attributes:

1. Practical guidelines of live laboratory management. This is vital to administratively guide access to and utilisation of the laboratory while ensuring the safety of users and the live laboratory.
2. Operation and setup documentation. The operation, description, specifications, and the associated components of the live laboratory need to be documented. In context, documentation ought to include the live laboratory energy sources, the configuration, an indication about whether the laboratory is grid-connected or operates as an island, the capacity of the entire live laboratory and the individual components among other technical related aspects.
3. The business model of the live laboratory including the financial performance, that is profits/savings and losses need to be logged.

6.1.3 Online Learning Platforms

Incorporation of online learning possibilities in curricula coupled with other training programmes can equip learners with skills that are relevant to the world of work and enhance employability. Examples of such online platforms are: (1) the VIMLE platform in section 6.3 [156] and (2) the “Coursera for campus” platform [127]. The Coursera for campus platform emphasises IoT and embedded sensors for students pursuing Elec Eng studies [127, p. 20]. IoT and sensors are vital in enabling remote control and monitoring of microgrids.

Universities ought, therefore, to select and ascertain the authenticity of online learning platforms and have such platforms legitimised and thus included in curricula. In line with online learning platforms, the following attributes should be ensured:

1. Prescribed criteria for awarding academic credits. Universities ought to task their quality assurance directorates/departments to craft, and consequently seek approval, of

credits awarding criteria. With approved criteria, students who successfully do courseworks and/or courses online receive academic credits that can later be included on academic transcripts cf. [127, p. 22].

2. Catalogue of recommended online platforms and courses/modules. The recommendations of such platforms by the mother university departments ought to be based on: (1) Availability of envisaged relevant workplace skills on such platforms. (2) Platforms that offer learner engagement options through (a) *interaction* with other learners, instructors, content, and a seamless interface with the platform. (b) *community* – a sense of peer community or belonging to a classroom. (c) *presence* – a sense of both teaching presence and social presence. (d) *collaboration* – support online teamwork. (e) *communication* – support asynchronous and synchronous communication cf. [174, p. 166]. Definitions of (a) through (e) are given in [175, pp. 251, 255].

Reference [176, p. 199] indicates that the community of inquiry (CoI) model is vital in understanding aspects of learners' engagement. Learners' engagement being a significant factor for effective skills acquisition through online learning, it is therefore vital that recommended platforms are a revelation of (or exhibit) the three vital CoI model elements. The three CoI model elements are social, cognitive, and teaching presence.

In summary, universities need to adopt knowledge transfer concepts such as WBL, live laboratories, and online learning platforms, among others. This calls for the formal inclusion of the mentioned concepts as part of the instructional resources in curricula. As education systems advance to address the needs of contemporary society and learners, integration of digital tools is crucial. This sets the need to explore virtual and interactive learning environments, presented in section 6.2, which offer innovative approaches to enhance student engagement and teaching-learning processes. To further contribute to available online learning platforms, a VIMLE platform is designed as described in section 6.3.

6.2 Virtual and Interactive Learning Environments

The concept of a didactic virtual and interactive learning environment is premised on the adverse effects the COVID-19 outbreak had on the teaching-learning processes and academic institutions in particular. Although distance learning was in place way before the outbreak, the COVID-19 pandemic was a wake-up call for many academic institutions to scale up and utilise ELPs to the maximum. Many of the ELPs at academic institutions are used to share course materials including outlines, references, notes, and video clips and enable message exchanges. ELPs also allow tests and examinations to be administered – with noticeable limitations! The functions and associated limitations reduce ELPs to Learning Management Systems (LMSs) with no real-time or active interactivity between instructors and their students. Instructors resort to using Zoom, Google Meet, and other conferencing platforms to supplement ELPs. Even then; there is the limitation for instructors to demonstrate knowledge content related concepts, laws, and theories.

On a related note; the use of mobile phones and short message-based tools in [177] and the learning of domestic electrical installations outside educational settings in [178], [179] reveal that virtual and interactive learning environments can equally benefit populations, such as electrical energy consumers, outside the traditional academic environments. Therefore; virtual and interactive learning environments apply to formal and nonformal teaching-learning situations. In teaching-learning situations and didactics of technology in particular; illustration of concepts, laws and theories simplifies the rather would-be abstract content matter and improves learners' comprehension and competency. Many researchers give various reasons to justify the ELPs, LMSs, virtual, and remote labs that are developed. The reasons range from safety, flexible access, to cost-effectiveness [180], [181], [182]. However; two features are missing in the available published works on LMSs, virtual, and remote labs. The missing features are a focus on microgrids-related knowledge transfer and real-time interactivity between both the learners and virtual laboratories and between the instructors and learners.

Previous works on virtual microgrid laboratories, such as [183], were majorly concerned with building infrastructure testbeds but not particularly knowledge transfer. Research works that consider knowledge transfer, for example [184], ignore the feature of real-time interactivity. Activity theory being a powerful constructivist framework, according to [72], is benchmarked in the development of a virtual and interactive environment for didactic constructivism of microgrids knowledge cf. [185]. To this end, a virtual and interactive microgrid learning environment (VIMLE) is developed as elaborated in section 6.3. VIMLE is an online didactically thought-through system, that manages (through hosting, enabling interaction between learners and instructors and granting access to) content and software-based virtual laboratories for purposes of microgrids-related knowledge transfer and acquisition, skills and relevant competencies to different stakeholder categories. The stakeholders in question include secondary school learners aged 14 – 18, BSc Elec Eng and technical teacher university students, consumers of electrical energy services and the general public. It should be noted that, with reference to VIMLE, the words system and platform are used. VIMLE system refers to the entire back and front ends combined whereas the VIMLE platform is the front end of the system visible and accessible by the users.

6.2.1 VIMLE Core Features and User Requirements

The VIMLE system should combine the functionalities of synchronous, asynchronous, and cooperative learning to offer instructors and trainees an excellent teaching and learning experience. Hence; the VIMLE system should enable real-time interaction between instructors and learners – synchronous. In addition; VIMLE should enable self-experiential learning, that is, learners interacting with the system and learning on one's own according to their convenience – asynchronous. Furthermore; VIMLE should enable learners to interact and discuss with their peers – cooperative [186]. Attributes of synchronous, asynchronous, and cooperative learning are presented in Fig. 45.

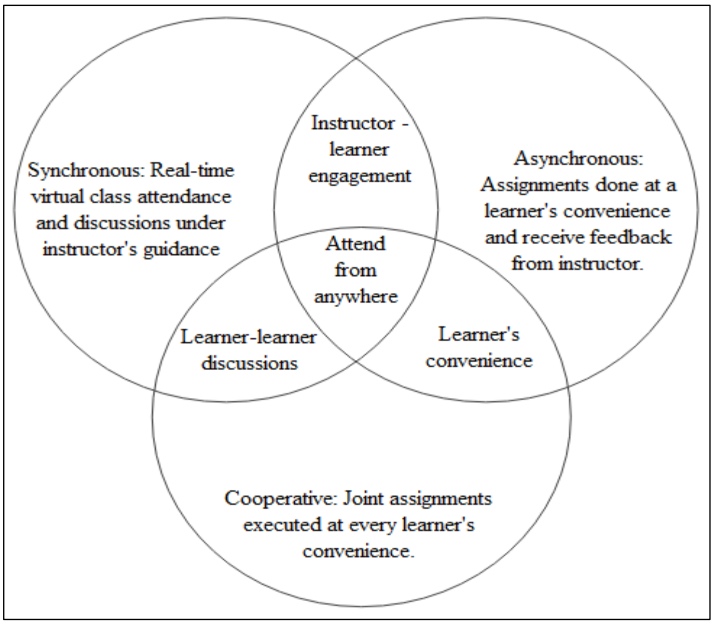


Fig. 45: Attributes of synchronous, asynchronous, and cooperative learning.

The VIMLE system should have the following core features and user requirements:

- Real-time interactivity with video conferencing: The system should enable real-time interactivity between the instructor and the learners (course participants) in a "classroom-like" setting. This therefore suggests that the system should:
  - Have the capacity to handle a considerable number of participants in the range of 10 – 500. It should also work smoothly when participants either join or drop off during real-time streaming.
  - Enable video, audio, and graphics live streaming to a group of participants (broadcast) in real-time and recording. The recording requires storage. System users can store on their devices or in the cloud.
  - Have an inbuilt whiteboard and associated accessories – pen, hand-raising emoji, applause emoji, and poll feature for participants' response collection on a topic.
  - Enable the instructor to share lecture/training material, in real-time, through both file and screen-sharing features.
- Course instructional materials: In addition to sharing during training sessions, the platform should permit instructors to upload and store instructional materials for a stipulated course or training session duration. This therefore suggests that the VIMLE system should have storage capability.
- Communication: The VIMLE platform should have an included chat feature configured to link instructors' and participants' email addresses. In addition; the chat feature should be linked to some instant social communication applications, platforms and/or systems like WhatsApp, Facebook, LinkedIn, Instagram, YouTube, Signal, Skype, Imo, Telegram, sms to mobile telephone numbers, and others so that participants are given a wide variety of options to choose from.

- Feedback: The VIMLE platform should aid feedback regarding electronic activities (e-tivities), virtual laboratory assessments, and generally about the course or training to be shared (offered and received) by and between the appropriate agents – instructor, trainee, or peers. Feedback should enable the recipient to assess learning progress to re-evaluate their learning strategies. Feedback should be corrective, should offer alternative approaches, should clarify ideas, and offer encouragement [187, p. 81].
- User profiles and roles: The VIMLE system should be used by the following categories of people:
  - Instructors to offer training and guidance during synchronous, asynchronous, and virtual laboratory sessions. Instructors will also use the VIMLE platform to offer and receive feedback to and from learners.
  - The trainees will use the VIMLE platform to attend training sessions in real-time, execute virtual laboratory assignments, submit e-tivity assignments, and offer and receive feedback to and from peers and instructors.
  - Guests – these include instructors and learners who, for some reason, might not need to sign up and acquire accounts on the VIMLE platform.
  - Administrators to extend appropriate technical support to instructors, trainees, and guests. The technical support might include system setup, installation, troubleshooting and, generally, the whole user experience to end users. Administrators are responsible for the network architecture including the backend infrastructure. To monitor and enhance system performance, server, storage, security and the general configuration of the system.
- User Interface: The user interface should be made cognisant of the possibility that some users might access the VIMLE platform using devices with small screens and having challenges pertaining to battery life.
- Scalability: Since microgrids are an evolving technology, the VIMLE system should be scalable and enable the addition of both content and virtual laboratories as dictated by microgrids technology advancements.

6.2.2 VIMLE System Design-based Learning Management System

Literature reveals many electronic LMSs including both closed and open source. Some of the closed-source LMSs from several vendors include Learnster, Docebo, iSpring Learn, Cornerstone LMS, Looop, Rise Up, eloomi, Absorb LMS, LearnWorlds, and Eurekos, among others. According to [188]; Atutor, Ilias, and Moodle are some of the web-based open-source LMSs whose architectural designs have been studied by various scholars. Atutor uniqueness is the usability features for the visually impaired. However, it has an architectural drawback of lack of modularity. Ilias on the other hand has a complicated architecture which is difficult to debug and work with [188, p. 1]. Moodle supports social constructivism in learning and the architecture is good, relatively simple, and enables modularity and high cohesion [188, p. 1]. In addition, Moodle architecture is widely adapted globally and EA is no exceptional. Other features, capabilities and shortcomings of LMSs in question have been reported by [188] and need not be repeated. It is vital to note, though, that [188] explored the interoperability potential of Atutor, Ilias, and Moodle to implement an architecture with modularity and interoperability features [188, p. 1]. Some of the desirable features of an effective LMS include gamification, mobile learning, social learning, and video conferencing among others.

Consequently; the VIMLE platform is based on Moodle LMS. In addition, the VIMLE platform should support the system core features and user requirements described in subsection 6.2.1. Further, the platform should allow as much flexibility as possible. As such, users should access and use the VIMLE platform on any device, that is to say; laptops, desktops, and all other smart devices such as phones and tablets, among others. To enable the platform to run on a variety of devices, the VIMLE architectural design and thus implementation of VIMLE is based on a Web Real-Time Communication (WebRTC) technology as elaborated in section 6.3.

6.2.3 Tools for the Development of VIMLE Laboratories

The concept of VIMLE is dependent on virtual laboratories to support comprehension of the developed content. The author maintains that VIMLE laboratories, dubbed V-Labs, are important in eliciting and thus facilitating a deeper understanding of fundamental microgrid concepts. Virtual three-dimensional (3D) models are used for this purpose. 3D models are developed using Unity 3D and Vuforia AR Software Development Kit (SDK). The Visual Studio development environment is integrated into Unity and is vital during V-Labs development to enable the interactive feature.

Virtual Reality is an evolving technology and embraced by many researchers, such as [180], in the development of virtual labs. Owing to its ability to enable the coexistence of both real and virtual worlds, the Augmented Reality concept is employed in the development of V-Labs. Developed V-Labs are then added to the V-Labs Management System of VIMLE. The beginning point in the development of V-Labs is a didactical lens through the CA concept. The CA concept, illustrated in Fig. 46, is simply the interrelation between ILOs, teaching-learning activities, assessment and feedback.

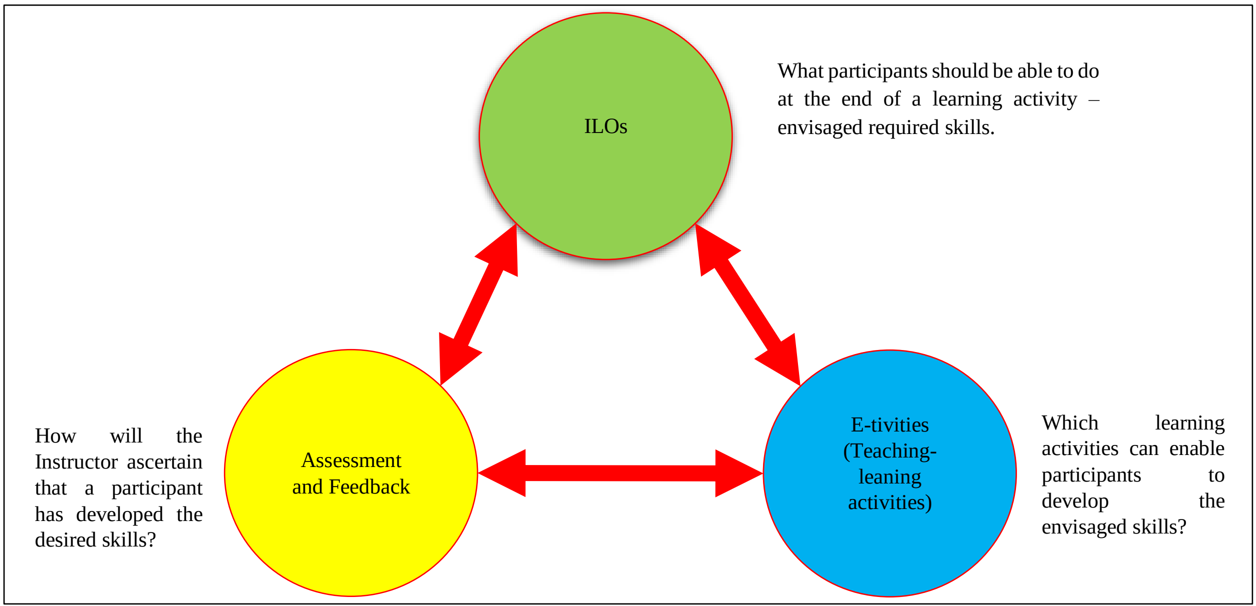


Fig. 46: Constructive alignment concept illustration, adopted from [156, p. 676].

Various scholars have published about the CA concept and they refer to it as a modern didactic tool for knowledge constructivism [153, p. 4]. According to [189, p. 2]; ILOs, learning activities, and assessments are vital steps to consider in the development of teaching-learning systems/environments. Skills desired to be acquired by learners at the end of any learning activity performed within the VIMLE system are written as ILOs. This is followed by preparing well-thought-through teaching-learning electronic activities (e-tivities) that enable learners to gain the envisioned skills and competencies. Methods and tools of assessing whether ILOs are achieved at the end of a learning activity and feedback links are determined. The interrelation between ILOs, learning activities, assessment and feedback is referred to as constructive alignment. Using the concept in Fig. 46 and the stakeholder-specific developed content in section 4.2, a CA frame presented in Table 24 is designed to support V-Labs development for microgrids-related knowledge transfer.

6.3 VIMLE Architectural and System Designs

As mentioned in subsection 6.2.2 of this monograph, the VIMLE architectural design is based on WebRTC technology. WebRTC is a web-based technology that allows web clients (devices of VIMLE platform users in this case) which support HTML5 to communicate, interact, or video conference in real time. Clients only need to have a browser which supports WebRTC technology. Browsers that support WebRTC technology include Chrome, Firefox, and Safari, among others.

A WebRTC architecture, with two clients and a centralised VIMLE server, is shown in Fig. 47. The server receives and responds to service requests from clients. Client A signals to the server indicating the need to interact with Client B. The server sends information of A to Client B who in turn sends signal information to the server. If Client B is willing to interact with Client A, the server forwards details of Client B to A. Upon receipt of Client B's particulars, Client A uses that information to set up a peer-to-peer connection between A and B. This is based on the Session Initialization Protocol (SIP) [190, p. 77].

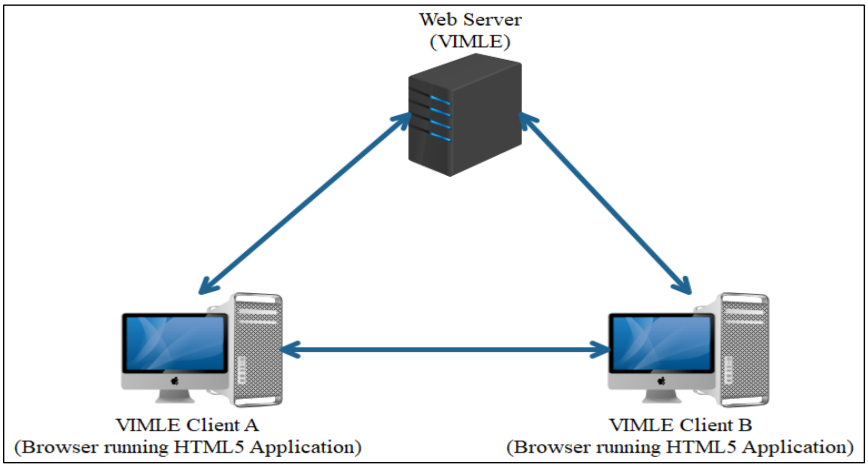


Fig. 47: Illustration of the VIMLE architectural design based on WebRTC technology, adopted from [156, p. 674].

For more than two clients and for clients on different IP networks, the proposed VIMLE architectural design based on WebRTC technology is shown in Fig. 48. The architecture indicates the developed instructional course materials, the VIMLE laboratories (V-Labs) and the microgrid demonstrator accessible via the VIMLE web server based on WebRTC technology.

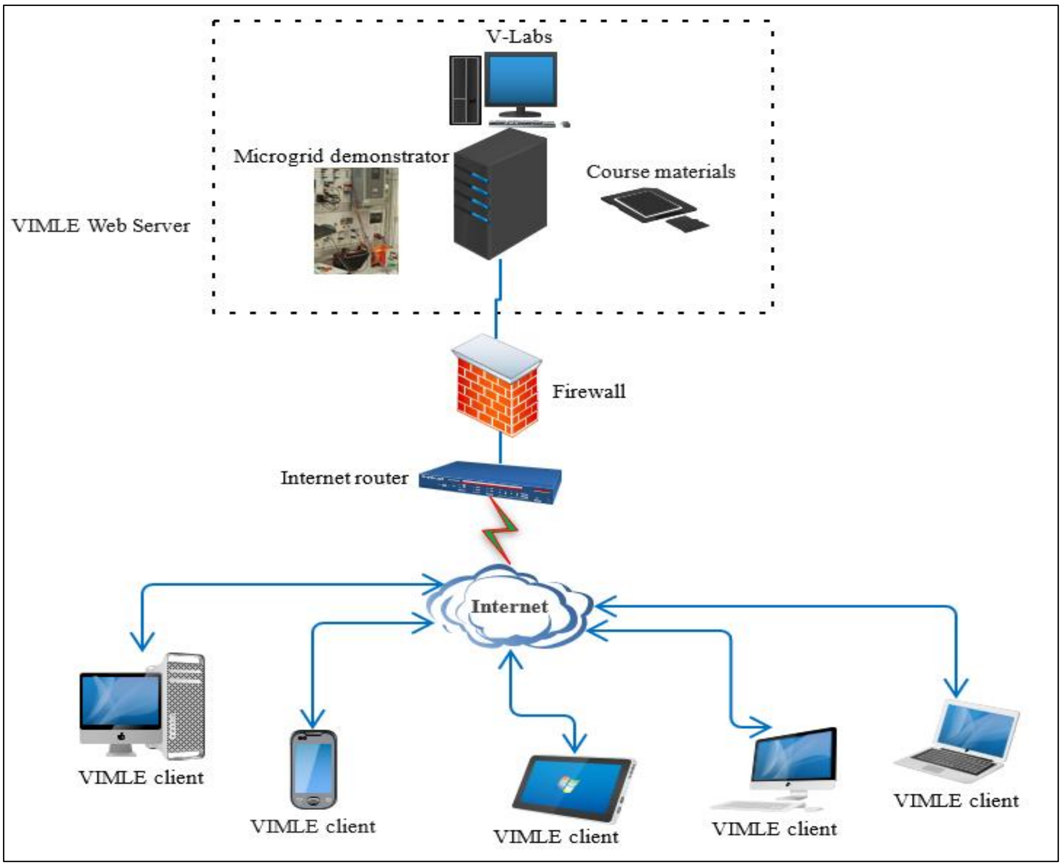


Fig. 48: VIMLE Architectural design based on WebRTC technology for more than two clients.

Architectural frameworks based on WebRTC technology have many advantages, for example, they can run on any device. This is because their APIs contain the majority of browsers so, the system (or app) can run on any device with any of the major browsers installed.

However; although end-to-end encryption is used by WebRTC, one notable disadvantage is that it (WebRTC) leaks once connected to a VPN. The problem can be solved by ensuring that once connected to a VPN, the VPN extension is installed on the browser of choice and that the leak protection functionality is enabled. This justifies the inclusion of a network-based firewall in Fig. 48 to ensure access authorisation to only clients, who meet a prescribed set of security guidelines. One of such guidelines could be limiting clients to a particular VPN for example PureVPN whose extension is installed on browsers like Chrome and Firefox. Once a client is logged in and the leak protection functionality is enabled, the communication is secure.

Whereas the VIMLE architectural design, which provides a broader outlook of VIMLE system operation, is based on WebRTC technology; VIMLE's internal system design is based on the

Model View Controller (MVC) architecture which appears in [186, p. 2], [188, p. 57]. The MVC architecture illustrates relationships between information, information display, and user command objects [191, p. 310]. Command objects are simply programming language statements that trigger procedures to retrieve stored information. Stored information fields, on the other hand, with distinct characteristics and behaviour are referred to as objects. Fig. 49 represents a VIMLE system design, based on MVC architecture, with objects in four levels. The levels are the resource, VIMLE services, common service, and the presentation level. The VIMLE system design, based on MVC, therefore explains how different internal VIMLE components communicate and/or work.

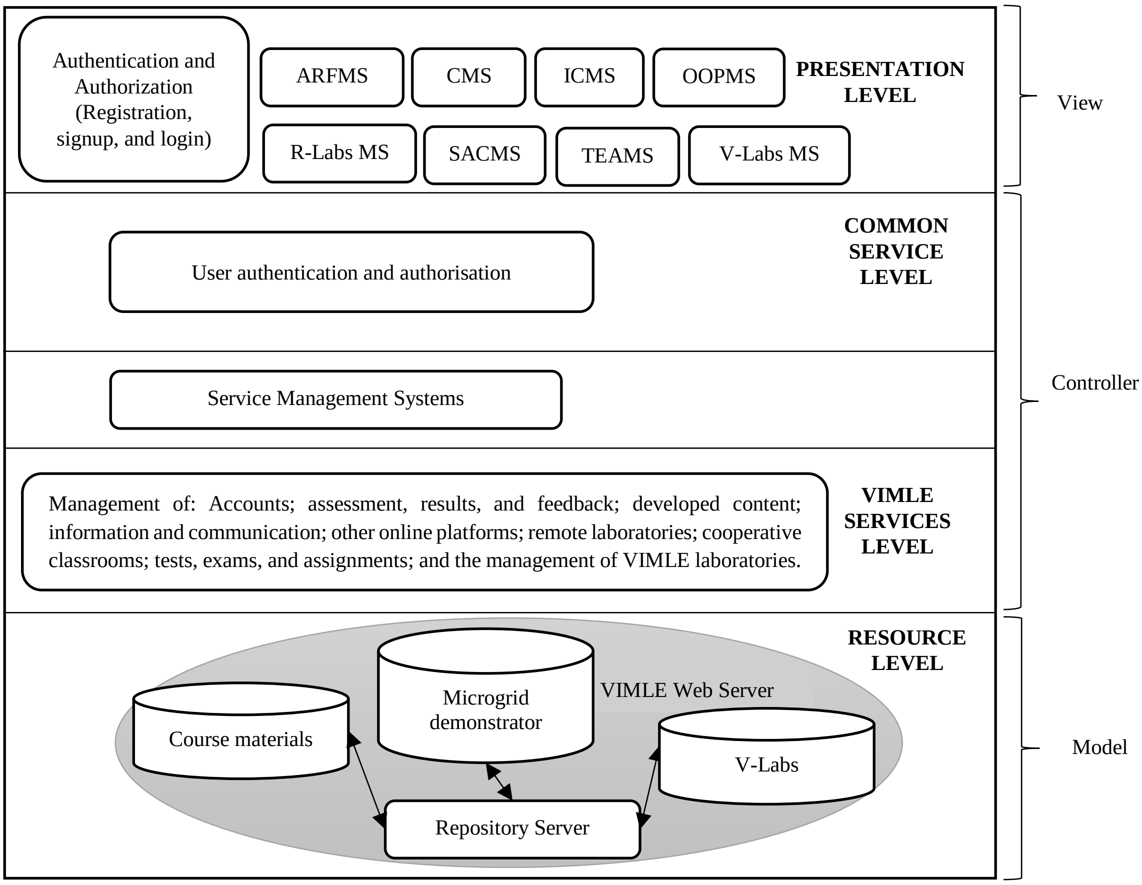


Fig. 49: VIMLE System design based on the MVC architecture, adapted from [188, p. 57].

The resource level, in the model part of the MVC architecture, manages resources in the services level by enabling service applications to retrieve information (required by users) from the repository server through the VIMLE web server. The resources in the repository include the instructional materials and the Virtual laboratories. The resource level enables access to VIMLE system resources and is thus responsible for the VIMLE system logic regarding access to the repository.

The VIMLE services level, in the MVC's controller part, is home to all the VIMLE information management system (MS) components. The VIMLE services level organises related information for ease of access and efficient operation of the VIMLE system. Information related to all accounts for administrators, instructors, learners, and guests is organised in the Accounts Management System (AMS). Other MS components include the Content Management System (CMS) which manages all instructional materials including but not limited to the developed content, the VIMLE Laboratories Management System (V-Labs MS), the Synchronous, Asynchronous, and Cooperative Classrooms Management System (SACMS); the Tests, Exams, and Assignments Management System (TEAMS); Assessment, Results, and Feedback Management System (ARFMS); the Remote Laboratories Management System (R-Labs MS) such as the microgrid demonstrator; Other Online Platforms Management System (OOPMS) that provide microgrids-related training; and any other Information and Communication Management System (ICMS). The VIMLE services level provides VIMLE system application features to, and as required by, the users by calling the implemented services of VIMLE components/objects.

The common service level, on the other hand, is responsible for users' authentication and authorisation. The common service level has the service management system which is a representation of the VIMLE services level. Thus, the common services level interrogates the VIMLE services level and conveys the required results to users through the presentation level. The common service level is the bridge between the presentation level and the VIMLE services level. Generally; the common service and VIMLE services levels form the controller part of the MVC architecture. Therefore, the controller provides the linkage between the model and view parts of the MVC architecture. In linking the model to the view parts; the controller receives requests from users, forwards them to the model and sends responses from the model either to users directly or to the repository for storage.

The presentation level, in the view part of the MVC architecture, is responsible for the user-to-VIMLE services level coordination. The coordination is enabled after the user authentication and authorisation and facilitated by the common service level. The coordination function is well accomplished using graphical user interfaces (GUIs). The user interacts with icons (GUIs) on their devices, visual indicators, or tabs as the case might be so as to access VIMLE services for example the developed content and V-Labs. When users browse the VIMLE platform website, requests are received and responses are sent as HTTP. HTTP is an application layer that transmits information as hypermedia documents for example HTML. Therefore, information flow and exchange between users and the VIMLE platform are transmitted as HTML documents between the web browser and the VIMLE server. Based on the foregoing VIMLE system design explanation, the VIMLE architectural design in Fig. 48 is as illustrated in Fig. 50.

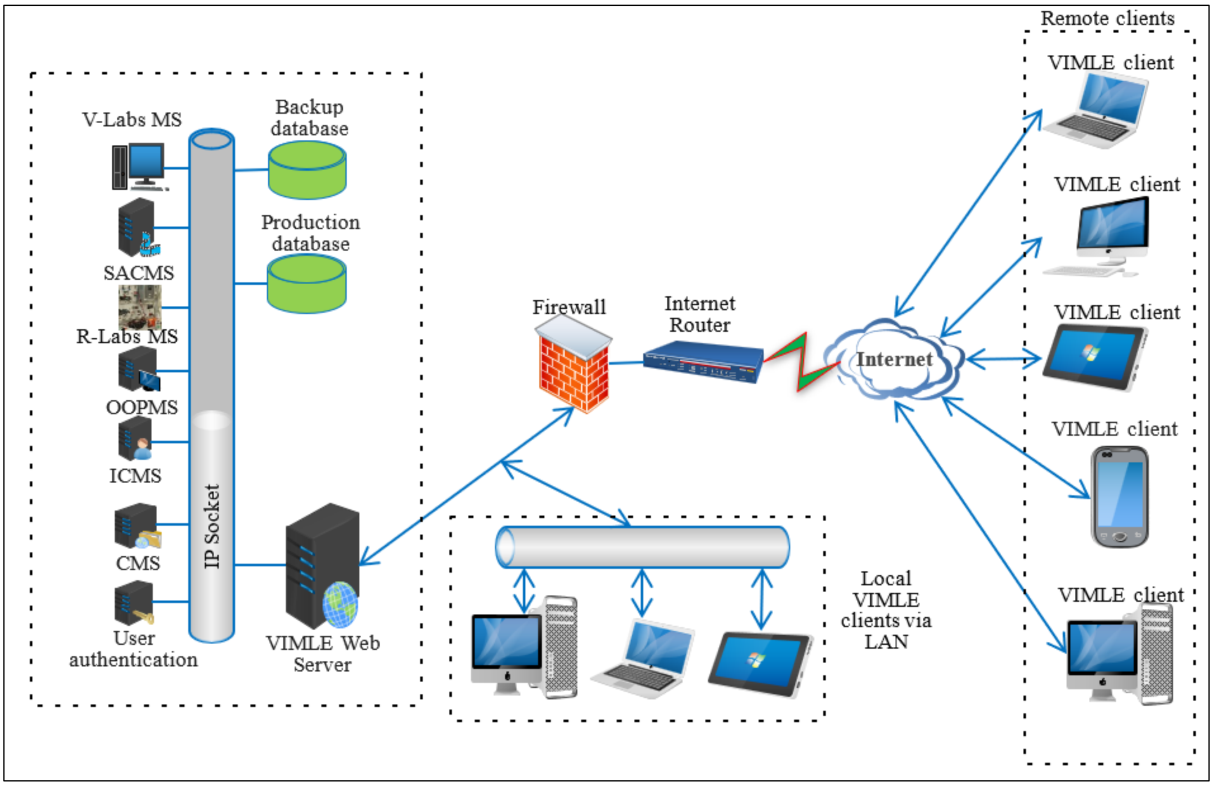


Fig. 50: VIMLE Architectural design with selected VIMLE services, local and remote clients.

Reverting to the presentation level in Fig. 49, it should be noted that decisions about presentation logic are made in the presentation level in view part of the MVC. The decisions include the position, colour, and size of the text among others. Further, in implementing the authentication and authorisation module; access to registration/signup, login, and utilisation of the VIMLE platform is guided by the flowchart in Fig. 51.

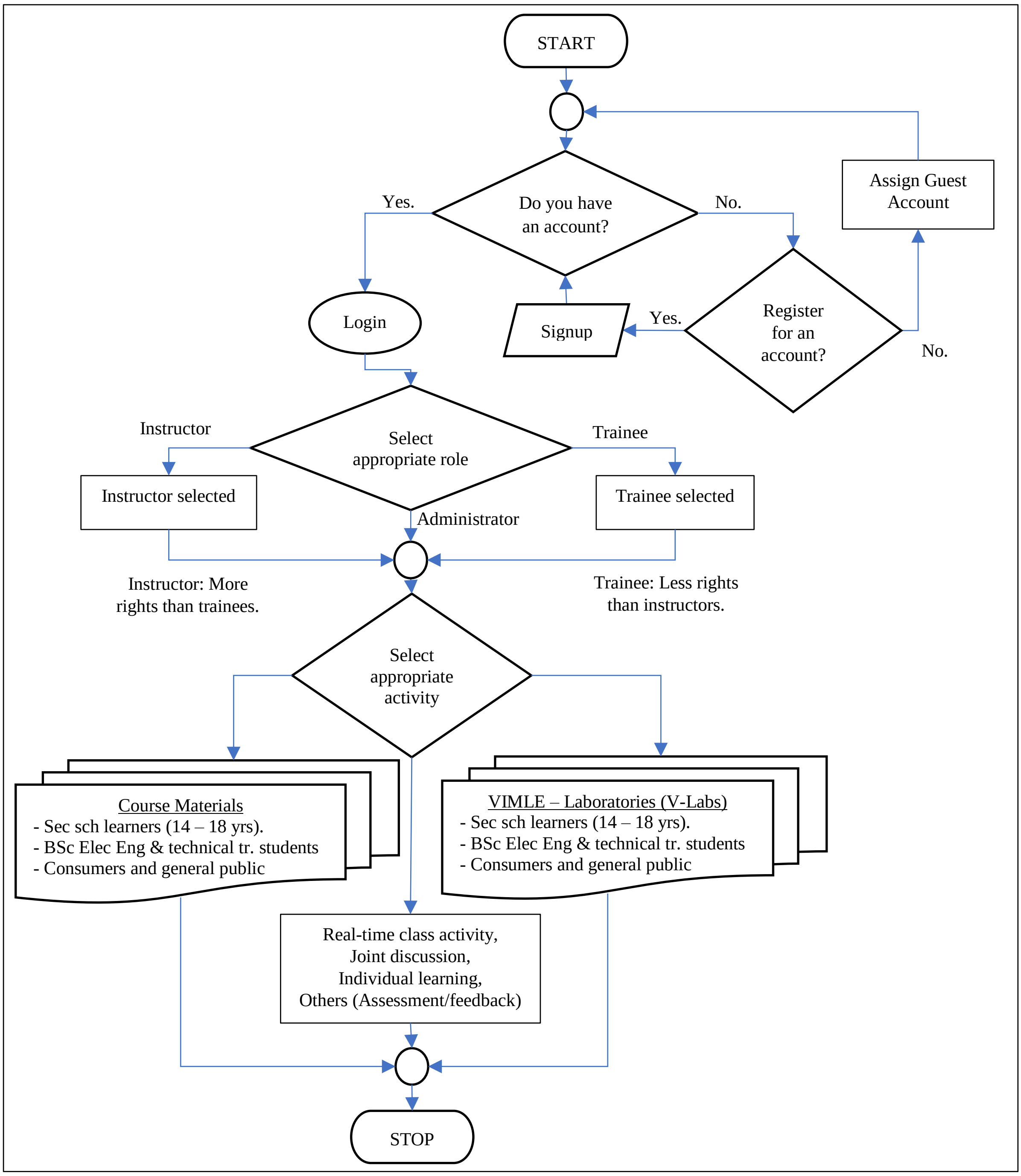


Fig. 51: VIMLE platform user authentication, authorisation and utilisation flowchart.

The VIMLE system layout on the other hand is shown in Fig. 52. The layout indicates both the back and front ends. The back end indicates the resource and VIMLE services levels of the VIMLE system design. Vital to note are the three required functionalities of synchronous, asynchronous, and cooperative learning, represented by the SACMS object at the services level. The front end, on the other hand, depicts the VIMLE platform website impression from a user's viewpoint. It (the front-end) therefore indicates the interface tabs that the platform end users will interact with from time to time. It is vital to note that the *course materials* tab enables access to the developed content and the *V-Labs* tab enables access to the VIMLE labs. From a designer's viewpoint, the front end illustrates the users and the presentation level of the VIMLE system design.

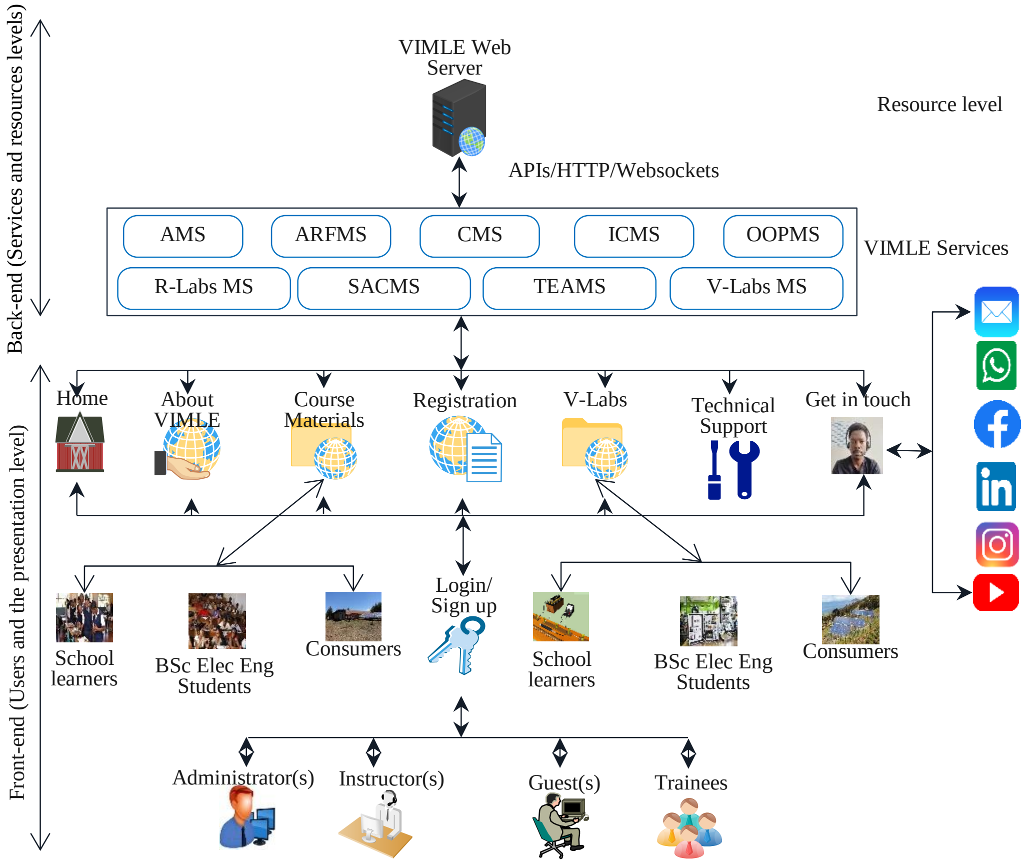


Fig. 52: VIMLE system layout, adapted from [156, p. 677].

6.4 Chapter Summary

In summary, Chapter 6 describes microgrids-related knowledge transfer concepts particularly WBL, live microgrid laboratories, and online learning platforms. The mentioned concepts are envisaged as essential microgrids-related knowledge transfer approaches that can be leveraged to minimise curriculum design-related challenges. WBL, live microgrid laboratories, and online learning platforms can enable stakeholders to acquire microgrids-related knowledge, skills and competencies by providing real-world experience and blending practical hands-on practice with digital learning tools. The chapter further highlights the significance of virtual and interactive learning environments and virtual laboratories in microgrids knowledge transfer. The core system features, user requirements, the preferred LMS, and tools for the design and development of a VIMLE platform are detailed. Vital to note is the CA concept that underpins the development of virtual laboratories for microgrids knowledge transfer. This leads to the design of a VIMLE platform concept. Finally, the proposed VIMLE architectural design based on WebRTC technology and the VIMLE system design based on MVC architecture are described. The concept of the VIMLE platform underscores the importance of innovative educational strategies.

7 Conclusion, Recommendations, and Future Work

Research is worthless unless it contributes and positively impacts society! It was worth conducting this research given that there are findings and hence significant contributions. The findings and contributions, in addition to recommendations, are worth noting. This chapter, therefore, presents the research summary, findings, and significant contributions in section 7.1. In addition; recommendations of this research appear in section 7.2 and, finally, further research work is equally presented in section 7.3.

7.1 Research Summary

In this section; the research conclusion, findings and contributions are summarised highlighting the achieved set objectives and the answered guiding research questions as appropriate. As a result of the first objective; this research developed knowledge content, as the main output, for the three stakeholder categories. The knowledge content is aimed at enabling the stakeholders to acquire relevant skills and competencies to contribute to microgrids sustainability. The knowledge content development is underpinned by the stakeholder-specific context which includes: (1) The lack of microgrids-specific knowledge and the skills gap identified in the analysed curricula, microgrids world of work or workplace required skills and competencies, employability skills, among others underpin knowledge content development for BSc Elec Eng students. (2) The faced electrical energy utilisation challenges, the interests, training needs, transferable skills from previous training, repair and maintenance needs, among others underpin knowledge content development for electrical energy consumers in rural communities. (3) The analysed physics syllabi for lower secondary schools in EA underpin knowledge content development for secondary school learners.

University curricula analysis in subsection 4.1.1 answers the first research question. As indicated in Fig. 15, the analysis shows that 48% of all Uni A curricula content categories and 42% of Uni B are relevant to microgrids although they do not precisely address microgrid-specific technologies. The content from the renewable energy category, which is relevant to microgrids, is 2% and 4%; for the sustainability category, the content is 0% and 3% for Uni A and Uni B respectively. The current BSc Elec Eng curricula content at Uni A and Uni B do not, therefore, enable students to attain precise microgrids-specific knowledge and skills. Microgrids-related skills, for microgrids sustainability, that students miss are identified. Basing on the analysis of the collected data responses from BSc Elec Eng junior and senior students, lecturers of electrical power-related courses, and those of microgrid operators; BSc Elec Eng microgrids-related employability and workplace required skills are categorised into a number of themes. The skills missed by candidates trained using the curricula in force at the time of data collection, microgrids-related employability and workplace-required skills informed the developed content for the BSc Elec Eng DEES course which is proposed for inclusion in BSc Elec Eng curricula.

Skill sets to enable the three stakeholder categories to contribute to microgrids sustainability are categorised in section 4.2 and this answers the second research question. There are four indicated skill sets for BSc Elec Eng students in 4.2.1, six for electrical energy consumers in 4.2.2, and three for secondary school learners in 4.2.3. Secondary school learners can contribute to microgrids sustainability if given appropriate skills. For example; following the implementation of the secondary school microgrids course in [138], 64% of the learners indicated their ability to provide recommendations for suitable household appliances, 64% to perform basic domestic electrical installations, and 79% to adhere to electrical health and safety protocols. The foregoing results are, however, based on students' self-assessment in response to the statements using a 4-point Likert scale tool rather than on formative or summative assessment methods to establish accomplishment of ILOs. Nevertheless, microgrids knowledge is transferred to the learners and the knowledge ripples to the communities where learners come from. For example, if the learners recommend efficient electrical appliances to members of their communities, including parents, bills ought to be reduced, hence, contributing to the affordability of electrical energy in communities.

Electrical energy consumers are equally vital stakeholders in the microgrids' entrepreneurial ecosystem. To solve challenges related to electrical energy utilisation and enable contribution to microgrids sustainability, skilling programmes for consumers of electrical energy services should aim at imparting skill sets related to appropriate and cost-effective electrical energy utilisation approaches, acquisition of entrepreneurship knowledge and skills for income generation, plus the ability to perform electrical installations and repair and maintenance of selected electrical accessories, appliances, and devices among others. Acquisition of the mentioned skill sets is enabled through the developed seven topics consumers' skilling program in Appendix G.

Relatedly, BSc Elec Eng students need to develop knowledge and skills that are specific to microgrids. As this research reveals; it is essential that BSc Elec Eng students acquire both technical and non-technical (soft) skills. It is therefore recommended that skill sets related to microgrid systems design, battery storage systems design, demand side management interventions, and application of AI to microgrids optimisation, among other competencies, are acquired by BSc Elec Eng students desirous of microgrids-related careers. In addition, soft skills aimed at equipping future graduates with customer support and care skills should be included in BSc Elec Eng curricula. As such ten topics expected to enable graduates to acquire the mentioned competencies are proposed as indicated in Appendix C. It should be noted that the initial results of skill sets, for the three stakeholder categories considered in this research, are published in [2].

As a result of the second objective; a microgrids-related knowledge transfer didactic architectural model is developed in section 5.1. The developed model illustrates how knowledge transfer contributes to microgrids sustainability through local capacity building of school children, students pursuing BSc Elec Eng, and consumers of electrical energy services in rural EA communities. A recap of the analysis and discussion leading to the skills and competencies of the considered stakeholders connecting the input to the process and output stages of the design structure in Fig. 35 through to the didactic architectural model that appears in Fig. 37 is presented. The didactic concepts employed during knowledge content development such as Bloom's taxonomy, the CA, and the taxonomy table are presented. In the same way, the knowledge transfer (train the trainer) strategy and the didactic (teaching and learning) strategy are illustrated. It is vital to note that the classification of ILOs using a taxonomy table enables visualisation and reflection on the relevance of the developed content for microgrids sustainability. During the development of the didactic architectural mode, the classification of ILOs reveals that the developed content shall enable: (1) BSc Elec Eng students to acquire practical hands-on skills, problem-solving, creative, and innovative skills. (2) Consumers and secondary school learners to acquire knowledge and practical skills to solve challenges in their rural communities. Given that the didactic architectural model summarises the content development process, it is a good reference tool for curriculum developers, and training officers in industries, academics and researchers interested in developing related training content for microgrids and other specialisations. Partial results of this objective are published in [160] and received a Best Paper award.

In light of the developed course content that is proposed for inclusion in BSc Elec Eng curricula; the curriculum development, review, and implementation processes and challenges are illuminated in section 5.2. Consequently, knowledge transfer concepts such as WBL, real microgrids dubbed live laboratories, and online learning platforms are proposed, in section 6.1, as solutions. The highlighted knowledge transfer concepts are the envisaged solutions to the challenges that affect curriculum development, review, and implementation hence; answering the third research question. The knowledge transfer concepts are applicable to all the three stakeholders considered in this monograph and can complement the instruction (teaching and learning) strategy aimed at ensuring skills acquisition to contribute to microgrids sustainability. Knowledge transfer concepts are published in [192].

In line with the third objective and to facilitate access to the developed microgrids-related knowledge content, the VIMLE platform is designed. Through literature reviews, system features and user requirements desired for VIMLE are documented in subsections 6.2.1 and 6.2.2 and they answer the fourth research question. The features and requirements guide the VIMLE design and two of the key feature requirements are that VIMLE should: (1) enable social constructivism and (2) allow as much flexibility as possible. For social constructivism, moodle is the preferred LMS and on flexibility, the implementation is based on WebRTC technology. As illustrated in section 6.3; the VIMLE architectural design is based on WebRTC technology while the system design is based on the MVC architecture. The concept of CA on the other hand guides the development of V-Labs, which are instrumental in microgrid-related knowledge transfer. The aim is to transfer microgrids-related knowledge to BSc Elec Eng students, electrical energy consumers in EA rural communities, and secondary school learners. The initial results of this objective are published in [156] and received a Best Paper award.

To this end; the developed content for the three stakeholder categories, the developed didactic architectural model, and the designed VIMLE platform are tools that are collectively referred to as the didactics of technology paraphernalia. The developed didactics of technology paraphernalia is for the purpose of transferring microgrids-related knowledge so as to build local capacity in the EA region for microgrids sustainability. Given the developed tools, in the didactics of technology paraphernalia, and thus through microgrids-related knowledge transfer efforts, this study contributes to SDGs 4 and 7. With both the knowledge transfer and the didactic strategies, coupled with the developed materials and their implementation; this study directly contributes to the seventh target of the fourth SDG. According to [193, p. 5], target 4.7 statement is as follows:

> By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development … and appreciation of cultural diversity and of culture's contribution to sustainable development.

In line with the aforementioned target 4.7 statement; this study contributes to the target indicator, in [193, p. 5], of mainstreaming "education for sustainable development" through: (1) Curricula – the developed BSc Elec Eng knowledge content proposed for inclusion in curricula and the developed secondary school learners' knowledge content based on the physics syllabi. (2) Teacher education – train the trainer by training instructors such as secondary school teachers, technical teacher students, community leaders, village representatives and energy committee members in rural communities. (3) Student assessment – the indicated methods, in the CA concept, that instructors use to establish whether the ILOs are achieved.

As a result of this study; knowledge is transferred hence, the knowledge and the skills gaps are closed and technical local capacity is built. With built technical local capacity; skills for designing, installing, operating, maintaining, controlling and monitoring microgrids plus efficient and economical electrical energy utilisation among others are assured. In essence; microgrids-related knowledge transfer is a microgrids sustainability element. Consequently, sustainable microgrids increase the numbers with access to electrical energy thereby contributing to SDG 7 realisation through the first target – target 7.1. According to [193, p. 8], target 7.1 states that "by 2030, ensure universal access to affordable, reliable and modern energy services" whose indicator is a population that accesses electrical energy.

Other SDGs to which this research indirectly contributes include: (1) SDG 1 – target 1.1 on eradication of extreme poverty given the PUE and entrepreneurship consumer skilling programme [193, p. 1]. (2) SDG 7 – target 7.2 on raising the share of renewable energy contribution to the energy mix and target 7.3 on improving energy efficiency [193, p. 8]. (3) SDG 8 – target 8.3 on the creation of informal employment given that this research promotes PUE, entrepreneurship and, creative innovation of income-generating activities through training [193, p. 8]. (4) SDG 12 – target 12.a on "scientific and technological capacity" strengthening towards sustainable energy production and consumption. The target indicator is installed renewable energy capacity [193, p. 14]. (5) SDG 17 – target 17.9 on capacity building in developing countries [193, p. 21]. (6) SDG 17 – target 17.16 on multi-stakeholder partnerships for knowledge sharing [193, p. 22]. Relatedly, since this monograph is premised on the A:RT-D Grids project objective; summarising this research's contributions to the project WPs as indicated in Table 28 is deserving.

Table 28: Summary of the A:RT-D Grids project WPs and this research work's corresponding contributions.

WP No.	WP Theme	Sub Theme	Monograph Objective	Research Contribution
WP 2.1	Education and Gender	Networking Education	Develop stakeholder-specific microgrids-related knowledge content.	Analysed BSc Elec Eng Curricular from selected universities in EA to establish microgrids-related and sustainability knowledge. Documented microgrids-related skills as perceived by students, lecturers, & operators. Proposed microgrids-related knowledge content to bridge the academia-workplace skills gap. Examined curricula development, implementation, and review challenges including inadequate microgrids-related skills, long periods taken to review, and inadequate resources. Established consumers' electrical energy utilisation challenges, training interests, transferrable skills, and repair and maintenance needs. Analysed the lower secondary physics syllabi to inform microgrids-related knowledge content development. Characterised stakeholder-specific skill sets to enable the respective stakeholders to acquire the necessary skills. Consequently, developed stakeholder-specific microgrids-related content for microgrids knowledge transfer.
		Teaching microgrids Technology	Develop a didactic architectural model for microgrids knowledge transfer.	Didactic concepts, frameworks, and standards applied during content development are documented. Microgrids-related knowledge transfer to secondary school learners, BSc Elec Eng students, and consumers. Stakeholder instruction and knowledge transfer strategies are highlighted. Consequently, a microgrids knowledge transfer didactic architectural model is developed.
		Innovation in Scientific Teaching	Design a virtual and interactive learning environment for didactic constructivism of microgrids-related knowledge.	Proposed concepts that include WBL, live laboratories, and online learning platforms as plausible solutions to curricula-related challenges. Development of virtual and interactive practicals (V-Labs). Designed a Virtual and Interactive Microgrids Learning Environment (VIMLE).
WP 3.1	Training	Development of a toolbox		VIMLE V-Labs Developed content for each stakeholder category.
WP 5.2	Communication & Training	Dissemination		Graduate Training
				Conferences
				Peer-reviewed Publications

7.2 Research Recommendations

7.2.1 Inclusion of a Microgrids-related Course Unit in BSc Elec Eng Curricula

The author recommends inclusion of a microgrids-related course unit in the BSc Elec Eng curricula for both Uni A and Uni B. At the prerogative of the respective university authorities, the suggested course unit name is Distributed Electrical Energy Systems (DEES). The goal, objectives, ILOs, and the corresponding content in the course unit aim to transfer the identified missing skills in the analysed curricula and the workplace required skills. It is further recommended that the course unit is implemented as an independent course, elective, in the third year of study (to enable those who might need to do fourth-year final projects research in microgrids-related areas to think of relevant research topics). The course unit is expected to emphasise practical hands-on and solar as the microgrids energy source. On a lighter note, a course unit on Business Management and/or Project Planning and Management ought to be included in the Uni A curriculum. This would complement the DEES course unit.

7.2.2 Inclusion of the Knowledge Transfer Concepts in Curricula Guidelines

Given the persistent delay in curricula review, as one of the identified challenges, BSc Elec Eng students shall miss new microgrids-related technological developments even with the inclusion of the developed DEES course unit in curricula. Although this is partly solved by the practice of instructors introducing topics related to new industrial developments, this has limitations including: (1) The quantity of content that is not in approved curricula has to be minimised. (2) Examination of content that is not in approved curricula can be queried. (3) Not all instructors are privy to information relating to new industrial developments. It is therefore recommended that universities embrace knowledge transfer concepts such as WBL, live laboratories, and online learning platforms among others. To embrace the mentioned concepts, there is a need to formally include the concepts as part of the instructional resources in curricula. Although the focus of this monograph is on microgrids, the proposed concepts are generally applicable to other specialisations in the entire education sector. The knowledge transfer concepts in question are equally applicable to electrical energy consumers and secondary school learners.

7.2.3 Establishment of Full-time Curricula Review Committees

Given that the curriculum review process is long, tedious, and normally started after statutory accreditation of the study programmes has expired; departments, schools, institutes, faculties, and colleges should constitute full-time curricula review committees. The committees ought to be integrated within the structures of the departments through to colleges and enable the review process to start as soon as a study programme curriculum is accredited. The current practice is that curricula review committees are composed in the initial stages of a review process. Since curricula review ought to be an ongoing activity, university departments through to the college level should have integral full-time curricula review committees whose mandate should include overseeing curricula implementation and ensuring that timely review processes are initiated. This will guarantee periodic and consistent reviews.

7.2.4 Skilling of Electrical Energy Consumers

Government rural electrification agencies, private microgrids energy developers, and local authorities, among others, should embrace and implement consistent and periodic skilling of electrical energy consumers. It is recommended that the skilling programmes be based on the consumers' knowledge transfer content developed in this research. It is envisaged that consumers will embrace the training programmes since the content is based on consumers' electrical energy utilisation challenges, their interests, needs, and transferrable skills. Skilling of consumers empowers them with knowledge and skills to optimize electrical energy utilisation, lower bill costs, and improve PUE demand to the benefit of microgrids sustainability. To feed into microgrids sustainability, therefore; it is recommended that the skilling considers microgrids sustainability, at all times, as perceived by the consumers and be as practical as possible.

7.2.5 Introduction of the Microgrids Course in Secondary Schools

The author recommends the introduction of a microgrids course in secondary schools in EA. The recommendation is well in line with the CBE as a strategic step towards building a future workforce that is able to advance sustainable energy solutions in general and sustainable microgrids in particular. By incorporating demonstrations, hands-on project assignments and real-world case scenarios in the teaching-learning tasks, learners can gain practical hands-on skills and knowledge of how microgrids work, enhance energy resilience, and accessibility, and contribute to solutions of electrical energy utilisation challenges, especially in rural communities. Imparting secondary school learners with microgrids-related knowledge not only encourages innovation and technical skills acquisition but also promotes environmental protection and prepares learners to be leaders in the transition to sustainable electrical energy systems. To facilitate a feasible and sustainable knowledge transfer, secondary school teachers need to equally be trained.

7.3 Future Research Work

Although this study achieved the set objectives, there exists further research work to improve and complement the contributions made. Areas to complement this research work are highlighted in this section.

7.3.1 Inclusive Implementation of the VIMLE Platform

Considering the many emails received following the publication of the initial work-in-progress VIMLE article, further work needs to be done to fully implement the VIMLE platform. Full implementation requires the development of V-Labs in light of all envisaged teaching-learning tasks cognisant of the core VIMLE platform features and user requirements indicated in this monograph. The phrase “inclusive implementation” is used to mean implementation for all the stakeholder categories. That is to say the BSc Elec Eng students, sec. sch. learners, and electrical energy consumers in rural communities. In all this; particular attention should be to translate microgrid component names and V-Labs to the vernacular of the respective EA countries, where data is collected, not forgetting though that English is the language of instruction in academic institutions of learning. To vernacularise the VIMLE platform though would ensure that a large audience is reached.

7.3.2 Inclusion of the Remote Feature to the VIMLE Platform

With the purchase of a Lucas Nülle-made advanced photovoltaics trainer, dubbed microgrid demonstrator, future research is vital to ensure the integration of a remote feature to the VIMLE platform. A remote feature would ensure that BSc Elec Eng engineering students access the demonstrator and perform practicals remotely. Particular attention should be given to the security of the network that hosts the physical demonstrator and an access control algorithm that avoids overloading the demonstrator in situations of many user requests.

7.3.3 Evaluation of the Alignment Degree based on the Taxonomy Table

It is noted that the use of the taxonomy table in this monograph is limited to what will be learnt, the learning and instruction question, and hence the classification of ILOs. To complement this, future work should consider answering the alignment and assessment question. This should be done by establishing the degree to which the ILOs, learning activities, and assessment methods are aligned. This can be achieved by the use of a taxonomy table and it is another way of validating results.

7.3.4 Evaluation of the Secondary School Content based on ILOs Achievement

During the implementation of the microgrids course for secondary school learners, pre- and post-evaluations of the content were done. The post-evaluation was based on learners' self-assessments using a 4-point Likert scale tool. Future research work should be done to evaluate the content based on the learners' achievement of ILOs using either formative or summative assessment.

7.3.5 Standardisation of the Developed Content

It is noted that the DIT is responsible for both formal and non-formal standardisation of certificates. The developed content, especially for secondary school learners and electrical energy consumers, should be DIT standardised. This means adapting the content to the DIT assessment and training package requirements and formally applying to the DIT qualification standards department for approval as appropriate occupation modules. Upon approval; the content can then be administered in DIT assessment centres, secondary schools inclusive, and in rural communities. It should be noted that DIT quality assurance mechanisms are ISO compliant as per ISO 9001:2015 certificate number UG92580A. Therefore; once the developed content is standardised, trained participants can acquire international recognition under formal and non-formal training for secondary school learners and consumers respectively.

7.4 Chapter Summary

This chapter summarises the entire research work of this study and highlights the key findings and contributions. The findings include the lack of microgrids-specific knowledge in the analysed BSc Elec Eng curricula and the consumers' electrical energy utilisation challenges, among others, which guide the development of stakeholder-specific microgrids-related knowledge content. The developed knowledge content is the main contribution of this research and aims to ensure that the respective stakeholders acquire appropriate skills and competencies to contribute to microgrids sustainability. The chapter highlights that stakeholder-specific skill sets are characterised and this is another contribution of this research work. Knowledge transfer concepts are presented to complement the teaching and learning strategy to support the acquisition of the skill sets. The chapter further emphasises the importance of enabling access to the developed knowledge content as the reason for designing the VIMLE platform which is another research contribution. The chapter mentions yet another research contribution which is the microgrids knowledge transfer didactic architectural model. Similarly, the chapter highlights the peer-reviewed publications and the best paper awards. Important to note is that the chapter recaps six SDGs to which this research directly and indirectly contributes. A summary of this research's contributions to the A:RT-D Grids project WPs is also presented.

The chapter makes actionable recommendations informed by the results and contributions of this research. The inclusion of a microgrids-related course unit and the proposed knowledge transfer concepts in BSc Elec Eng curricula, the establishment of full-time curricula review committees at departments through to colleges, consistent and periodic skilling of electrical energy consumers, the introduction of a microgrids course in secondary schools, and training of the physics teachers are the recommendations made. To improve and complement the contributions made, the chapter highlights recommended future research ideas. Recommendations for future research work include full implementation of the VIMLE platform, integration of a remote feature to the VIMLE platform, and DIT standardisation of the developed content, among others.

References

[1] S. Krauter *et al.*, ‘Africa: Research and Teaching platform for Development-Sustainable Modular Grids for Grid Stability (ART-D Grids)’, 2019.

[2] P. Bogere, H. Bode, and K. Temmen, ‘Skill Sets for Microgrids Sustainability - The Case of East Africa’, in *IEEE AFRICON Conference*, Institute of Electrical and Electronics Engineers Inc., 2023. doi: 10.1109/AFRICON55910.2023.10293306.

[3] K. Klette, ‘Didactics meet Classroom Studies’, in *Perspektiven der Didaktik*, 9th ed., M. A. Meyer, M. Prenzel, and S. Hellekamps, Eds., VS Verlag für Sozialwissenschaften, 2008, pp. 101–114.

[4] S. Nanu, ‘Educational Aspects in Control System Design Technology’, *Scientific and Technical Bulletin Series: Electrotechnics, Electronics, Automatic Control and Computer Science*, vol. 4, no. 1, pp. 41–52, 2007.

[5] United Nations, ‘Resolution Adopted by the General Assembly on 25 September 2015 (A/RES/70/1)’, 2015. doi: 10.1163/157180910X12665776638740.

[6] IEA, IRENA, UNSD, World Bank, and WHO, ‘Tracking SDG 7: The Energy Progress Report 2020’, 2020. [Online]. Available: https://trackingsdg7.esmap.org/

[7] S. Emili, F. Ceschin, and D. Harrison, ‘Product-Service System applied to Distributed Renewable Energy: A classification system, 15 archetypal models and a strategic design tool’, *Energy for Sustainable Development*, vol. 32, pp. 71–98, 2016, doi: 10.1016/j.esd.2016.03.004.

[8] H. Ritchie and P. Rosado, ‘Access to Energy’, OurWorldInData.org. Accessed: Apr. 13, 2024. [Online]. Available: https://ourworldindata.org/energy-access

[9] IEA, IRENA, UNSD, World Bank, and WHO, ‘Tracking SDG7: The energy progress report 2023’, 2023. [Online]. Available: www.worldbank.org

[10] T. Ajewole, J. Mutale, and P. Dauenhauer, ‘Micro-grids Empowering Communities and Enabling Transformation in Africa - A Report by the High-Level African Panel on Emerging Technologies [APET]’, 2018.

[11] IEA, IRENA, UNSD, World Bank, and WHO, ‘Tracking SDG7: The energy progress report 2024’, 2024. [Online]. Available: https://trackingsdg7.esmap.org/downloads.

[12] T. Adefarati and R. C. Bansal, ‘Energizing Renewable Energy Systems and Distribution Generation’, in *Pathways to a Smarter Power System*, A. Taşcıkaraoğlu and O. Erdinç, Eds., Elsevier Ltd., 2019, ch. 2, pp. 29–65. doi: 10.1016/B978-0-08-102592-5.00002-8.

[13] UNDP and WHO, ‘The Energy Access Situation in Developing Countries: A Review Focusing on the Least Developed Countries and Sub-Saharan Africa’, 2009. [Online]. Available: https://www.undp.org/content/undp/en/home/librarypage/environment-energy/sustainable_energy/energy-access-in-developing-countries.html

[14] Uganda Bureau of Statistics (UBOS), ‘2018 Energy for Rural Transformation (ERT III) Survey - Uganda Report.’, Kampala, Uganda, 2020.

[15] IEA, ‘Defining energy access: 2020 methodology’. Accessed: Jul. 11, 2024. [Online]. Available: https://www.iea.org/articles/defining-energy-access-2020-methodology

[16] M. P. Blimpo, A. Postepska, and Y. Xu, ‘Why is household electricity uptake low in Sub-Saharan Africa?’, *World Dev*, vol. 133, pp. 1–20, Sep. 2020, doi: 10.1016/j.worlddev.2020.105002.

[17] M. P. Blimpo and M. Cosgrove-Davies, *Electricity Access in Sub-Saharan Africa: Uptake, Reliability, and Complementary Factors for Economic Impact*. Washington, DC 20433, USA, 2019. doi: 10.1596/978-1-4648-1361-0.

[18] D. Li, J. H. Bae, and M. Rishi, 'Sustainable Development and SDG-7 in Sub-Saharan Africa: Balancing Energy Access, Economic Growth, and Carbon Emissions', *European Journal of Development Research*, vol. 35, no. 1, pp. 112–137, Feb. 2022, doi: 10.1057/s41287-021-00502-0.

[19] I. Demidov, H. Dibaba, A. Pinomaa, S. Honkapuro, and M. Nieminen, 'System Platform Enabling Peer-to-Peer Electricity Market Model for Off-Grid Microgrids in Rural Africa', in *2020 17th International Conference on the European Energy Market (EEM)*, Stockholm, Sweden: IEEE Xplore, 2020, pp. 1–6. doi: 10.1109/EEM49802.2020.9221915.

[20] J. Namaganda-Kiyimba and J. Mutale, 'Sustainability Metrics for Rural Electrification in Developing Countries', in *IEEE PES/IAS PowerAfrica Conference*, IEEE Xplore, 2018, pp. 426–431. doi: 10.1109/PowerAfrica.2018.8521140.

[21] S. Shahzad, M. A. Abbasi, H. Ali, M. Iqbal, R. Munir, and H. Kilic, 'Possibilities, Challenges, and Future Opportunities of Microgrids: A Review', *Sustainability*, vol. 15, no. 8, pp. 1–28, Apr. 2023, doi: 10.3390/su15086366.

[22] J. P. Murenzi and T. S. Ustun, 'The Case for Microgrids in Electrifying Sub-Saharan Africa', in *6th International Renewable Energy Congress (IREC)*, Sousse, Tunisia: IEEE, 2015. doi: 10.1109/IREC.2015.7110858.

[23] D. T. Ton and M. A. Smith, 'The U.S. Department of Energy's Microgrid Initiative', *The Electricity Journal*, vol. 25, no. 8, pp. 84–94, 2012, [Online]. Available: http://dx.doi.org/10.1016/j.tej.2012.09.013

[24] T. Huh, 'Analyzing the configuration of knowledge transfer of the green island projects in S. Korea', *The Korean Journal of Policy Studies*, vol. 32, no. 1, pp. 1–26, 2017, doi: 10.52372/kjps32101.

[25] E. C. X. Ikejemba, P. B. Mpuan, P. C. Schuur, and J. Van Hillegersberg, 'The empirical reality & sustainable management failures of renewable energy projects in Sub-Saharan Africa (part 1 of 2)', *Renew Energy*, vol. 102, pp. 234–240, 2017, doi: 10.1016/j.renene.2016.10.037.

[26] P. M. Dauenhauer and D. F. Frame, 'Sustainability Analysis Off-grid Community Solar PV Projects in Malawi', *GHTC 2016 - IEEE Global Humanitarian Technology Conference: Technology for the Benefit of Humanity, Conference Proceedings*, pp. 113–120, 2017, doi: 10.1109/GHTC.2016.7857268.

[27] O. Babayomi and T. Okharedia, 'Challenges to Sub-Saharan Africa's Renewable Microgrid Expansion - ACETEP Solution Model', in *2019 IEEE PES/IAS PowerAfrica Conference*, Abuja, Nigeria: IEEE, 2019, pp. 617–621.

[28] J. Ehnberg, H. Ahlborg, and E. Hartvigsson, 'Approach for flexible and adaptive distribution and transformation design in rural electrification and its implications', *Energy for Sustainable Development*, vol. 54, pp. 101–110, Feb. 2020, doi: 10.1016/j.esd.2019.10.002.

[29] E. Hartvigsson, J. Ehnberg, E. O. Ahlgren, and S. Molander, 'Linking household and productive use of electricity with mini-grid dimensioning and operation', *Energy for Sustainable Development*, vol. 60, pp. 82–89, Feb. 2021, doi: 10.1016/j.esd.2020.12.004.

[30] N. Scott and W. Coley, 'Understanding load profiles of mini-grid customers in Tanzania', *Energies (Basel)*, vol. 14, no. 14, pp. 1–17, Jul. 2021, doi: 10.3390/en14144207.

[31] T. Raji, F. Aleotti, A. Bharadwaj, and N. J. Williams, 'Challenges of microgrid project development in sub-Saharan Africa: An industry perspective', in *2021 IEEE PES/IAS PowerAfrica Conference*, Institute of Electrical and Electronics Engineers Inc., Aug. 2021, pp. 1–3. doi: 10.1109/PowerAfrica52236.2021.9543155.

[32] I. S. Bayram, 'Teaching Smart Power Grids: A Sustainability Perspective', in *12th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG)*, Doha, Qatar: IEEE, 2018.

[33] S. Booth, X. Li, I. Baring-Gould, D. Kollanyi, A. Bharadwaj, and P. Weston, 'Productive use of Energy in African Micro-grids: Technical and Business Considerations', 2018. [Online]. Available: www.nrel.gov/publications.

[34] A. Boche, C. Foucher, and L. F. L. Villa, 'Understanding Microgrid Sustainability: A Systemic and Comprehensive Review', *Energies (Basel)*, vol. 15, no. 8, pp. 1–29, Apr. 2022, doi: 10.3390/en15082906.

[35] J. Raymond, J. H. Kihedu, and C. Z. M. Kimambo, 'A Model for Sustainable Adoption of Solar Photovoltaic Technology in Tanzania', *Tanzania Journal of Engineering and Technology*, vol. 41, no. 2, pp. 16–34, Jun. 2022, doi: 10.52339/tjet.v41i2.776.

[36] C. F. Chen, K. Tomsovic, and M. Aydeniz, 'Filling the pipeline: Power system and energy curricula for middle and high school students through summer programs', *IEEE Transactions on Power Systems*, vol. 29, no. 4, pp. 1874–1879, 2014, doi: 10.1109/TPWRS.2013.2293752.

[37] R. Palma-Behnke *et al.*, 'Lowering Electricity Access Barriers by Means of Participative Processes Applied to Microgrid Solutions: The Chilean Case', *Proceedings of the IEEE*, vol. 107, no. 9, pp. 1857–1871, 2019, doi: 10.1109/JPROC.2019.2922342.

[38] A. M. S. Alonso *et al.*, 'Experimental Implementation of a Single-Phase Microgrid: A Flexible Resource for Research and Educational Activities', in *2021 Brazilian Power Electronics Conference, COBEP 2021*, IEEE, 2021. doi: 10.1109/COBEP53665.2021.9684053.

[39] C. Murtagh, O. Mihirig, Y. Gonzalez, A. Palizban, and K. Manson, 'Educational microgrid - A microgrid training platform and emulator', in *2016 IEEE Electrical Power and Energy Conference (EPEC)*, Ottawa, ON, Canada: IEEE, 2016, pp. 1–5. doi: 10.1109/EPEC.2016.7771792.

[40] L.-L. Ebidor and I. G. Ikhide, 'Literature Review in Scientific Research: An Overview', *East African Journal of Education Studies*, vol. 7, no. 2, pp. 211–218, May 2024, doi: 10.37284/eajes.7.2.1909.

[41] S. Ahmad Dar and P. Sakhtivel, 'Review of Literature is Foundation and Blood of Research', *International Journal of Management Practice and Commerce*, vol. 1, no. 1, pp. 21–26, Jun. 2022, doi: 10.55083/cct.ijmpc.2022.v01i01008.

[42] T. Bin Nadeem, M. Siddiqui, M. Khalid, and M. Asif, 'Distributed energy systems: A review of classification, technologies, applications, and policies', *Energy Strategy Reviews*, vol. 48, pp. 1–23, Jul. 2023, doi: 10.1016/j.esr.2023.101096.

[43] L. Fusheng, L. Ruisheng, and Z. Fengquan, 'Microgrid and distributed generation', in *Microgrid Technology and Engineering Application,* Elsevier Inc., 2016, ch. 3, pp. 29–46. doi: 10.1016/B978-0-12-803598-6/00003-6.

[44] C. Greacen, R. Engel, and T. Quetchenbach, *A Guidebook on Grid Interconnection and Islanded Operation of Mini--Grid Power Systems Up to 200 kW*. 2013. Accessed: Nov. 20, 2023. [Online]. Available: https://eta-publications.lbl.gov/sites/default/files/a_guidebook_for_minigrids-serc_lbnl_march_2013.pdf

[45] IRENA, 'Off-grid renewable energy systems: Status and methodological issues', Abu Dhabi, United Arab Emirates, 2015.

[46] S. C. Bhattacharyya, 'Mini-grids for the base of the pyramid market: A critical review', *Energies (Basel)*, vol. 11, no. 4, Apr. 2018, doi: 10.3390/en11040813.

[47] J. Cloke, A. Mohr, and E. Brown, ‘Imagining renewable energy: Towards a Social Energy Systems approach to community renewable energy projects in the Global South’, *Energy Res Soc Sci*, vol. 31, pp. 263–272, Sep. 2017, doi: 10.1016/j.erss.2017.06.023.

[48] O. O. Babayomi *et al.*, ‘A review of renewable off-grid mini-grids in Sub-Saharan Africa’, *Front Energy Res*, vol. 10, pp. 1–30, Jan. 2023, doi: 10.3389/fenrg.2022.1089025.

[49] R. Metcalf and P. Zakkour, ‘Geothermal projects in East Africa - full steam ahead?’ Accessed: Nov. 16, 2023. [Online]. Available: https://www.nortonrosefulbright.com/en/knowledge/publications/ed7d5a3e/geothermal-projects-in-east-africa---full-steam-ahead#:~:text=Typical%20costs%20for%20geothermal%20power,of%20US%2490%2D150%20million.

[50] IRENA, ‘Renewable Power Generation Costs in 2020’, *International Renewable Energy Agency*, 2021, [Online]. Available: www.irena.org

[51] C. Vezzoli *et al.*, *Designing Sustainable Energy for All*. Cham, Switzerland: Springer International Publishing AG, 2018. doi: https://doi.org/10.1007/978-3-319-70223-0.

[52] MEM, ‘Sustainable Energy for All: Rapid Assessment and Gap Analysis’, Dodoma, May 2013. Accessed: Nov. 23, 2023. [Online]. Available: https://www.se4all-africa.org/fileadmin/uploads/se4all/Documents/Country_RAGAs/Tanzania_RAGA_EN_Released.pdf

[53] J. Ngungui and R. Maina, ‘East Africa Climatic Data and Guidelines for Bioclimatic Architectural Design’, Nairobi GPO Kenya, 2016.

[54] D. N. Katongole, K. Nyeinga, D. Okello, D. Mukiibi, J. Mubiru, and Y. Kisira, ‘Spatial and Temporal Solar Potential Variation Analysis in Uganda Using Measured Data’, *Tanzania Journal of Science*, vol. 49, no. 1, pp. 1–14, Mar. 2023, doi: 10.4314/tjs.v49i1.1.

[55] V. Mukoro, M. Sharmina, and A. Gallego-Schmid, ‘A review of business models for access to affordable and clean energy in Africa: Do they deliver social, economic, and environmental value?’, *Energy Res Soc Sci*, vol. 88, Jun. 2022, doi: 10.1016/j.erss.2022.102530.

[56] J. P. Ihirwe *et al.*, ‘Solar PV Minigrid Technology: Peak Shaving Analysis in the East African Community Countries’, *International Journal of Photoenergy*, vol. 2021, 2021, doi: 10.1155/2021/5580264.

[57] UNDP, ‘Delivering Sustainable Energy in a Changing Climate: Strategy Note on Sustainable Energy’, 2016. Accessed: Nov. 28, 2023. [Online]. Available: https://www.undp.org/publications/undps-energy-strategy

[58] IRENA and AfDB, ‘Renewable Energy Market Analysis: Africa and its Regions - A Summary for Policy Makers’, Abu Dhabi and Abidjan, 2022. Accessed: Nov. 23, 2023. [Online]. Available: https://www.irena.org/Publications/2022/Jan/Renewable-Energy-Market-Analysis-Africa

[59] KfW Development Bank, GIZ, and IRENA, ‘The Renewable Energy Transition in Africa: Powering Access, Resilience and Prosperity’, Frankfurt am Main, Eschborn, and Abu Dhabi, Jan. 2020.

[60] Associated Press (Berlin), ‘Germany pledges to invest 4 billion euros in energy projects in Africa’. Accessed: Nov. 21, 2023. [Online]. Available: https://apnews.com/article/germany-g20-compact-africa-green-energy-investment-dfd9e54ee108758bc22a8ce8e842a910

[61] African Solar Design, CIRCODU, and REN21, ‘EAC Renewable Energy and Energy Efficiency - Regional Status Report’, Nairobi, Kampala, and Paris, 2016.

[62] U. E. Hansen, M. B. Pedersen, and I. Nygaard, ‘Review of Solar PV Market Development in East Africa’, APA, Copenhagen, 2014. [Online]. Available:

http://www.uneprisoe.org/~/media/Sites/Uneprisoe/Working%20Papers/Working%20paper%20Solar%20PV%20East%20Africa.ashx

[63] MEM, 'Tanzania's SE4ALL Action Agenda', Dodoma, Dec. 2015. Accessed: Nov. 23, 2023. [Online]. Available: https://www.seforall.org/sites/default/files/TANZANIA_AA-Final.pdf

[64] MEMD, 'Energy and Mineral Development Sector Development Plan', Kampala, Jun. 2015. Accessed: Nov. 23, 2023. [Online]. Available: http://npa.go.ug/wp-content/uploads/2018/01/Energy-Sector-Development-plan-Final.pdf

[65] L. Argote and P. Ingram, 'Knowledge Transfer: A Basis for Competitive Advantage in Firms', *Organ Behav Hum Decis Process*, vol. 82, no. 1, pp. 150–169, 2000.

[66] Y. Demchenko, V. Degeler, A. Opresu, and S. Brewer, 'Professional and 21st Century Skills for Data Driven Digital Economy', in *IEEE Global Engineering Education Conference, EDUCON*, IEEE Computer Society, 2023. doi: 10.1109/EDUCON54358.2023.10125263.

[67] J. Kang, M. Rhee, and K. H. Kang, 'Revisiting knowledge transfer: Effects of knowledge characteristics on organizational effort for knowledge transfer', *Expert Syst Appl*, vol. 37, no. 12, pp. 8155–8160, 2010, doi: 10.1016/j.eswa.2010.05.072.

[68] J. Lilian Ogendo, *Exploring the Integration of Knowledge Transfer and Strategy for Sustainable Performance*. Springer Nature, 2017. doi: 10.1007/978-3-319-52036-0.

[69] C. C. van Waveren, L. A. G. Oerlemans, and M. W. Pretorius, 'Knowledge Transfer in Project-based Organizations. A Conceptual Model for Investigating Knowledge Type, Transfer Mechanisms and Transfer Success', in *IEEE International Conference on Industrial Engineering and Engineering Management*, Petaling Jaya, Malaysia: IEEE, Dec. 2014, pp. 1176–1181.

[70] T. J. Nokes, 'Mechanisms of knowledge transfer', *Think Reason*, vol. 15, no. 1, pp. 1–36, Feb. 2009, doi: 10.1080/13546780802490186.

[71] M. Nissen, M. Kamel, and K. Sengupta, 'Integrated Analysis and Design of Knowledge Systems and Process', *Information Resources Management Journal*, vol. 13, no. 1, pp. 24–43, 2000, [Online]. Available: http://hdl.handle.net/10945/52646

[72] J. Ihlström and F. Westerlund, *Interactive learning environments: The effects of interactivity in online learning environments*. 2013. doi: 10.1080/10494820.2012.675739.

[73] M. Moallem, 'Applying Constructivist and Objectivist Learning Theories in the Design of A Web-Based Course : Implications for Practice', *Educational Technology & Society*, vol. 4, no. 3, 2001.

[74] M. Ouadoud, A. Nejjari, M. Y. Chkouri, and K. E. El-Kadiri, 'Learning Management System and the Underlying Learning Theories', in *Proceedings of the mediterranean symposium on smart city applications*, M. Ben Ahmed and A. A. Boudhir, Eds., Springer, Cham, 2018, pp. 732–744. doi: 10.1007/978-3-319-74500-8.

[75] R. N. Kibuku and D. O. Ochieng, 'Contributions and Shortcomings of Classical Learning Theories as Applied to E-Learning: A Literature Review', in *2019 IST-Africa Week Conference (IST-Africa 2019)*, Nairobi, Kenya: IEEE, 2019, pp. 1–10. doi: 10.23919/ISTAFRICA.2019.8764886.

[76] B. Z. M. Nyembe and G. R. Howard, 'The Utilities of Prominent Learning Theories for Mobile Collaborative Learning (MCL) with Reference to WhatsApp and M-learning', in *2019 - 2nd International Conference on Advances in Big Data, Computing and Data Communication Systems (icABCD)*, Winterton, South Africa: IEEE, 2019. doi: 10.1109/ICABCD.2019.8851042.

[77] G. M. Kundi and A. Nawaz, 'From Objectivism to Social Constructivism: The Impacts of Information and Communication Technologies (ICTs) on Higher Education', *Journal of Science and Technology Education Research*, vol. 1, no. 2, pp. 30–36, 2010.

[78] J. Cronjé, ‘Paradigms Regained: Toward Integrating Objectivism and Constructivism in Instructional Design and the Learning Sciences’, *Educational Technology Research and Development*, vol. 54, no. 4, pp. 387–416, 2006.

[79] D. H. . Schunk, *Learning Theories: An Educational Perspective*, 6th ed. Pearson, 2012.

[80] S. O. Bada, ‘Constructivism: A Paradigm for Teaching and Learning’, *IOSR Journal of Research & Method in Education (IOSR-JRME)*, vol. 5, no. 6, 2015, doi: 10.4172/2151-6200.1000200.

[81] L. S. Vygotsky, *Mind in Society: The Development of Higher Psychological Processes*. 1978.

[82] T. Fani and F. Ghaemi, ‘Implications of Vygotsky’s Zone of Proximal Development (ZPD) in Teacher Education: ZPTD and Self-scaffolding’, *Procedia Soc Behav Sci*, vol. 29, pp. 1549–1554, 2011, doi: 10.1016/j.sbspro.2011.11.396.

[83] K. Shaban, M. Khatib, and S. Ebadi, ‘Vygotsky’s Zone of Proximal Development: Instructional Implications and Teachers’ Professional Development’, *English Language Teaching*, vol. 3, no. 4, pp. 237–248, 2010, doi: 10.4028/www.scientific.net/AMM.411-414.2952.

[84] L. S. Ni, J. J. Ya, and Z. Jing, ‘Organization of Online Chinese Teaching Activities in Township Primary Schools during the Epidemic: A Case Study Based on Activity Theory’, in *Proceedings - 2020 International Conference on Artificial Intelligence and Education, (ICAIE 2020)*, Tianjin, China: IEEE, 2020, pp. 220–224. doi: 10.1109/ICAIE50891.2020.00058.

[85] S. S. Liaw, M. Hatala, and H. M. Huang, ‘Investigating acceptance toward mobile learning to assist individual knowledge management: Based on activity theory approach’, *Comput Educ*, vol. 54, no. 2, pp. 446–454, 2010, doi: 10.1016/j.compedu.2009.08.029.

[86] D. Ashton *et al.*, *Working to learn: transforming learning in the workplace*. Kogan Page Ltd, 2002.

[87] L. Uden, ‘Activity theory for designing mobile learning’, *International Journal of Mobile Learning and Organisation*, vol. 1, no. 1, pp. 81–102, 2007, doi: 10.1504/IJMLO.2007.011190.

[88] Y. Engeström, ‘Expansive Learning at Work: Toward an activity theoretical reconceptualization’, *Journal of Education and Work*, vol. 14, no. 1, pp. 133–156, 2001, doi: 10.1080/13639080020028747.

[89] B. Youngkwon, L. Jinsook, and L. Taewuk, ‘Work in progress - A study on educational computer games for e-Learning based on activity theory’, in *Proceedings - Frontiers in Education 35th Annual Conference, FIE*, Indianopolis, IN, USA: IEEE, 2005, pp. 27–28. doi: 10.1109/fie.2005.1612004.

[90] J. Yeo, S.-C. Tan, and Y.-J. Lee, ‘A Learning Journey in Problem-based Learning in a Physics Classroom’, *The Asia-Pacific Education Researcher*, vol. 21, no. 1, pp. 39–50, 2012.

[91] N. N. Nurdin and B. P. Uleng, ‘The Implementation of Problem-based Learning Activity through Online School Field Practice’, *Jurnal Ilmiah Global Education*, vol. 4, no. 1, pp. 111–117, 2023.

[92] S. C. Komba and M. Mwandaji, ‘Reflections on the Implementation of Competence Based Curriculum in Tanzanian Secondary Schools’, *Journal of Education and Learning*, vol. 4, no. 2, May 2015, doi: 10.5539/jel.v4n2p73.

[93] M. Ismail, T. Shavega, and J. Kigobe, ‘Implementation of competence-based teaching and learning in pre-primary schools in Tanzania’, *International Journal of Research Studies in Education*, vol. 13, no. 1, Apr. 2024, doi: 10.5861/ijrse.2024.24010.

[94] M. A. Tambwe, ‘Challenges Facing the Implementation of a Competency-Based Education and Training (CBET) System in Tanzanian Technical Institutions’, *Education Research Journal*, vol. 7, no. 11, pp. 277–283, May 2017, doi: 10.2307/j.ctvh8r02h.24.

[95] B. Namaalwa, J. Bweyale, and O. Mugula, ‘The Stakeholders’ Attitudes on the Transition from Knowledge-Based Curriculum (KBC) to a Competence-Based Curriculum (CBC) in Selected Secondary

Schools in Kampala District', *International Journal of Innovative Science and Research Technology (IJISRT)*, pp. 88–100, Mar. 2024, doi: 10.38124/ijisrt/IJISRT24MAR105.

[96] J. McKenzie-White *et al.*, 'Evaluation of a competency based medical curriculum in a Sub-Saharan African medical school', *BMC Med Educ*, vol. 22, no. 1, pp. 1–9, Dec. 2022, doi: 10.1186/s12909-022-03781-1.

[97] I. M. Okumu and E. Bbaale, 'Technical and vocational education and training in Uganda: A critical analysis', *Development Policy Review*, vol. 37, no. 6, pp. 735–749, Nov. 2019, doi: 10.1111/dpr.12407.

[98] Inter-University Council for East Africa, 'East African Qualifications Framework For Higher Education', 2015.

[99] Tanzania Commission for Universities, 'University Qualifications Framework', 2012.

[100] Uganda National Council for Higher Education, 'The Uganda Higher Education Qualifications Framework (UHEQF)', Kampala, Uganda, 2016.

[101] C. Ruth, 'The Role of Competency in Curbing Youth Unemployment: Competency-based Curriculum Approach', *Shanlax International Journal of Education*, vol. 8, no. 4, pp. 33–37, Sep. 2020, doi: 10.34293/education.v8i4.3343.

[102] H. Onderi, J. Ajowi, and G. Malala, 'Restructuring Technical and Vocational Education and Training (TVET) For Sustainable Development in Sub-Saharan Africa', *International Journal of Interdisciplinary Research and Innovations*, vol. 2, no. 1, pp. 40–45, 2014, [Online]. Available: www.researchpublish.com

[103] J. Oola, D. K. Olema, D. Z. Atibuni, and D. Omara, 'Enabling and Impeding Factors in the Provision of Business, Vocational, Entrepreneurship, and Technical Training Education under COVID-19', *Asian Journal of Education and Social Studies*, vol. 42, no. 2, pp. 48–57, Apr. 2023, doi: 10.9734/ajess/2023/v42i2913.

[104] A. J. Onwuegbuzie and N. L. Leech, 'On Becoming a Pragmatic Researcher: The Importance of Combining Quantitative and Qualitative Research Methodologies', *International Journal of Social Research Methodology: Theory and Practice*, vol. 8, no. 5, pp. 375–387, Dec. 2005, doi: 10.1080/13645570500402447.

[105] J. Pool and D. Laubscher, 'Design-based research: is this a suitable methodology for short-term projects?', *EMI Educ Media Int*, vol. 53, no. 1, pp. 42–52, 2016, doi: 10.1080/09523987.2016.1189246.

[106] T. Amiel and T. C. Reeves, 'Design-Based Research and Educational Technology: Rethinking Technology and the Research Agenda', *J Educ Techno Soc*, vol. 11, no. 4, pp. 29–40, 2008, doi: 10.2307/jeductechsoci.11.4.29.

[107] J. Shattuck and T. Anderson, 'Using a Design-Based Research Study to Identify Principles for Training Instructors to Teach Online', *International Review of Research in Open and Distance Learning*, vol. 14, no. 5, pp. 186–210, 2013, doi: 10.19173/irrodl.v14i5.1626.

[108] C. Hoadley and F. C. Campos, 'Design-based research: What it is and why it matters to studying online learning', *Educ Psychol*, vol. 57, no. 3, pp. 207–220, 2022, doi: 10.1080/00461520.2022.2079128.

[109] J. van den Akker *et al.*, *Educational Design Research*. London and New York: Routledge, 2006. [Online]. Available: https://www.researchgate.net/publication/285854675

[110] E. F. R. Kartika, S. V. Elfi, and N. Y. Indriyanti, 'Development and Validation of Web-based STEAM Online Platform to Improve Learning Quality in Pre-service Chemistry Teachers', *J Technol Sci Educ*, vol. 11, no. 2, pp. 513–525, 2021, doi: 10.3926/JOTSE.1316.

[111] F. Wang and M. J. Hannafin, 'Design-Based Research and Technology-Enhanced Learning Environments', *Educational Technology Research and Development*, vol. 53, no. 4, pp. 5–23, 2005.

[112] S. McKenney and T. C. Reeves, ‘Educational design research: Portraying, conducting, and enhancing productive scholarship’, *Med Educ*, vol. 55, no. 1, pp. 82–92, Jan. 2021, doi: 10.1111/medu.14280.

[113] S. McKenney and T. C. Reeves, *Conducting Educational Design Research*, 2nd ed. London and New York : Routledge, Taylor & Francis Group, 2019. Accessed: May 17, 2024. [Online]. Available: https://www.taylorfrancis.com/books/mono/10.4324/9781315105642/conducting-educational-design-research-susan-mckenney-thomas-reeves

[114] S. McKenney and T. C. Reeves, *Conducting Educational Design Research*. London and New York: Routledge, Taylor & Francis Group, 2012.

[115] T. Muzari, G. Nevers Shava, and S. Shonhiwa, ‘Qualitative Research Paradigm, a Key Research Design for Educational Researchers, Processes and Procedures: A Theoretical Overview’, *Indiana Journal of Humanities and Social Sciences*, vol. 3, no. 1, pp. 14–20, 2022, [Online]. Available: https://indianapublications.com/Journals/IJHSS

[116] G. T. Owen, ‘Qualitative Methods in Higher Education Policy Analysis: Using Interviews and Document Analysis’, *The Qualitative Report*, vol. 19, pp. 1–19, 2014, [Online]. Available: http://www.nova.edu/ssss/QR/QR19/owen52.pdf

[117] G. A. Bowen, ‘Document Analysis as a Qualitative Research Method’, *Qualitative Research Journal*, vol. 9, no. 2, pp. 27–40, 2009, doi: 10.3316/QRJ0902027.

[118] D. N. Caulley, ‘Document Analysis in Program Evaluation’, *Eval Program Plann*, vol. 6, pp. 19–29, 1983.

[119] M. Dixon-Woods, S. Agarwal, D. Jones, B. Young, and A. Sutton, ‘Synthesising qualitative and quantitative evidence: a review of possible methods’, *J Health Serv Res Policy*, vol. 10, no. 1, pp. 45–53, 2005, [Online]. Available: http://www.ingentaselect.com/rpsv/cw/rsm/13558196/

[120] N. Amir, F. Jabeen, and S. Niaz, ‘A Brief Review of Conditions, Circumstances and Applicability of Sampling Techniques in Computer Science Domain’, in *Proceedings - 2020 23rd IEEE International Multi-Topic Conference, INMIC 2020*, Institute of Electrical and Electronics Engineers Inc., Nov. 2020. doi: 10.1109/INMIC50486.2020.9318209.

[121] E. de O. da Costa, F. Fabris, A. R. Loureiros, H. Ahonen, F. M. Varejao, and R. M. Ferro, ‘Using GA for the Stratified Sampling of Electricity Consumers’, in *2013 IEEE Congress on Evolutionary Computation*, Cancum, Mexico: IEEE, 2013, pp. 261–268.

[122] D. Lakens, ‘Sample Size Justification’, *Collabra Psychol*, vol. 8, no. 1, pp. 1–28, Mar. 2022, doi: 10.1525/collabra.33267.

[123] S. E. Harpe, ‘How to analyze Likert and other rating scale data’, *Curr Pharm Teach Learn*, vol. 7, no. 6, pp. 836–850, Nov. 2015, doi: 10.1016/j.cptl.2015.08.001.

[124] D. Douglas, ‘Inductive theory generation: A grounded approach to business inquiry’, *Electronic Journal of Business Research Methods*, vol. 2, no. 1, pp. 47–54, 2003, [Online]. Available: http://www.ejbrm.com

[125] U. Kuckartz, ‘Qualitative Text Analysis: A Systematic Approach’, in *Compendium for Early Career Researchers in Mathematics Education*, G. Kaiser and N. Presmeg, Eds., Springer Open, 2019, ch. 8, pp. 181–197. doi: 10.1007/978-3-030-15636-7_8.

[126] S. R. Sheikh, H. Sheikh, and Z. U. Koreshi, ‘Emerging smart community concept and microgrid technology - a study of lagging skill development in Pakistan’, *International Journal of Training Research*, vol. 17, no. sup1, pp. 170–181, Jul. 2019, doi: 10.1080/14480220.2019.1639288.

[127] Coursera for campus, ‘Curriculum Mapping for Student Employability - Advance Campus Curriculum with Blended Learning Curations’, 2021.

[128] IRENA and ILO, ‘Renewable Energy and Jobs: Annual Review 2022’, 2022. [Online]. Available: www.irena.org

[129] IEA, ‘World Energy Employment 2023’, Paris, 2023. Accessed: Aug. 15, 2024. [Online]. Available: https://www.iea.org/reports/world-energy-employment-2023

[130] S. Huckstep and H. Dempster, ‘Meeting Skill Needs for the Global Green Transition: A Role for Labour Migration?’, Washington, DC, 2024. Accessed: Aug. 15, 2024. [Online]. Available: https://www.cgdev.org/publication/meeting-skill-needs-global-green-transition-role-labour-migration

[131] International Labour Office and European Union, ‘Skills and Occupational Needs in Renewable Energy’, 2011.

[132] International Labour Organization, ‘Skills for Green Jobs in Uganda’, Turin, Italy, 2018.

[133] H. Chai, M. Priestley, X. Tang, and J. Ravishankar, ‘Implementation of microgrid virtual laboratory in a design course in electrical engineering’, in *Proceedings of 2020 IEEE International Conference on Teaching, Assessment, and Learning for Engineering, TALE 2020*, Institute of Electrical and Electronics Engineers Inc., Dec. 2020, pp. 509–515. doi: 10.1109/TALE48869.2020.9368350.

[134] L. R. Lattuca, P. T. Terenzini, and J. F. Volkwein, ‘Engineering Change - A Study of the Impact of EC2000’, Mar. 2006. [Online]. Available: http://www.abet.org/wp-content/uploads/2015/04/EngineeringChange-executive-summary.pdf

[135] Tanzania Commission for Universities, ‘Handbook for Standards and Guidelines for University Education in Tanzania’, 2019.

[136] R. Trivedi and S. Khadem, ‘Implementation of artificial intelligence techniques in microgrid control environment: Current progress and future scopes’, *Energy and AI*, vol. 8, pp. 1–19, May 2022, doi: 10.1016/j.egyai.2022.100147.

[137] L. W. Anderson *et al.*, *A Taxonomy for Learning, Teaching, and Assessing - A Revision of Bloom’s Taxonomy of Educational Objectives*. Addison Wesley Longman, Inc., 2001.

[138] A. Belov, ‘Development, implementation and evaluation of microgrids course materials for secondary school learners’, Masters, Paderborn University, 2023.

[139] Elfizon, M. Muskhir, and Asnil, ‘Development of Industrial Electrical Installation Trainer Nuanced to Training within Industry for Students of Electrical Industrial Engineering Universitas Negeri Padang’, *J Phys Conf Ser*, vol. 1165, no. 1, Mar. 2019, doi: 10.1088/1742-6596/1165/1/012014.

[140] N. D. Bard *et al.*, ‘Development and content validation of a course in mental health nursing care’, *Rev Gaucha Enferm*, vol. 44, pp. 1–11, 2023, doi: 10.1590/1983-1447.2023.20210294.en.

[141] M. N. Bittencourt, R. dos S. Flexa, I. S. R. Santos, L. D. Ferreira, C. R. B. Nemer, and J. L. da C. Pena, ‘Validation of content and appearance of an educational manual to promote children’s mental health’, *Rev Rene*, pp. 1–8, 2020.

[142] N. A. El-Sayed, N. M. Eid, and Z. M. Rashad, ‘Designing and validating nursing care standards at National Liver Institute Hospital’, *Menoufia Nursing Journal (MNJ)*, vol. 6, no. 2, pp. 183–193, Nov. 2021, [Online]. Available: https://menj.journals.ekb.eg

[143] P. Bogere, A. Belov, and K. Temmen, ‘Teaching and Learning of Microgrids for Secondary School Learners – a Renewable Energy Sustainability Strategy for East African Communities’, in *First International Conference on Sustainable Energy Education (SEED 2024)*, E. de la P. Plaza, A. Blázquez-Soriano, R. Wang, and A. Sereni, Eds., Valencia, Spain: Editorial Universitat Politècnica de València, Jul. 2024, pp. 128–136. doi: 10.4995/SEED2024.2024.19007.

[144] M. Kipli and A. Z. Khairani, 'Content Validity Index: An Application of Validating CIPP Instrument for Programme Evaluation', *IOER International Multidisciplinary Research Journal*, vol. 2, no. 4, pp. 31–40, 2020, [Online]. Available: https://orcid.org/0000-0002-9330-4067

[145] M. Suhaini, A. Ahmad, and N. M. Bohari, 'Assessments on vocational knowledge and skills: A content validity analysis', *European Journal of Educational Research*, vol. 10, no. 3, pp. 1529–1540, Jul. 2021, doi: 10.12973/EU-JER.10.3.1529.

[146] D. R. Krathwohl, 'A Revision of Bloom's Taxonomy: An Overview', *Theory Pract*, vol. 41, no. 4, pp. 212–219, 2002.

[147] L. Owen Wilson, 'Bloom' s Taxonomy Revised', 2016.

[148] J. Biggs and C. Tang, *Teaching for quality learning at university*, 3rd ed. New York: Open University Press, 2007.

[149] M. D. Engelhart, E. J. Furst, W. H. Hill, and D. R. Krathwohl, *Taxonomy of Educational Objectives: The Classification of Educational Goals. Handbook 1 Cognitive domain*. New York: David McKay Company, Inc., 1956.

[150] D. R. Krathwohl, B. S. Bloom, and B. B. Masia, *Taxonomy of Educational Objectives: The classification of educational goals. Handbook II: Affective domain*. New York: David McKay Company, 1964.

[151] A. Sideeg, 'Bloom's Taxonomy, Backward Design, and Vygotsky's Zone of Proximal Development in Crafting Learning Outcomes', *International Journal of Linguistics*, vol. 8, no. 2, pp. 158–186, Apr. 2016, doi: 10.5296/ijl.v8i2.9252.

[152] A. Jordan, O. Carlile, and A. Stack, *Approaches to Learning: A guide for teachers*. Open University Press, 2008.

[153] V. Thurner and A. Böttcher, 'Designing an Architecture for Structuring Didactic Concepts, Methods and Tools', in *ICL2021 - 24th International Conference on Interactive Collaborative Learning*, Dresden, Germany, 2021, pp. 864–875.

[154] H. Asiimwe, H. Bode, P. Bogere, C. Freitag, and T. Mangeni, 'Which Media for Whom? The Implementation of Microgrids as a Trigger of Transformational Adult Learning Opportunities in Formal, Informal and Situational Settings in Times of Change', in *Educational Media for Adults*, E. Andrzejewska, E. Matthes, S. Schütze, and J. Van Wiele, Eds., Bad Heilbrunn: Verlag Julius Klinkhardt, 2024, pp. 245–255. doi: doi.org/10.35468/6126-18.

[155] K. R. Khan, M. M. Haque, D. Sachdeva, and M. B. K. Morgan, 'A campus microgrid used as an active learning tool for new generation of electrical power engineers', *International Journal of Electrical Engineering and Education*, vol. 59, no. 4, pp. 1–22, Oct. 2019, doi: 10.1177/0020720919837865.

[156] P. Bogere, H. Bode, and K. Temmen, 'Work-In-Progress: Development of a Virtual and Interactive Microgrids Learning Environment for Microgrids Sustainability – The Case of East Africa', in *Learning in the Age of Digital and Green Transition. ICL 2022. Lecture Notes in Networks and Systems*, M. E. Auer, W. Pachatz, and T. Rüütmann, Eds., Switzerland: Springer Nature, 2023, pp. 671–679.

[157] B. Özer, V. Duran, and M. Tekke, 'Training of trainers: An action-based research for improving the pedagogical skills of academicians', *International Journal of Evaluation and Research in Education*, vol. 9, no. 3, pp. 704–715, 2020, doi: 10.11591/ijere.v9i3.20327.

[158] R. Durrani, H. A. Akram, and S. Kanwal, 'Educating Dropouts in Rural Areas: Capacity Building of Teacher Trainers', *Global Educational Studies Review*, vol. VI, no. IV, pp. 64–72, Dec. 2021, doi: 10.31703/gesr.2021(vi-iv).07.

[159] N. T. Nukitrangsan and K. Chomsuwan, 'Work in Progress: Design and Development of Skill Mapping Focusing on Skills and Competencies Improvement for Factory Electricians: A Case Study in Glass Bottle

Beverage Factory', in *IEEE Global Engineering Education Conference, EDUCON*, IEEE, 2023. doi: 10.1109/EDUCON54358.2023.10125226.

[160] P. Bogere and K. Temmen, 'A Didactic Framework for Microgrids Knowledge Transfer – The Case of East Africa', in *2024 IEEE Global Engineering Education Conference (EDUCON)*, Kos Island, Greece: IEEE, May 2024, pp. 1–5. doi: 10.1109/EDUCON60312.2024.10578914.

[161] Stellenbosch University, 'Taxonomies of Learning Domains: Activities at Various Cognitive Levels of Learning (LoL)'. Accessed: Apr. 06, 2024. [Online]. Available: https://www.sun.ac.za/english/learning-teaching/ctl/Documents/Summary%20of%20all%20domains.pdf

[162] University of North Texas - Health Science Center, 'Verb list for writing educational objectives'. Accessed: Apr. 06, 2024. [Online]. Available: https://www.unthsc.edu/center-for-innovative-learning/wp-content/uploads/sites/35/verbs_checklist.pdf

[163] UNESCO, 'The ABCDs of Writing Instructional Objectives'. Accessed: Apr. 06, 2024. [Online]. Available: https://unevoc.unesco.org/e-forum/ActionVerbsforObjectives.pdf

[164] Tanzania Commission for Universities, 'Procedures for Programme Accreditation'. Accessed: Oct. 21, 2022. [Online]. Available: https://www.tcu.go.tz/sites/default/files/Procedures%20for%20prog%20Accreditation.pdf

[165] Tanzania Commission for Universities, 'Curriculum Development Framework for all Levels of University Education in Tanzania (UQF 6 -10)', Nov. 2021. Accessed: Oct. 20, 2022. [Online]. Available: https://pms.tcu.go.tz/CURRICULUM%20DEVELOPMENT%20FRAMEWORK,%20November%202021-FINAL%203.12.2021.pdf

[166] National Council for Higher Education, *The Universities and Other Tertiary Institutions (Grading and Classification of Undergraduate Degrees and Diplomas) Regulations, 2015.* Uganda, 2015.

[167] National Council for Higher Education, 'Quality Assurance Framework for Universities and the Licensing Process for Higher Education Institutions', 2014.

[168] UDSM, 'Criteria for Establishing Departments'. Accessed: Aug. 19, 2024. [Online]. Available: https://www.udsm.ac.tz/web/index.php/schools/sol/udsm-criteria-for-establishing-departments

[169] G. W. Kasule and R. Bisaso, 'Integration of Strategic Human Resource Management for Efficiency in Uganda Public Universitie', *West East Journal of Social Sciences*, vol. 8, pp. 122–132, 2019.

[170] E. F. Kipesha and R. Msigwa, 'Efficiency of Higher Learning Institutions: Evidences from Public Universities in Tanzania', *Journal of Education and Practice*, vol. 4, no. 7, pp. 63–72, 2013, [Online]. Available: https://www.researchgate.net/publication/236590423

[171] D. Strickland, L. Jenkins, S. Luke, J. Andrews, and B. Wood, 'Electrical Power Systems Education for Employment', in *2017 52nd International Universities Power Engineering Conference (UPEC)*, Heraklion, Greece: IEEE, Aug. 2017, pp. 1–6.

[172] L. Patricia Vega-garzon, P. Mauricio Acosta, H. Avella, and Y. Alejandra Castro Ortegon, 'Comparing trends, challenges and opportunities for renewable energies implementation at universities in the world: A review', *International Journal of Renewable Energy Sources*, vol. 6, pp. 43–57, 2021, [Online]. Available: http://www.iaras.org/iaras/journals/ijres

[173] M. Kabalan *et al.*, 'Commissioning a Real-World Industry-Grade Microgrid with Undergraduate and Graduate Students: An Educational Experience', in *2021 North American Power Symposium, NAPS 2021*, Institute of Electrical and Electronics Engineers Inc., 2021. doi: 10.1109/NAPS52732.2021.9654730.

[174] F. Martin and J. Borup, 'Online learner engagement: Conceptual definitions, research themes, and supportive practices', *Educ Psychol*, vol. 57, no. 3, pp. 162–177, 2022, doi: 10.1080/00461520.2022.2089147.

[175] R. M. WALLACE, 'Online Learning in Higher Education: a review of research on interactions among teachers and students', *Education, Communication & Information*, vol. 3, no. 2, pp. 241–280, Jul. 2003, doi: 10.1080/14636310303143.

[176] S. Kucuk and J. C. Richardson, 'A structural equation model of predictors of online learners' engagement and satisfaction', *Online Learning Journal*, vol. 23, no. 2, pp. 196–216, Jun. 2019, doi: 10.24059/olj.v23i2.1455.

[177] Å. Grönlund and Y. M. Islam, 'A mobile e-learning environment for developing countries: The Bangladesh Virtual Interactive Classroom', *Inf Technol Dev*, vol. 16, no. 4, pp. 244–259, 2010, doi: 10.1080/02681101003746490.

[178] J. F. Araújo, R. T. Guimarães, C. A. Silva, and H. D. Silva, 'Virtual Environment for Assisting Learning of Residential Electrical Installations', *IEEE Revista Iberoamericana de Tecnologias del Aprendizaje*, vol. 19, pp. 45–50, 2024, doi: 10.1109/RITA.2024.3368362.

[179] J. F. Araújo, L. M. R. Sales, C. A. Silva, and H. D. Silva, 'Virtual Environment for Teaching and Learning in Residential Electrical Installations Projects', *IEEE Revista Iberoamericana de Tecnologias del Aprendizaje*, vol. 19, pp. 39–44, 2024, doi: 10.1109/RITA.2024.3368368.

[180] B. Hasan, Y. Al-Quorashy, S. Al-Mousa, Y. Al-Sahhaf, and M. El-Abd, 'V-LAB - The Virtual Electric Machines Laboratory', in *IEEE Global Engineering Education Conference (EDUCON)*, Porto, Portugal: IEEE Xplore, 2020, pp. 72–77. doi: 10.1109/EDUCON45650.2020.9125349.

[181] M. Alptekin and K. Temmen, 'Teaching an Oscilloscope through Progressive Onboarding in an Augmented Reality Based Virtual Laboratory', in *IEEE Global Engineering Education Conference (EDUCON)*, Dubai, UAE.: IEEE Xplore, 2019, pp. 1047–1054.

[182] R. Costa, F. Perola, and C. Felgueiras, 'µLAB A remote laboratory to teach and learn the ATmega328p µC', in *IEEE Global Engineering Education Conference (EDUCON)*, Porto, Portugal: IEEE Xplore, 2020, pp. 12–13. doi: 10.1109/EDUCON45650.2020.9125336.

[183] J. Weimer *et al.*, 'A Virtual Laboratory for Micro-Grid Information and Communication infrastructures', in *3rd IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT Europe)*, Berlin, Germany: IEEE Xplore, 2012, pp. 1–6. doi: 10.1109/ISGTEurope.2012.6465836.

[184] C. S. Ioakimidis, K. N. Genikomsakis, A. Aragonés, A. Escuredo, and F. Sánchez, 'Design of a Virtual Power Plant in the presence of microrenewables and electric vehicles in a microgrid concept for real-time simulation as part of a remote lab', in *Renewable Energy and Power Quality Journal*, 2013, pp. 650–654. doi: 10.24084/repqj11.403.

[185] A. Nunez-Naranjo, 'Constructivist Didactics in the Teaching-Learning Process', in *Proceedings of the 2022 IEEE 2nd International Conference on Advanced Learning Technologies on Education and Research, ICALTER 2022*, Institute of Electrical and Electronics Engineers Inc., 2022. doi: 10.1109/ICALTER57193.2022.9965075.

[186] F. M. Huang and M. Chao, 'An Architecture of Virtual Environment for E-Learning (AVEE)', in *5th IEEE International Conference on Advanced Learning Technologies, ICALT 2005*, IEEE, 2005, pp. 148–149. doi: 10.1109/ICALT.2005.49.

[187] J. Hattie and H. Timperley, 'The power of feedback', *Rev Educ Res*, vol. 77, no. 1, pp. 81–112, 2007, doi: 10.3102/003465430298487.

[188] S. Pandit *et al.*, 'An Architecture Solution for E-Learning System - ESSA', in *International Conference on Technology for Education, T4E 2010*, IEEE, 2010, pp. 56–62. doi: 10.1109/T4E.2010.5550061.

[189] M. Alptekin and K. Temmen, 'Design Concept and Prototype for an Augmented Reality based virtual preparation laboratory training in Electrical Engineering', in *IEEE Global Engineering Education*

Conference (EDUCON), Santa Cruz de Tenerife, Canary Islands, Spain: IEEE Xplore, 2018, pp. 963–968. doi: 10.1109/EDUCON.2018.8363334.

[190] N. M. Edan, A. Al-Sherbaz, and S. Turner, 'Design and evaluation of browser-to-browser video conferencing in WebRTC', in *Global Information Infrastructure and Networking Symposium, GIIS 2017*, IEEE, 2017, pp. 75–78. doi: 10.1109/GIIS.2017.8169813.

[191] T. Reenskaug, P. Wold, and O. A. Lehne, *Working with objects: The OOram Software Engineering Method-Obsolete s*. 2001.

[192] P. Bogere, K. Temmen, and H. Bode, 'Knowledge Transfer Concepts for Microgrids Sustainability - The Case of East Africa', in *IEEE Global Engineering Education Conference (EDUCON)*, Kuwait, Kuwait: IEEE Computer Society, 2023, pp. 1–6. doi: 10.1109/EDUCON54358.2023.10125208.

[193] United Nations General Assembly, 'Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development', 2020. [Online]. Available: https://unstats.un.org/sdgs/indicators/Global Indicator Framework after 2019 refinement_Eng.pdf%0Ahttps://unstats.un.org/sdgs/indicators/Global Indicator Framework_A.RES.71.313 Annex.pdf

List of Figures

List of Tables

List of Appendices

Appendices

Appendix A *DEES Proposed Course Content for Microgrids Knowledge Transfer to BSc Elec Eng Students – Version 1*

Goal.
The goal of this content is to transfer appropriate microgrids knowledge and skills to engineering students so as to produce graduates with competency for microgrids sustainability.

Objectives.
Upon completion, the engineering student will be able to:

- Design microgrid energy systems in the range of, at least, 10 – 20 kWp capacity cognisant of a community´s electrical energy requirements.
- Propose suitable *Demand* versus *Supply* Management interventions for optimal energy use and generation relationships.
- Examine techno-economic case scenarios for efficient and reliable microgrid systems at realistic production costs and fair customer tariffs.

Content and Intended Learning Outcomes

1. Topic One: Microgrids.
   1.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:
   i) List auxiliary and main components of microgrid systems.
   ii) Explain microgrids and their operation/functionality.
   iii) Discuss Technical Details of microgrids´ auxiliary and main Components.
   iv) Sketch a block diagram of a microgrid system.
   v) Assess the needs of electrical energy in rural communities.
   vi) Determine electrical energy demand in rural communities.

   1.2 Topic Content
   Distributed energy systems as synonyms for microgrids. What Microgrids are; Main and Auxiliary Components; Schematic diagram; Functionality/Operation; Main and Auxiliary Components' Technical Details; Control. Advantages of microgrids – giving specific examples from communities. Engaging Communities in microgrid technology establishment: Electrical energy needs and demand assessment in rural communities.

2. Topic Two: Solar cells and Modules.
   2.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:
   i) Explain the solar cells *principle of operation*.
   ii) *Construct* solar modules.

iii) Determine the *capacity* of solar modules in (ii) above.

2.2 Topic Content

Solar cells and Modules: Photovoltaic conversion principle; Operation and Wiring of solar cells. Solar irradiance and associated properties; Standard Test Conditions.

3. Topic Three: Sizing of Solar Systems.

3.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Discuss the terms *String* and *Array*.

ii) Manipulate the *series-connected* and *parallel* configurations of solar PV modules for a required system output.

iii) Determine appropriate inverter and controller component sizes of solar PV systems.

iv) Calculate required number of modules to yield a required amount of nominal power.

3.2 Topic Content

Sizing of Solar Systems: Meaning of the terms *string* and *array,* Series-connection and parallel configuration of solar PV modules. Considerations when mounting modules: Spacing between modules to avoid shading, total required number of modules to yield a required amount of nominal power, total required area to yield a required amount of nominal power.

4. Topic Four: Smart Grid Technology.

4.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Distinguish between microgrid and smart grid technologies.

ii) Discuss primary engineering considerations in smart grid designs.

iii) Synthesize constraints to smart grid technology implementation due to physical fundamentals.

iv) Explain microgrids interconnection basics and the associated limitations.

v) Discuss solar PV system configurations.

4.2 Topic Content

Smart Grid Technology: Primary Engineering Design Considerations; Constraints imposed by physical fundamentals such as prevailing technology levels and market - with quantifiable evidence where possible; Solar system grid connection configurations, wiring, inverters, coupling mechanisms, microgrids interconnection basics and the associated limitations.

5. Topic Five: Energy Storage and Distribution.

5.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Distinguish between in-front of the meter (FTM - utility based) and behind the meter (BTM – consumer based) battery storage schemes.
ii) Determine battery storage to serve given load requirements.

5.2 Topic Content

Energy storage parameters and characteristics (Efficiency, Power, storage capacity, energy density, charge/discharge time, self-discharge rate, storage cycle number and depth of discharge, specific costs,), Energy Storage and Distribution: In-front of the meter (FTM - utility based) and behind the meter (BTM – consumer based) battery storage schemes, solar batteries. Energy Storage schemes: Electrical (e.g. double layer capacitors), Chemical (e.g. Batteries), and Mechanical (e.g. pumped storage plants – hydropower plants).

6. Topic Six: Demand-side Management.

6.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Discuss energy saving systems and practices in electrical installations.
ii) Appraise electrical energy tariff schemes, for affordability, from the consumers' viewpoint.
iii) Synthesize demand and supply side imbalances.

6.2 Topic Content

Demand-side Management: Energy losses; Tariffs and costs; Energy Saving Systems and Practices: timers, thermostats, sensor-activated switching, smart meters, efficient-energy conversion techniques and equipment – including those for reactive power management; Energy use and generation/availability relationships; Critical load considerations in the energy use versus availability relationships.

Appendix B *DEES Proposed Course Content for Microgrids Knowledge Transfer to BSc Elec Eng Students – Version 2*

Goal.
The goal of this content is to produce engineering graduates, with employable and entrepreneurial skills, equipped with appropriate knowledge for microgrids sustainability.

Objectives.
Upon completion, the engineering student will be able to:

- Design microgrid energy systems in the range of, at least, 10 – 20 kWp capacity cognisant of a community's electrical energy requirements.
- Propose suitable *Demand* versus *Supply* Management interventions for optimal energy use and generation relationships.
- Examine techno-economic case scenarios for efficient and reliable microgrid systems at realistic production costs and fair customer tariffs.

Content and Intended Learning Outcomes

1. Topic One: Microgrids.

   1.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:
   - i) List auxiliary and main components of microgrid systems.
   - ii) Explain microgrids and their operation/functionality.
   - iii) Discuss Technical Details of microgrids' auxiliary and main Components.
   - iv) Sketch a block diagram of microgrid system.

   1.2 Topic Content

   What Microgrids are; Main and Auxiliary Components; Schematic diagram; Functionality/Operation; Main and Auxiliary Components' Technical Details; Control. Advantages of microgrids – giving specific examples from communities.

2. Topic Two: Measure of solar module's capacity.

   2.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:
   - i) Relate power, voltage, and current in solar module's capacity determination/measurements.
   - ii) Produce I-V characteristic curves of ohmic resistance.
   - iii) Categorise elements/devices using their I-V Characteristic Curves.

2.2 Topic Content

Measure of solar module's capacity. Under this topic, the following sub-topics will also be introduced/taught:

a. Power as a product of voltage and current.
b. Ohmic Resistance.
c. Classification of elements/devices (e.g. resistors, solar cells) using their I-V Curves.

3. Topic Three: Solar cells and Modules.

3.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Explain the solar cells principle of operation.
ii) Construct solar modules.
iii) Determine the capacity of solar modules in (ii) above.

3.2 Topic Content

Solar cells and Modules: Operation and Wiring of solar cells.

4. Topic Four: Sizing of Solar Systems.

4.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Discuss the terms string and array.
ii) Manipulate the series-connected and parallel configurations of solar PV modules for a required system output.
iii) Determine appropriate inverter and controller component sizes of solar PV systems.

4.2 Topic Content

Sizing of Solar Systems. Under this topic, the following sub-topics will also be introduced/taught:

a. Meaning of the terms *string* and *array*.
b. Series-connected and parallel configuration of PV modules.

5. Topic Five: Smart Grid Technology.

5.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Distinguish between microgrid and smart grid technologies.
ii) Discuss primary engineering considerations in smart grid designs.
iii) Synthesize constraints to smart grid technology implementation due to physical fundamentals.
iv) Explain microgrids interconnection basics and the associated limitations.

5.2 Topic Content

Smart Grid Technology: Primary Engineering Design Considerations; Constraints imposed by physical fundamentals such as prevailing technology levels and market - with quantifiable evidence where possible; microgrids interconnection basics and the associated limitations.

6. Topic Six: Energy Storage and Distribution.

6.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Distinguish between in-front of the meter (FTM - utility based) and behind the meter (BTM – consumer based) battery storage schemes.
ii) Determine battery storage to serve given load requirements.

6.2 Topic Content

Energy Storage and Distribution: Storage schemes – Batteries.

7. Topic Seven: Demand-side Management.

7.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Discuss energy saving systems and practices in electrical installations
ii) Appraise electrical energy tariff schemes, for affordability, from the consumers' viewpoint.
iii) Synthesize demand and supply side imbalances.

7.2 Topic Content

Demand-side Management: Energy losses; Tariffs and costs; Energy Saving Systems and Practices: timers, thermostats, sensor-activated switching, smart meters, efficient-energy conversion techniques and equipment – including those for reactive power management; Energy use and generation/availability relationships; Critical load considerations in the energy use versus availability relationships.

8. Topic Eight: Energy Distribution Costs.

8.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Apply Kelvin's law in determining cost-effective conductor sizes.
ii) Plan a basic microgrid distribution system.
iii) Prepare an itemised quantity price list for a basic microgrid distribution system.
iv) Analyse techno-economic viability of microgrids in providing market-based solutions.

8.2 Topic Content

Energy Distribution Costs: Distribution system planning and automation; Load characteristics; Design Considerations; Review Kelvin's law: Overhead and Underground; DC distribution systems: Power control equipment, Transformer, and switchgear costs; Designing Engineering solutions on account of human/consumer reactions/needs; From centrally controlled to a modular grids industry – applying power systems economics principles and market-based solutions.

9. Topic Nine: Revenue Management.

9.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Discuss tariff types.
ii) Explain metering and billing systems.
iii) Describe meter testing and calibration procedures.
iv) Relate revenue management to load monitoring and control systems.

9.2 Topic Content

Revenue Management: Tariff types and determination; Metering and billing systems; statutory obligations, decentralisation, meter testing and maintenance, meter reading, billing, revenue collection and debt recovery, pre-payment systems; Load control devices and systems; Outages and customer response.

Appendix C *DEES Proposed Course Content for Microgrids Knowledge Transfer to BSc Elec Eng Students – Version 3*

Goal.

The goal of this content is to produce engineering graduates, with employable and entrepreneurial skills, equipped with appropriate knowledge for microgrids sustainability.

Objectives.

Upon completion, the engineering student will be able to:

- Design microgrid energy systems in the range of, at least, 10 – 20 kWp capacity cognisant of a community's electrical energy requirements.
- Propose suitable, *demand* versus s*upply,* management interventions for optimal energy use and generation relationships.
- Examine techno-economic case scenarios for efficient and reliable microgrid systems at realistic production costs and fair customer tariffs.
- Apply Artificial Intelligence (AI), Industrial Internet of Things and sensor technology to optimise microgrids operation and reliability.

Content and Intended Learning Outcomes

1. Topic One: Distributed Energy Systems. [Duration: 2 hours and 4 for a feasibility study]

   1.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

   i) Explain the role of distributed energy resources (DERs) in the modern electrical grid.
   ii) Classify distributed energy systems according to their generation technologies, sizes, and applications.
   iii) Assess the economic, environmental, and social impacts of distributed energy systems on local communities.
   iv) Perform technical evaluations and feasibility studies for the implementation of distributed energy projects.

   1.2 Topic Content

   Introduction to distributed energy systems (DES): What DESs are, Distributed energy concepts and principles in view of modern and emerging technologies, Comparison of centralised and distributed energy generation. Distributed energy resources (DER): Classification of DESs based on technology (DER, that is, generation technologies - solar, wind turbines), size and applications. Regulatory aspects and economics: Distributed projects cost-benefit, environmental, and social impact analysis. Policies, guidelines, and regulatory frameworks that support and oversee distributed energy projects implementation, Distributed energy projects financing options and sustainability strategies; Technical evaluations and feasibility studies for DES projects implementation.

2. Topic Two: Microgrids introduction. [Duration: 2 hours and 4 for an excursion]

2.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Label main and auxiliary components of a microgrid system.
ii) Explain microgrids operation/functionality and their role in DES.
iii) Relate components of a microgrid system to those of a real microgrid.
iv) Produce models of a microgrid system using physical laboratory components to represent a real microgrid.
v) Communicate microgrids technical concepts effectively to peers, consumers of electrical energy services, and local leaders in communities.
vi) Discuss pros and cons of a career in microgrids related environments.
vii) Choose whether to pursue a career in microgrids related environments given that microgrids are mostly installed in remote communities.

2.2 Topic Content

Introduction to microgrids: What microgrids are, Main and auxiliary components, Schematic diagram, Functionality/Operation. Microgrid components and control: Main and auxiliary components' technical details, Monitoring and control. Real world case studies: Advantages of microgrids – giving specific examples from communities, Electrical energy needs and demand assessment in communities, Engaging communities in microgrids project establishment, Examples of successful microgrid projects, case studies on resilient projects, community-based energy initiatives.

3. Topic Three: Solar cells and PV modules. [Duration: 4 hours and 6 for practicals]

3.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Explain the *principle of operation* of a solar cell.
ii) Construct solar cells to achieve a desired level of output.
iii) Produce I-V characteristic curves of ohmic resistance.
iv) Categorise elements/devices based on their I-V characteristic curves.
v) Assemble solar cells into PV modules.
vi) Produce I-V characteristic curves of solar PV modules in (v) – based on illumination, then temperature.
vii) Determine the *capacity* of solar PV modules in (vi) above.
viii) Discuss the terms *string* and *array* in relation to solar PV modules.
ix) Construct *series-connected* and *parallel* configurations of solar PV modules for a required system output.
x) Determine appropriate inverter and controller component sizes of a solar PV system through measurements and calculations.

3.2 Topic Content

Solar cells and PV modules: Photovoltaic conversion principle, operation and wiring of solar cells, solar irradiance and associated properties, standard test conditions. Measurement of solar PV modules: Measurement and determination of solar PV module's capacity, Power as a product of voltage and current, Ohmic Resistance, Classification of elements/devices (e.g. resistors, solar cells) using their I-V curves. Sizing of solar systems: Sizing of solar systems based on energy requirement, Meaning of the terms *string* and *array* in relation to PV modules, Series-connected and parallel configuration of PV modules. Considerations when mounting PV modules: Spacing between modules to avoid shading, total required number of modules to yield the required amount of nominal power, total required area to yield the required amount of nominal power.

4. Topic Four: Microgrids maturation. [Duration: 4 hours and 6 for practicals]

4.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Analyse electrical energy needs for a given community.
ii) Predict electrical energy demand for a microgrid project in a given community.
iii) Discuss technical details of microgrids' auxiliary and main components.
iv) Discuss primary engineering considerations in microgrid designs.
v) Design a microgrid system, for a specified load/predicted demand, using AutoCAD or any other up-to-date computer software.
vi) Construct microgrids from installation, testing for commissioning, through to operation.
vii) Apply fault diagnosis techniques in fault detection, repair and maintenance of microgrids.
viii) Implement control strategies for managing microgrids - monitoring and control; optimisation of resources for optimised and cost-effective performance.
ix) Explain microgrids interconnection basics and the associated limitations.
x) Define grid code parameters for safe, reliable, and cost-effective microgrid functioning.

4.2 Topic Content

Electrical energy needs analysis, demand prediction; Microgrids primary engineering design considerations, Constraints imposed by physical fundamentals such as prevailing technology levels and market - with quantifiable evidence where possible; Hands-on practical exercises (with physical components or simulations) on microgrids design, analysis, installation, testing, commissioning, operation, fault finding, repair, and maintenance. Monitoring and control strategies to manage microgrids and ensure stability; Microgrids interconnection basics and the associated limitations, Grid codes and standards (grid connection requirements) to ensure safe, reliable, and cost-effective microgrid functioning.

5. Topic Five: Energy storage systems. [Duration: 4 hours and 6 for practicals]

   5.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

   i) Describe energy storage technologies used in microgrids with emphasis on batteries.
   ii) Analyse the requirements for energy storage in view of the demand, load variability, and the considered microgrid energy sources.
   iii) Design battery energy storage systems, for microgrid applications, considering charging/discharging rates and the storage capacity to meet given load requirements.
   iv) Apply safety practices and maintenance procedures to ensure safe and reliable performance of battery energy storage systems in microgrids.

   5.2 Topic Content

   Energy storage parameters and characteristics: Efficiency, Power, storage capacity, energy density, charge/discharge time, self-discharge rate, storage cycle number and depth of discharge, and specific costs. Energy storage schemes: Electrical e.g. capacitors, chemical e.g. batteries, mechanical e.g. pumped storage plants. Batteries: In-front-of-the-meter and behind-the-meter battery storage schemes, Charge/discharge control and state-of-charge management, sizing criteria, series and parallel battery configuration to achieve a desired capacity; Practical illustrations of battery energy storage deployment in microgrid architectures, Peak shaving, and demand response using energy storage technologies; Emerging innovations in battery energy storage technologies. Battery safety and maintenance procedures: Lifecycle testing - repeated charge-discharge cycles under controlled conditions, internal resistance and voltage profiles; Battery maintenance tasks - cell balancing, temperature monitoring, and physical inspection of connections; Fault diagnosis and energy management simulations.

6. Topic Six: Energy distribution costs. [Duration: 4 hours and 6 for practicals]

   6.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

   i) Apply Kelvin’s law in determining cost-effective conductor sizes.
   ii) Prepare a Bill of Quantities (BoQ) for a basic microgrid distribution subsystem.
   iii) Analyse techno-economic viability of microgrids in providing market-based solutions.
   iv) Produce designed microgrid distribution schematic diagrams using AutoCAD or any other up-to-date computer software.
   v) Construct cost-effective overhead distribution lines.

6.2 Topic Content

Energy Distribution Costs: Microgrid distribution network planning and automation; Load characteristics; Design considerations in selection, sizing, and equipment placement in a microgrid distribution network; Review Kelvin's law: Overhead and Underground distribution network systems, distribution costs based on equipment capital investment, operation and maintenance costs, and energy losses such as I^2R; Design of engineering solutions on account of human/consumer reactions/needs – applying power systems economics principles and market-based solutions. Practical illustrations of distribution network cost analysis and optimisation in microgrid projects; Community-based microgrids and modernisation initiatives: Overhead distribution line construction and maintenance, Distributed energy management such as blockchain and peer-to-peer energy trading, Computer simulations in microgrid distribution network designs.

7. Topic Seven: Demand-side management. [Duration: 2 hours and 3 for practicals]

7.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Discuss energy saving systems and practices in electrical installations.
ii) Appraise electrical energy tariff schemes, for affordability, from the consumers' viewpoint.
iii) Design innovative demand and supply side imbalance management systems to ensure microgrid stability.
iv) Implement innovative demand and supply side imbalance management solutions to ensure microgrid reliability.

7.2 Topic Content

Demand-side management: Energy losses; Tariffs and costs, Advanced metering infrastructure (AMI). Energy saving systems and practices: Timers, thermostats, sensor-activated switching, smart meters, efficient-energy conversion techniques and equipment – including those for reactive power management; Energy use and generation/availability relationships; Critical load considerations in the energy use versus availability relationships.

8. Topic Eight: Revenue management. [Duration: 2 hours]

8.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Discuss tariff types and options applicable to microgrids.
ii) Explain metering and billing systems.
iii) Describe meter testing and calibration procedures.
iv) Relate revenue management to load monitoring and control systems.

8.2 Topic Content

Revenue Management: Tariff types and determination; Metering and billing systems; statutory obligations, decentralisation, meter testing and maintenance, meter reading, billing, revenue collection and debt recovery, pre-payment systems; Load control devices and systems; Outages and customer response.

9. Topic Nine: Artificial Intelligence (AI). [Duration: 2 hours and 4 for practicals]

9.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Write AI algorithms that can analyse sensor data (collected during monitoring, controlling and conditioning of microgrid components) and predict components failure.
ii) Apply AI algorithms to optimise microgrids performance, monitoring, and control.
iii) Design AI-based solutions for energy management - demand prediction versus (re)sources mix and hence;
iv) Implement AI-based solutions that enhance microgrids reliability.

NB: To achieve the set ILOs in this topic, learners need lots of data from operational microgrids.

9.2 Topic Content

Introduction to AI, machine learning, and neural networks; AI-based algorithms for microgrid optimisation, that is components predictive maintenance, monitoring and control, energy demand prediction and/or management; AI-based/machine learning techniques/models for load prediction and response management; data collection, pre-processing, and feature engineering (extraction from raw data) for microgrid datasets; Statistical analysis techniques and time-series prediction methods; Building and training AI models using python libraries and tools for microgrid applications; AI applications for microgrid reliability, and energy storage optimisation; Hands-on practical exercises and simulations to analyse and optimise microgrid performance using AI techniques.

10. Topic Ten: Industrial Internet of Things and Embedded Sensors. [Duration: 4 hours and 6 for practicals]

10.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Explain the concept and the relevance of Industrial Internet of Things (IIoT) implementation in microgrid systems.
ii) Explain the IIoT systems key technologies and protocols applicable to microgrid systems implementation.
iii) Appraise different sensor types, for deployment in microgrid systems, based on sensor specifications from datasheets.

iv) Set-up sensor networks for data acquisition and monitoring in microgrid environments.
v) Analyse sensor data collected from microgrid components to assess system performance, detect anomalies, and predict failure.
vi) Develop [and implement] control algorithms and logic based on sensor data input to optimise microgrid operation - load management, and energy dispatch.

10.2 Topic Content

Basics of IIoT: IoT devices, IIoT system key technologies and protocols such as wireless sensor networks, cloud and edge computing; Relevance of IIoT systems in microgrids. Introduction to embedded sensor technology, working principles, and communication protocols; Sensors that are relevant in microgrid applications including temperature, humidity, current, voltage, and power quality sensors. Sensor network implementation in microgrids, architecture and interfaces of microgrid control systems like Supervisory Control and Data Acquisition (SCADA) systems, Energy Management Systems (EMS), and Distributed Energy Resource Management Systems (DERMS); Methods for data acquisition, sampling, and transmission from embedded sensors to data acquisition systems; Sensor data processing techniques for cleaning, filtering, and normalization; machine learning algorithms for predictive maintenance, anomaly functioning and fault detection of microgrid components. Practical IIoT system and embedded sensor network deployment in microgrid projects to optimise operations through optimised energy management, and cost-effectiveness regarding decision-making in the renewable energy sources mix.

Appendix D *Microgrids where Data was Collected*

S/N	Village/Microgrid	PV capacity (kWp)	Battery capacity (kWh)	Peak loads (kW)	% utilisation against installed capacity	Country/Region	Remarks
1	Agoro	78.72	288	20.81	26	Uganda/Northern	Selected
2	Paloga	78.72	288	32.4	41	Uganda/Northern	
3	Ogili TC	78.72	288	36.92	47	Uganda/Northern	Selected
4	Pangira	39.36	144	18.68	47	Uganda/Northern	Selected
5	Potika	39.36	144	13.91	35	Uganda/Northern	
6	Ngomoromo	39.36	144	18.05	46	Uganda/Northern	
7	Kapeta	39.36	144	10.82	27	Uganda/Northern	
8	Apwoyo TC	39.36	144	16.31	41	Uganda/Northern	
9	Oboko TC	19.68	72	9.34	47	Uganda/Northern	Selected
10	Loromibeng	39.36	144	8.85	22	Uganda/Northern	Selected
11	Lelapwot	39.36	144	9.01	23	Uganda/Northern	
12	Opoki	39.36	144	18.02	46	Uganda/Northern	
13	Pany Buk	39.36	144	13.03	33	Uganda/Northern	
14	Muddu	39.36	144	15.78	40	Uganda/Northern	
15	Moroto East	39.36	144	6.55	17	Uganda/Northern	Selected
16	Otaa	39.36	144	10.23	26	Uganda/Northern	
17	Ywaya	39.36	144	7.92	20	Uganda/Northern	
18	Aweno Olwi	39.36	144	12.80	33	Uganda/Northern	
19	Ayuu Alali	39.36	144	17.16	44	Uganda/Northern	
20	Logwak	39.36	144	10.03	25	Uganda/Northern	
21	Lapidiyenyi	39.36	144	18	46	Uganda/Northern	Selected
22	Pawena	19.68	72		0	Uganda/Northern	Selected
23	Apyetta TC	39.36	144	19.10	49	Uganda/Northern	Selected
24	Apyetta West	39.36	144	13.19	34	Uganda/Northern	
25	Labayango	39.36	144	17.51	44	Uganda/Northern	
26	Senyondo	75.84	296.64	41.73	55	Uganda/Central	Selected
27	Buzaami	38.40	148.32	20.66	54	Uganda/Central	Selected

Appendix E *Questionnaire for Electrical Energy Consumers*

Preliminary information

Consumer category: □ Domestic □ Commercial – State nature of business ………….. □ Institution: School, hospital, others (specify) …………………...
Country:
District:
County:
Sub-county:
Parish:
Village:
Area Classification (Urban=1, Sub-Urban=2, Rural=3, Refugee Settlement=4):
Respondent's Gender (Male or Female) *:
Respondent's Position or responsibility held*:
Respondent's contact: Email*: Telephone*:

* Personal information that a respondent is not comfortable sharing can be ignored.

1. Do you ever experience power outages (periods of no electrical power)?
   □ YES □ NO
2. If yes:

a) Do power outages ever affect you in any way?
   □ YES – How?...
   □ NO

b) What are the causes of power outages?
   □ Load shedding
   □ Routine maintenance works
   □ Technical failure. Examples ……………………………………………………………………
   □ Non-payments/lack of money to buy units/disconnections
   □ Theft or vandalism of network facilities. Name such facilities ……………………………...
   □ Harsh climatic damage of network facilities. Examples ……………………………………..
   □ Others (please specify) ……………………………………………………………………….

3. What electrical energy utilisation-related challenges do you face as a consumer?
   a) ……………………………… e) ………………………………
   b) ……………………………… f) ………………………………
   c) ……………………………… g) ………………………………
   d) ……………………………… h) ………………………………

KNOWLEDGE AND SKILLS RELATED QUESTIONS

4. Did you receive any form of training before electrical energy was introduced in your area?
   □ YES □ NO

4. a) If no, what training would you need?

…………………………………………………………………………………………………...

…………………………………………………………………………………………………...

…………………………………………………………………………………………………...

4. b) If yes, how have you utilised/applied the knowledge or skills gained during the training?

…………………………………………………………………………………………………...

…………………………………………………………………………………………………...

…………………………………………………………………………………………………...

5. What kind of training should electrical energy consumers like you receive so as to support the day-to-day operation of a microgrid?
   a) ……………………………… e) ………………………………
   b) ……………………………… f) ………………………………
   c) ……………………………… g) ………………………………
   d) ……………………………… h) ………………………………

6. What form of support should microgrid operators provide you with in order to enable you to generate income off the microgrid?
   i) ……………………………… vi) ………………………………
   ii) ……………………………… vii) ………………………………
   iii) ……………………………… viii) ……………………… …………
   iv) ………………………………
   v) ………………………………

MAINTENANCE

7. What kind of electrical-related maintenance/repair services do you normally need, if any?

   …………………………………………………………………………………………………...

   …………………………………………………………………………………………………...

   …………………………………………………………………………………………………...

8. Who normally provides maintenance or repair services whenever you have a problem at your premises?
   - ☐ Locally untrained community members
   - ☐ Locally trained community members
   - ☐ Technicians from the community but not employed by the operator
   - ☐ Technicians appointed by microgrid operators
   - ☐ A firm contracted by the microgrid operator
   - ☐ Others (Specify)………………………………………………………………………………

9. Are the maintenance or repair service providers readily available to offer required services?

   ☐ YES ☐ NO

10. How much do you normally spend on repairs per month?...…………………….. (UGX/TZS)

11. What items are normally repaired/serviced/replaced, at your premises, and after how long?

Component (indicate availability as well by ticking)	Duration in months					Key maintenance activities done
	1–3	3–6	6–9	9–12	Other	
Lights						
Switches						
Socket outlets						
Radio						
Television (TV) set						
Decoder						
Flat Iron						
Mobile Phone						
Refrigerator/Freezer						
Water Heater/ Kettle						
Desktop Computer/Laptop						
Printer						
Photocopier						
Scanner						
Hair Trimmer/ Hair Drier						
Welding machine						
Milling machine						
Sewing machine						
Other ___________________						
Other ___________________						
Other ___________________						

12. Would you be interested in being trained to start doing repairs yourself?
 YES NO
If yes, why?..

SDG 7: "Access to affordable, reliable, sustainable and modern energy services" by 2030

13. How much money, on average, do you spend on electricity bills per month? (state the amount in the local currency) ……………………………………………………………. (UGX/TZS)

14. To what extent do you agree with the following statements?

Statement	Rating: I agree to a very large extent = 5; I agree to a large extent = 4; Neutral = 3; I somewhat agree = 2; I do not agree at all = 1; Not applicable = 0	Remarks if any
The electrical power provided is affordable (in terms of cost)	5 4 3 2 1 0	
The electrical energy provided is reliable	5 4 3 2 1 0	
The microgrid is sustainable (electrical energy provision will be for a long period)	5 4 3 2 1 0	
The microgrid operator provides some modern energy services	5 4 3 2 1 0	
I am satisfied with the maintenance services of the provider	5 4 3 2 1 0	

15. What cost of electrical energy would you consider affordable? (state the amount in the local currency) ………………………………. (UGX/TZS)
16. What would you say reliable electrical energy is?
………………………………………………………………………………………………
………………………………………………………………………………………………
17. What would you say a sustainable microgrid is?
………………………………………………………………………………………………
………………………………………………………………………………………………

END

Appendix F *Proposed Content for Microgrids Knowledge Transfer to Electrical Energy Consumers – version 1*

Goal.

The goal of this content is to transfer basic microgrids knowledge to consumers and/or prospective consumers of electrical energy services through training of East African rural community inhabitants so that they (inhabitants) "own" microgrid projects and make informed decisions regarding appropriate use to suit local requirements for microgrids sustainability.

Objectives.

Upon completion, a consumer of electrical energy services will be able to:

- Demonstrate relevant microgrids knowledge and skills for microgrids sustainability in communities.
- Participate in microgrid projects' lifecycle, in their respective communities, for microgrids sustainability.
- Select appropriate household appliances for efficient and economical electrical energy utilisation.
- Perform basic household electrical installations for microgrids sustainability in communities.
- Adhere to electrical health and safety rules in electrical-related undertakings.

Content and Intended Learning Outcomes

1. Topic One: Microgrids.

   1.1 Intended Learning Outcomes. By the end of this topic, a consumer of electrical energy services should be able to:

   i) Identify main components of microgrid systems.
   ii) Discuss advantages of microgrids to their community giving specific examples in line with social, economic, health, and education perspectives.
   iii) Carryout simple maintenance tasks of selected components in a microgrid ecosystem.

   1.2 Topic Content

   Microgrids description; Components of microgrid systems; Microgrids sub-systems; Schematic diagram; Functionality/Operation of microgrids; Applications (uses) of microgrids; Advantages (benefits) of microgrids – giving specific health, educational, economical, and social related examples from rural African communities; Lwak microgrid architecture; maintenance of microgrids – solar modules and other components in the ecosystem; roles of electrical energy consumers/customers/communities in microgrid projects.

2. Topic Two: Electrical Energy Generation, Distribution and Storage

2.1 Intended Learning Outcomes. By the end of this topic, a consumer of electrical energy services should be able to:

i) List sources of electrical energy.
ii) Explain the generation, transmission, and distribution of electrical energy from generation stations to consumers.
iii) Discuss maintenance of secondary cells/batteries.
iv) Distinguish between in-front of the meter (FTM - utility based) and behind the meter (BTM – consumer based) battery storage schemes.

2.2 Topic Content

Sources of electrical energy, Solar modules/panels as sources of electrical energy; Generation, transmission, and distribution of electrical energy – central and distributed systems; Batteries as an energy storage scheme and their maintenance, utility based in-front of the meter (FTM) versus customer based behind the meter (BTM) battery storage schemes, Converters and Inverters – what to consider when buying/designing for BTM.

3. Topic Three: Electrical Energy Utilisation.

3.1 Intended Learning Outcomes. By the end of this topic, a consumer of electrical energy services should be able to:

i) List domestic, commercial, industrial, and social applications (uses) of electrical energy.
ii) Perform electrical installations of basic households.
iii) Determine the per month electrical energy cost for their respective homes – as a case study.
iv) List the dos and don’ts for *Human Disturbance minimization* on microgrid networks.

3.2 Topic Content

Applications of electrical energy for domestic, commercial, industrial and social facilities. Heating effect of current; Applications of the heating effect: Cooking – electric cookers, kettles and heater; lighting (bulb filament); Ironing (electric iron). Institutional and Domestic electrical installation, Safety of electrical installations with emphasis given to earthing; kWh as a unit of electrical energy; Procedure for getting connected to a grid; Calculations involving electrical energy cost, cost of consumed electrical energy; Efficient utilisation of electrical energy; Tariff and Bills: Tariff considerations, Peak and off-peak tariffs/charges, per hour and block charges. Maintenance of all components at the consumer premises. Consumer dos and don’ts for *Human Disturbance minimisation* on the network.

Appendix G *Proposed Content for Microgrids Knowledge Transfer to Electrical Energy Consumers – version 3*

Goal.

The goal of this content is to enable transfer of basic microgrids knowledge to consumers and/or prospective consumers of electrical energy services through training of East African rural community inhabitants so that they (inhabitants) "own" microgrid projects and make informed decisions regarding appropriate use to suit local requirements for microgrids sustainability.

Objectives.

Upon completion, a consumer of electrical energy services will be able to:

- Demonstrate relevant microgrids knowledge and skills for microgrids sustainability in communities.
- Participate in microgrid projects' lifecycle, in their respective communities, for microgrids sustainability.
- Recognise electrical energy generation, distribution and storage systems.
- Adhere to electrical health and safety rules in electrical-related undertakings cognisant of environmental concerns.
- Adapt efficient and cost-effective electrical energy utilisation approaches.
- Perform simple electrical installations for microgrids sustainability in communities.
- Acquire entrepreneurship knowledge and skills for income generation while consuming electrical energy on one hand and solving local problems on the other.

Content and Intended Learning Outcomes

1. Topic One: Microgrids. Duration: 10 hours (2 days)

   1.1 Intended Learning Outcomes. By the end of this topic, a consumer of electrical energy services should be able to:

   i) Identify main components of microgrid systems.
   ii) Discuss advantages of microgrids to their community giving specific examples in line with social, economic, health, and education perspectives.
   iii) Support microgrid projects, throughout projects lifecycle, in their respective communities.
   iv) Carryout simple maintenance tasks of selected components in a microgrid ecosystem while ensuring their safety to avoid power outages.

   1.2 Topic Content

   Microgrids description; Components of microgrid systems; Microgrids sub-systems; Schematic diagram; Functionality/Operation of microgrids; Applications (uses) of microgrids; Advantages (benefits) of microgrids – giving specific health, educational, economical, and social related examples from rural African communities; microgrid architecture; maintenance and safety of microgrid components – solar modules and other components in the entire ecosystem; Microgrid projects and roles of electrical energy consumers/customers/communities in microgrid projects.

2. Topic Two: Electrical Energy Generation, Distribution and Storage. Duration: 5 hours

2.1 Intended Learning Outcomes. By the end of this topic, a consumer of electrical energy services should be able to:

- i) Discuss sources of electrical energy.
- ii) Explain the generation and distribution of electrical energy from generating stations to consumers at the demand side.
- iii) Discuss maintenance of secondary cells/batteries.
- iv) Distinguish between in-front-of-the-meter (FTM - utility-based) and behind-the-meter (BTM – consumer based) battery storage schemes.

2.2 Topic Content

Sources of electrical energy, Solar modules/panels as sources of electrical energy; Generation, transmission, and distribution of electrical energy – central and distributed systems; Batteries as an energy storage scheme and their maintenance, utility-based in-front of the meter (FTM) versus customer based behind the meter (BTM) battery storage schemes, Converters and Inverters – what to consider when buying/designing for BTM.

3. Topic Three: Safety, Health and the environment. Duration: 2.5 hrs

3.1 Intended Learning Outcomes. By the end of this topic, a consumer of electrical energy services should be able to:

- i) Practice electrical safety and health guidelines.
- ii) Apply first-aid procedures to electric shock victims.

3.2 Topic Content

Electrical work-related safety and health concerns; First aid to electric shock victims; Environmental dangers (risks and hazards) to electrical energy; Fire safety in electrical installations; Safety of persons, electrical accessories, appliances, and devices in electrical installations.

4. Topic Four: Electrical Energy Utilisation. Duration: 10 hrs

4.1 Intended Learning Outcomes. By the end of this topic, a consumer of electrical energy services should be able to:

- i) Discuss domestic, commercial, industrial, and social applications (uses) of electrical energy.

ii) Determine the per month electrical energy cost for a random homestead – as a case study.
iii) Evaluate electrical energy cost, based on appliances' ratings, for a random homestead – as a case study.
iv) Implement efficient electrical energy utilisation approaches.
v) Choose appropriate appliances for efficient and cost-effective electrical energy utilisation.
vi) Discuss the dos and don'ts for *Human Disturbance minimisation* on microgrid networks.

4.2 Topic Content

Applications of electrical energy for domestic, commercial, industrial and social facilities. Heating effect of current; Applications of the heating effect: Cooking – electric cookers, kettles and heater; lighting (bulb filament); Ironing (electric iron); cooling (freezers and fridges); kWh as a unit of electrical energy; Calculative and other illustrations leading to electrical energy cost due to consumption (based on appliance power rating and time), cost of consumed electrical energy; approaches to efficient utilisation of electrical energy; Tariff and Bills: Tariff considerations, Peak and off-peak tariffs/charges, per hour and block charges; Consumer dos and don'ts for *Human Disturbance minimization* on the network.

5. Topic Five: Electrical installations. Duration: 10 hrs

5.1 Intended Learning Outcomes. By the end of this topic, a consumer of electrical energy services should be able to:

i) Identify domestic and commercial electrical accessories necessary for electrical installations.
ii) Interpret multi-meter readings.
iii) Perform electrical installations of basic households.
iv) Apply fault finding & rectification procedures (troubleshoot) in electrical installations.
v) Choose effective electrical energy accessories.
vi) Perform repairs & maintenance (or replacement as the case might be) of accessories and selected devices in electrical installations.

5.2 Topic Content

National standards and guidelines for electrical installation in buildings (relevant national guidelines, approved standards and IEEE wiring regulations such as BS 7671); Accessories for electrical installations; Institutional and Domestic electrical installation, Safety of persons, electrical accessories and appliances in electrical installations - with emphasis given to earthing; Fault identification and rectification procedures in electrical installations;

kWh as a unit of electrical energy (repeated for emphasis); cost of consumed electrical energy (repeated for emphasis); Efficient utilisation of electrical energy (repeated for emphasis); Maintenance and protection of components at the consumer premises; repair and or replacement of electrical accessories.

6. Topic Six: Microgrid operator-specific business model. Duration: 2.5 hrs

6.1 Intended Learning Outcomes. By the end of this topic, a consumer of electrical energy services should be able to:

i) Explain the procedure for getting connected to a grid.
ii) Describe operator-specific complaints handling procedures and communication channels.
iii) Use the appropriate applicable channels to pay for the consumed energy bills.

6.2 Topic Content

Procedure for getting connected to a grid; channels of communication including complaints reporting procedure; energy cost, channels of bill payments and how to use them to pay for bills.

7. Topic Seven: Entrepreneurship and Productive use of electrical energy. Duration: 10 hrs

7.1 Intended Learning Outcomes. By the end of this topic, a consumer of electrical energy services should demonstrate the ability to:

i) Discuss local challenges that are potential entrepreneurial opportunities.
ii) Devise entrepreneurial opportunities/business ideas that solve the challenges in i) above.
iii) Set-up income-generating businesses that match the devised ideas in ii) above while maximising the potential of electrical energy utilisation.
iv) Keep financial records for a business of their choice considered in iii) above.
v) Perform repairs and maintenance of selected electrical energy utilisation appliances and devices based on envisaged business ideas.

7.2 Topic Content

Mind-set change for entrepreneurship – motivation of locals to invent business ideas that solve indigenous problems in their communities; Entrepreneurship challenges and opportunities related to PUE; Financial literacy – Capital mobilisation, management of finances and budgeting; Fundamentals of accounting; Business records keeping; Operation of installations/appliances for PUE; Maintenance and repair of selected electrical appliances (Welding machines, milling machines, water pumps, fridges, freezers, phones).

Appendix H *Proposed Content for Microgrids Knowledge Transfer to Secondary School Learners (14–18 years) – version 1*

Goal.
The goal of this content is to transfer basic microgrids knowledge to secondary school learners, aged 14 – 18, through training so that they acquire appropriate skills to benefit local communities and be motivated to join a career in engineering.

Objectives.
Upon completion, the student will be able to:

- Demonstrate relevant microgrids knowledge and skills for microgrids sustainability in communities.
- Provide recommendations for suitable household appliances for efficient and economical electrical energy utilisation.
- Perform basic household electrical installations in communities.
- Adhere to electrical health and safety protocols in any electrical-related undertakings.

Content and Intended Learning Outcomes.

1. Topic One: Microgrids.
   1.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:
      i) List the main components and/or sub-systems of microgrids.
      ii) Explain microgrids operation.
      iii) Discuss advantages of microgrids giving specific examples from communities.
      iv) Sketch a microgrid system block diagram.
      v) Relate different microgrid sub-systems with the Lwak community microgrid architecture.

   1.2 Topic Content.
   What Microgrids are; Microgrids main components and/or sub-systems; Schematic diagram; Functionality/Operation; Applications and advantages of microgrids – giving specific examples from rural communities; Lwak microgrid architecture.

2. Topic Two: Electrical Circuits.
   2.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:
      i) Construct simple electric circuits.
      ii) Identify symbols used in electric circuits.
      iii) Define electric current, voltage, and resistance.
      iv) Differentiate between static and variable resistors.
      v) Differentiate between primary and secondary cells.
      vi) Measure voltage across resistors in simple electric circuits.

vii) Measure current in simple electric circuits.
viii) Discuss maintenance of secondary cells.
ix) Distinguish between in-front of the meter (FTM - utility based) and behind the meter (BTM – consumer based) battery storage schemes.

2.2 Topic Content.

Components that make up simple electric circuits and their symbols: cell, ammeter, voltmeter, resistors (static/fixed and variable), connecting wires, bulb and switches; Electric current and the SI units; Voltage and the SI units; Resistance and the SI units, effective resistance in series and parallel connections; Construction of simple electric circuits; Current and voltage measurements; Operation of primary (dry) cells and secondary cells (lead acid battery), maintenance of secondary cells; Batteries as an energy storage scheme, utility based (FTM) versus customer based (BTM) battery storage schemes.

3. Topic Three: Work, Energy, and Power.

3.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Define the terms Work, Energy, and Power.
ii) Write the SI units of Work, Energy, and Power.
iii) Explain energy conversions.
iv) Discuss renewable sources of energy.
v) Relate Power, Voltage, and Current.

3.2 Topic Content.

Definitions and SI units of Work, Energy, and Power; Energy: Energy forms and energy conversions, the law of conservation of energy, Renewable sources of energy; Power as a product of voltage and current.

4. Topic Four: Electrical Energy.

4.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) List sources of electrical energy.
ii) Explain the generation, transmission, and distribution of electrical energy from generation station to consumers.
iii) Compare microgrid or distributed electrical energy systems to centralised systems.
iv) Perform, practically, basic household electrical wiring circuits.
v) Define kilowatt hour.

4.2 Topic Content.

Sources of electrical energy – hydro, geothermal; Generation, transmission, and distribution of electrical energy with a comparison to microgrids; Domestic electrical installations, Earthing and its importance; kWh definition.

5. Topic Five: Uses of Electrical Energy.

5.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) List domestic, commercial, industrial, and social applications of electrical energy.
ii) Explain the heating effect.
iii) Perform simple electric current effect experiments.
iv) Name devices in which electric current heating effect is applied.
v) Solve electrical energy and electrical power numerical problems.
vi) Solve electrical energy consumption and cost numerical problems.
vii) Determine the per month electrical power cost for their respective homes – as a case study.

5.2 Topic Content.

Applications of electrical energy for domestic, commercial, industrial and social facilities. Heating effect of current; Applications of the heating effect: Cooking – electric cookers, kettles and heater; lighting (bulb filament); Ironing (electric iron). Calculations involving electrical energy and electrical power; Calculations involving electrical energy cost, cost of consumed electrical energy.

6. Topic Six: Photoelectric Effect and Solar cells.

6.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Explain the photoelectric effect.
ii) Define threshold frequency, work function and the electron volt.
iii) Perform simple photoelectric effect experiments.
iv) Explain applications of photoelectric effect.
v) Explain the solar cells principle of operation.
vi) Construct solar modules.
vii) Determine the capacity of solar modules in (vi) above.

6.2 Topic Content.

The photoelectric effect phenomenon, photons, threshold frequency, work function, Planck's constant, and electron-volt; Photoelectric effect applications: Photo emissive cells, Photo conductive cells, Photovoltaic (or solar) cells; Solar cells principle of operation, wiring of solar cells to form modules; Power as a measure of solar module's capacity.

7. Topic Seven: Sizing of Solar Systems.

7.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Discuss the terms *String* and *Array*.

ii) Manipulate the *series-connected* and *parallel* configuration of solar PV modules for a required system output.

7.2 Topic Content.
Sizing of Solar Systems. Under this topic, the following sub-topics will also be introduced/taught:

a. Meaning of the terms *string* and *array*.
b. Series-connected and parallel configuration of solar PV modules.

8. Topic Eight: Electronics and converters.

8.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Differentiate between conductors, semi-conductors, and insulators.
ii) Explain doping in semi-conductors.
iii) List electronic devices made of extrinsic semi-conductors.
iv) Explain a p-n junction diode principle of operation.
v) Differentiate between rectifiers and inverters.

8.2 Topic Content.
Conductors, semi-conductors, insulators; Doping in semi-conductors; Intrinsic and extrinsic semi-conductors; Uses of extrinsic semi-conductors; p-n junction diode; Converters: Rectifiers and Inverters, half wave and full wave rectification.

9. Topic Nine: Demand-side Management – Consumer Concerns.

9.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Discuss energy saving systems and practices in electrical installations
ii) Discuss tariff types.
iii) Explain metering and billing systems.
iv) Recognise energy use and generation/availability relationships.
v) Explain health and safety practices expected in electrical installations.

9.2 Topic Content.
Demand-side Management: Energy losses; Tariff types, determination and costs; Energy Saving Systems and Practices: timers, thermostats, sensor-activated switching, smart meters, efficient-energy conversion techniques and equipment; Energy use and generation/availability relationships; Metering and billing systems; statutory obligations, meter reading, billing, revenue collection and debt recovery, pre and post-payment systems, energy outages (load shedding); Load control devices and systems; Health and safety in electrical installations, Electrical connection application procedure.

Appendix I *Proposed Content for Microgrids Knowledge Transfer to Secondary School Learners (14–18 years) – version 2*

Goal.
The goal of this content is to transfer basic microgrids knowledge to secondary school learners, aged 14 – 18, through training so that they acquire appropriate skills to benefit local communities and be motivated to join a career in engineering.

Objectives.
Upon completion, the student will be able to:

- Demonstrate relevant microgrids knowledge and skills for microgrids sustainability in communities.
- Provide recommendations for suitable household appliances for efficient and economical electrical energy utilisation.
- Perform basic household electrical installations in communities.
- Adhere to electrical health and safety protocols in any electrical-related undertakings.

Content and Intended Learning Outcomes.

0. Topic Zero: Microgrids introduction and Pre-survey. Duration: 20 min
   Objectives: To introduce the microgrids course to the students
   To perform a pre-survey

   Content: The teacher briefs learners about what microgrids are, the microgrids course in general, the course objectives, and informs learners on how they are expected to use the knowledge – sensitize and educate their parents, community members, solve community electricity related challenges, but also motivate them to pursue engineering study programmes. Shares the course information sheet and work sheet with the students and introduces the advance organise. Performs a pre-survey to capture learners' interests, expectations, and motivation. Learners watch a documentary showcasing an overview about micrograds.

1. Topic One: Microgrids. Duration: 80 Min. (2 periods)
   1.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:
   i) List the main components and sub-systems of a microgrid.
   ii) Explain the operation of a microgrid.
   iii) Discuss the advantages of microgrids giving specific examples from communities.
   iv) Discuss renewable sources of energy that power microgrids.
   v) Sketch a microgrid system block diagram.
   vi) Relate different microgrid sub-systems with those of a real microgrid.

vii) Differentiate between a microgrid or distributed electrical energy system to a centralised system.

1.2 Topic Content.

What Microgrids are; Microgrids main components, microgrids sub-systems – generation, distribution, and demand-side; Schematic diagram; Functionality/Operation of microgrids; Applications and advantages of microgrids – giving specific examples from rural communities; Renewable energy sources for power generation in microgrids; Microgrid architecture – an excursion to a nearby community microgrid is a requirement. Microgrids as distributed energy systems versus centralised grid systems.

2. Topic Two: Electrical Circuits. Duration: 80 Min. (2 periods)

2.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Define electric current, voltage, and resistance.
ii) Identify symbols used in electric circuits.
iii) Produce simple electric circuits.
iv) Use a multimeter for current and voltage measurements in simple electric circuits.
v) Differentiate between primary and secondary cells.
vi) Perform maintenance of secondary cells.
vii) Distinguish between in-front-of-the-meter (FTM – utility-based) and behind-the-meter (BTM – consumer-based) battery storage schemes.

2.2 Topic Content.

Electric current and the SI units; Voltage and the SI units; Resistance and the SI units, effective resistance in series and parallel connections; Components that make up simple electric circuits and their symbols: cell, ammeter, voltmeter, resistors (static/fixed and variable), connecting wires, bulb and switches; Construction of simple electric circuits; Current and voltage measurements; Operation of primary (dry) cells and secondary cells (lead acid battery), maintenance of secondary cells; Batteries as an energy storage scheme, utility-based (FTM) versus customer-based (BTM) battery storage schemes.

3. Topic Three: Solar PV systems. Duration: 160 Min. (4 periods)

3.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:

i) Explain the solar cells principle of operation.
ii) Perform simple photoelectric effect experiments.
iii) Wire solar cells to create PV solar modules.
iv) Determine the capacity of solar modules in (ii) above.
v) Discuss the terms *String* and *Array*.

vi) Manipulate the *series*-connected and *parallel* configurations of solar PV modules for a desired PV system output.
vii) Design a basic PV solar home system – taking the respective learners' homes as a case study.
viii) Produce a microgrid system model.
ix) Recognise energy use and generation/availability relationships.

3.2 Topic Content.
Photoelectric effect; Solar cells and PV modules: Photovoltaic (or solar) cells; Solar cells principle of operation, wiring of solar cells to form modules; Power as a measure of solar module's capacity. Sizing of Solar Systems: Meaning of the terms *string* and *array,* Series-connected and parallel configurations of modules. Solar home system design – The case of appliances in a learner's own home, or a simple household or a school office: Determination of daily energy consumption, Determination of storage (battery) capacity, Determination of PV module size, Determination of inverter and charge controller capacity. Microgrid systems models using physical components of PV solar modules, solar charge controllers, batteries, inverters, cables, and load accessories among others; Energy use and generation/availability relationships.

4. Topic Four: Domestic electrical installation. Duration: 200 Min. (5 periods)
4.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:
i) Identify accessories used in domestic electrical wiring.
ii) Explain health and safety guidelines during electrical wiring.
iii) Demonstrate the purpose of circuit breakers in electrical installations.
iv) Identify symbols of accessories used in domestic electrical wiring circuit diagrams.
v) Sketch electrical wiring circuit diagrams of basic households.
vi) Interpret electrical wiring circuit diagrams.
vii) Produce electrical wiring circuits of the sketches in ILO v) practically on soft boards.
viii) Apply fault finding and rectification procedures to electrical wiring circuits.
ix) Illustrate health and safety practices expected in electrical installations.

4.2 Topic Content.
Accessories used in domestic electrical wiring, their symbols, purpose, and the market cost: Cables (1.5 and 2.5 mm^2), circuit breakers, wall sockets, plugs, lamp holders, switches, and junction boxes, among others; Health and safety guidelines during electrical wiring, Earthing and its importance; Tools required to perform domestic electrical installations; Practical exercises on domestic electrical installations; Practical earthing in electrical installations; health and safety practices expected in electrical installations – avoid outlet overload, use of wet hands, connection of high consumption

appliances to extension sockets, among others. Electrical connection application procedure.

5. Topic Five: Uses of Electrical Energy. Duration: 80 Min. (2 periods)
   5.1 Intended Learning Outcomes. By the end of this topic, the student should be able to:
   i) List domestic, social, commercial, and industrial applications of electrical energy.
   ii) Explain the heating effect.
   iii) Perform simple electric current effect experiments.
   iv) Identify devices in which electric current heating effect is applied.
   v) Solve electrical energy and electrical power numerical problems.
   vi) Solve electrical energy consumption and cost numerical problems.
   vii) Determine the per month electrical power cost for their respective homes – as a case study.
   viii) Evaluate electrical energy cost, based on appliances' ratings, for their respective homes – as a case study.
   ix) Recommend energy-saving systems and practices in electrical installations.

   5.2 Topic Content.
   Applications of electrical energy for domestic, commercial, industrial and social facilities. Heating effect of current; Applications of the heating effect: Cooking – electric cookers, kettles and heater; lighting (bulb filament); Ironing (electric iron). Calculations involving electrical energy and electrical power; Calculations involving electrical energy cost, cost of consumed electrical energy. Demand-side management: Energy losses; Energy Saving Systems and Practices: timers, thermostats, sensor-activated switching, smart meters, efficient-energy conversion techniques and equipment; Load control devices and systems.

6. Topic Zero: Conclusion and Post-survey. Duration: 20 min
   Objectives: To summarise the microgrids course and
   To perform a post-survey.

Content: The teacher summarises the entire microgrids course, reiterates the microgrids course objectives, reminds learners on how they are expected to use the acquired knowledge – sensitise and educate their parents, community members, and solve electricity-related challenges in communities, but also motivate them to pursue engineering study programmes. Performs a post-survey to capture learners' acquired knowledge, skills, how they plan to utilize the knowledge gained, whether their expectations are met, and future career path plans.

Appendix J *Consumer Training Content Evaluation Tool*

Evaluation of the proposed content for microgrids knowledge transfer to electrical energy consumers in rural communities of East Africa

Training title: Skills to empower electrical energy consumers - for microgrids sustainability
Date of content creation: 02. January. 2024
Version: Draft 2
Creator/Author: Paul Bogere

EVALUATED BY*:

Name:	
Email:	Tel number:
Current highest education level (PLE, A-level, Craft certificate, Diploma, Degree, Masters, PhD, None):	
Where applicable:	
1. Company of employment:	Designation:
2. Consumer category: ☐ Domestic ☐ Commercial – State nature of business ………….................... ☐ Institution: School, hospital, others (specify) …………………...	Village:
Gender: ☐ Male ☐ Female Age:	Work experience/years as consumer:

*Personal information that a respondent is not comfortable sharing can be ignored.

EVALUATION

Item	Excellent (4)	Good (3)	Fair (2)	Poor (1)	Remarks if any
Intro: Microgrids sustainability can be achieved through knowledge transfer to:					
Secondary school children aged 14 – 18					
BSc Electrical Engineering students					
Electrical energy consumers					
Objectives					
The objectives are clearly defined					
The objectives align with the overall goal					
Target audience					
The target audience is clearly identified					
The content complexity is appropriate to the level of the audience					
The content aligns with the challenges of the target audience and is thus suitable to provide solutions.					
The content is suitable to the needs of the target audience					

The content is suitable to the interests of the target audience					
Content structure and intended learning outcomes (ILOs)					
The content is broken-down into themes					
The themes are clearly defined					
The ILOs are clearly defined to communicate what will be learnt					
The ILOs align with the objectives					
The ILOs are achievable					
The themes are logically and sequentially organised					
The content workload is manageable					
The content is factually correct and up-to-date					
Standardization					
The content complies with the competence-based training (CBT) requirement in terms of practical to theory ratio					
The content complies with the relevant standards and guidelines for electrical installation in buildings.					
Peer /expert review feedback					
Content was reviewed by a peer/expert					
Expert/peer suggestions are incorporated					

<u>OTHER ASPECTS</u>

1. What language should be used by the trainers?..

2. What days of the week are suggested/preferred for the trainings? (Tick all that is preferred)
   - ☐ Monday
   - ☐ Tuesday
   - ☐ Wednesday
   - ☐ Thursday
   - ☐ Friday
   - ☐ Saturday
   - ☐ Sunday
3. What time of the day is preferred for the trainings? Start ………………… End ……………

4. For how long should the training be conducted?
   - ☐ 1 – 2 weeks
   - ☐ 3 – 4 weeks
   - ☐ 5 – 6 weeks
   - ☐ 7 – 8 weeks
   - ☐ 9 – 10 weeks
   - ☐ 11 – 12 weeks
   - ☐ Other (specify) …………………...

Appendix K *Department Head/Chair Interview Guide*

Preliminary information

1. Can the University name be used and mentioned in academic publications?
2. Obtain detailed BSc Elec Eng degree curriculum currently in force/use. This is for further analysis.

B Sc EE Curriculum

1. Preamble about the reviewed curricula, the lack of microgrids knowledge.
2. Do you think it is appropriate to propose an independent microgrid course unit for inclusion in the curriculum or better to incorporate microgrid related content in existing course units?
3. How often is the BSc Elec Eng curriculum reviewed?
4. How much money is normally spent in the process of curriculum review?
5. Where does the money for curriculum review come from? Source of funds for curriculum review?
6. What is the process like for curriculum review from department through to approval and accreditation?
7. At what stage in the review process can the curriculum be used?
8. Is the BSc Elec Eng curriculum currently in force/use accredited?

   ☐ YES ☐ NO
9. What are some of the challenges that the department faces?

Admission and sponsorship

1. Are there private and government sponsored students in the department? Apart from private and government schemes, are there other sponsorship schemes?
2. How much do students pay per annum? ……………………………….. (indicate currency)
3. Are there special considerations for admission of female students to engineering academic study programmes?
4. Which special considerations are those? ……………………………………………
5. To what extent do engineering female students benefit from the special considerations?

   ☐ To a very big extent ☐ To a big extent ☐ To a small extent ☐ They do not benefit
6. Are there policies which were explicitly established to benefit female students for admission to engineering degree programmes?

   If yes:

   a) Which policies are these? Are they national or only for this University?

b) To what extent do the policies benefit female students for admission to engineering degree programmes?

□ To a very big extent □ To a big extent □ To a small extent □ They do not benefit

Others (Human resource, Career services, online teaching)

1. Obtain department statistics – **numbers of academic staff, lab/workshop technicians/engineers, and students admitted to electrical engineering programmes during the previous five (5) academic years**.
2. Which companies/organisations normally provide internship opportunities to B.Sc. Electrical Engineering students?
3. Are there any career services (mentorship and career guidance sessions or talks by invited experts from the field) organised by the department?
4. Does the University offer online teaching?
5. What is the name of the University's online learning platform/environment?
6. On which LMS (LMS) is the online platform based?

END

Appendix L *University Lecturers Interview Guide*

Preliminary information

University Identifier:	Lecturer Identifier:
Study programme:	Duration (No. of years):
Course code and name:	
CU: CH: Practical Hours:	
Year of study in which the course is taught:	Semester:
Gender of the Respondent: □ Male □ Female	Age of the respondent*:
Current highest education level (Diploma, Degree, Masters, PhD):	

* Personal information that a respondent is not comfortable sharing can be ignored.

1) Is this core or optional course?

2) What is pass mark?

3) What are the components that contribute to the course assessment for a student to pass?

4) Are there any practicals done in the department labs for this course?

5) If yes how many hours in a week? Hrs. Do you normally assist lab instructors in the process of conducting laboratories?

6) Which skills do students who opt for this course gain?

7) Where can students who do this course apply the skills gained in this course? In other words, where can they possibly be employed? Which areas/companies/organisations?

8) Are there any career services (mentorship and career guidance sessions or talks by invited experts from the field) organised in your course?

Microgrids skills

I need your expert opinion here:

1. Do you think the current BSc Elec Eng curriculum, as a whole, prepares electrical engineering students of this university to work in microgrid related environments?
   ☐ Yes ☐ No ☐ Not sure

2. Do you think it is appropriate to propose an independent microgrid course unit for inclusion in the curriculum or better to incorporate microgrid-related content in existing course units?

3. Which skills do you think should be imparted to electrical engineering students during their studies at universities to prepare them for work in microgrid-related environments?

4. What Distributed Energy Resources (DER) would you recommend or consider teaching students as vital Energy sources for microgrids?

5. Talking about microgrids, these are being fronted to ensure **sustainable electrical energy** service provision.
   i. How can sustainability be incorporated in scientific teaching?
   ii. What would you say "sustainable electrical energy" is in the local or East African context?

Microgrids Developed Content

1. Go through the proposed microgrid content with them so that they:
   a. Identify what they have previously covered in other courses (to provide names of those courses)
2. Propose what can be removed and what can be added

END

Appendix M *Questionnaire for BSc Elec Eng Junior and Senior Students*

Preliminary information

University Identifier:	Student Identifier:
Study programme:	Duration (No. of years):
Current year of study:	Current semester of study:
CGPA: on a scale of:	
Gender of the Respondent: ☐ Male ☐ Female	Age of the respondent*:
Current highest education level (A-level, Craft certificate, Diploma, Degree):	

* Personal information that a respondent is not comfortable sharing can be ignored.

1. Category of student ☐ Private ☐ Government ☐ Other(Specify) ………………….

2. Did you benefit from any special considerations for admission to the study programme? ☐ Yes ☐ No ☐ Not sure

3. If yes, which special considerations are those? ……………………………………………

4. How much money do you pay per year (indicate the currency)?

   a. Functional fees ……………………………………………………….....

   b. Tuition fees ………………………………………………………………..

   c. Accommodation ………………………………………………………...

Microgrid knowledge

1. Do you know what a microgrid is?

   ☐ Yes ☐ No ☐ Not sure

2. If yes; what do you know about a microgrid? ……………………………………………

   ………………………………………………………………………………………………

   ………………………………………………………………………………………………

Motivation, interests and skills/competencies

1. Why did you choose to do electrical engineering? What was the motivation?

2. What are your plans after graduation (tick whatever applies)?
   - ☐ Look for employment (indicate your preferred organisation/company) ………………..
   - ☐ Start own business (indicate preferred nature of business) …………..…………………..
   - ☐ Further studies (indicate target qualification) …………………………………………...
   - ☐ Other(s) – please specify …………………………………………………………………...

3. Provide information about the company/organisation where you did your internships and skills gained during every internship did.

S/N	PERIOD		COMPANY NAME	NATURE OF COMPANY BUSINESS	SKILLS GAINED
	From MM/YY	To MM/YY			
1					
2					
3					
4					

4. Would you be interested in working in a microgrid related environment?
   ☐ Yes ☐ No ☐ Not sure

5. If yes, what do you think are the required skills? ………………………………………….

<u>HERE, AN EXPLANATION OF WHAT A MICROGRID IS MAY BE GIVEN</u>

Microgrid knowledge II

1. Do you know what a microgrid is?
   ☐ Yes ☐ No ☐ Not sure

2. If yes; what do you know about a microgrid? ……………………………………………
   ………………………………………………………………………………………………

3. Would you be interested in working in a microgrid related environment?
   ☐ Yes ☐ No ☐ Not sure

4. If yes, what do you think are the required skills? ………………………………………….

END

Appendix N *Questionnaire for Laboratory Instructors*

Preliminary information

University Identifier:	Respondent Identifier:
Study programme:	Duration (No. of years):
Course code(s) and name(s):	
CU: CH: Practical Hours:	
Year of study in which the course(s) is(are) taught:	Semester:
Gender of the Respondent: □ Male □ Female	Age of the respondent:
Current highest education level (Certificate, Diploma, Degree, Masters, PhD):	

* Personal information that a respondent is not comfortable sharing can be ignored.

Laboratory/Workshop facilities.

1. Provide information regarding laboratories/workshops in the table below:

Laboratory/Workshop	Floor dimension (Sq. meter)	No. of Work benches	No. of Lab Technicians/Engineers	No. of Students handled per shift	Can the facilities adequately handle the available no. of students? Indicate on a scale of 5 (high) to 1 (low)
Machines					□5 □4 □3 □2 □1
Power					□5 □4 □3 □2 □1
Electronics					□5 □4 □3 □2 □1
Renewable Energies					□5 □4 □3 □2 □1
Telecommunications					□5 □4 □3 □2 □1
Others (Specify)					□5 □4 □3 □2 □1
1.					□5 □4 □3 □2 □1
2.					□5 □4 □3 □2 □1
3.					□5 □4 □3 □2 □1
4.					□5 □4 □3 □2 □1

2. State special considerations, if any, given to the following categories of students in the laboratories/workshops, during students' practical training sessions?
   a) Female students:
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………
   b) Students with disabilities:
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………

3. How often, in a year, are practical experiments conducted in line with the following technologies/themes? Indicate the corresponding course unit(s).

Technology/Themes	No of times in a year.	Course Unit(s)
Solar cells		
PV modules		
Wind energy		
Hydro power		
Distributed energy		

4. Is there a University policy on management of laboratories/workshops?

    ☐ Yes ☐ No. ☐ I do not know

    If the answer is yes, it would be good to get a copy.

5. Under what circumstances are lab Technicians, Technologists or Engineers recruited? Tick whatever applies

    ☐ Dependent on the number of students
    ☐ According to staff established positions
    ☐ Following approval of a new study programme in the department
    ☐ Replacement following death or resignation of a member
    ☐ Others (specify) ……………………………………………..

6. Provide short comments on how the following issues are handled:

    Skills development/training/continuous professional development of lab Technicians/Technologists/Engineers:
    ………………………………………………………………………………………
    ………………………………………………………………………………………
    ………………………………………………………………………………………
    ………………

    Maintenance/repairs/refurbishments in laboratories/workshops:
    ………………………………………………………………………………………
    ………………………………………………………………………………………
    ………………………………………………………………………………………
    ………………

    Waste management of obsolete laboratory/workshop equipment:
    ………………………………………………………………………………………
    ………………………………………………………………………………………
    ………………………………………………………………………………………
    ………………

    How should sustainability be integrated in the laboratory scientific teaching?
    ………………………………………………………………………………………
    ………………………………………………………………………………………
    ………………………………………………………………………………………
    ………………

END

Appendix O *Questionnaire for Microgrid Operators (Engineers and Technicians in Charge of day-to-day Operations)*

Preliminary information

Name of the Microgrid/Organisation:
Country:
District:
County:
Sub-county:
Parish:
Village:
Area Classification (Urban=1, Sub-Urban=2, Rural=3, Refugee Settlement=4):
Respondent's Gender (Male or Female) *:
Respondent's Position or responsibility held*:
Respondent's contact: Email*: Telephone*:

* Personal information that a respondent is not comfortable sharing can be ignored.

PRELIMINARY INFORMATION about a microgrid

1. Is the microgrid connected to any other grid?
   □ YES: If yes, select whatever applies: □ Another microgrid □ National grid
   □ NO
2. Is there any planned load-shedding?
   □ YES
   □ NO

3. Do you ever experience unplanned operational power outages?
   □ YES □ NO

4. If yes, what are the causes of the unplanned operational power outages?
   □ Technical failure. Examples …………………………………………………………………

   □ Theft or vandalism of network facilities. Name such facilities ……………………………...

   □ Harsh climatic damage of network facilities. Examples ……………………………………..

   □ Others (please specify) …………………………………………………………………….

HUMAN RESOURCE

5. Did you have experience before assuming your current position?

   □ YES; If yes how many years? ……. □ NO

6. Provide the following information:
   a) Highest qualification ………………………
   b) Sex: ☐ Male ☐ Female
   c) Years of experience ………. yrs

KNOWLEDGE AND SKILLS RELATED QUESTIONS

7. What tasks do you execute in the day-to-day operations of the microgrid?
   a) ……………………………………………………………………………………
   b) ……………………………………………………………………………………
   c) ……………………………………………………………………………………
   d) ……………………………………………………………………………………
   e) ……………………………………………………………………………………
   f) ……………………………………………………………………………………
   g) ……………………………………………………………………………………
   h) ……………………………………………………………………………………

8. What skills do you need to have so as to ably execute your duties for the day to day running of the microgrid?
   a) ………………………………
   b) ………………………………
   c) ………………………………
   d) ………………………………
   e) ………………………………
   f) ………………………………
   g) ………………………………
   h) ………………………………

9. What skills, if any, do you lack and hinder your efficient execution of duties in the day to day operation of the microgrid?
   i) ………………………………
   j) ………………………………
   k) ………………………………
   l) ………………………………
   m) ………………………………
   n) ………………………………
   o) ………………………………
   p) ………………………………

10. What skills should higher institutions of learning consider teaching students so as to enable their employability in microgrids related environments?
   a) ………………………………
   b) ………………………………
   c) ………………………………
   d) ………………………………
   e) ………………………………
   f) ………………………………
   g) ………………………………
   h) ………………………………

11. Do you provide field tours, practical/internship/industrial training opportunities to students from academic institutions?

☐ YES ☐ NO

If yes, indicate the categories of academic institutions that normally benefit from such opportunities

☐ Primary schools
☐ Secondary schools
☐ Technical institutes
☐ Technical colleges
☐ Universities
Others (please specify) ……………………………………………………

12. Do you get opportunities to attend continuous professional development or refresher trainings?

☐ YES ☐ NO

If yes, how often do you attend continuous professional development or refresher trainings?

☐ Once a year ☐ Four times a year or more
☐ Twice a year ☐ Never
☐ Three times a year ☐ Other ……….

MAINTENANCE

13. Which one of the following maintenance strategies do you employ?

☐ Routine/scheduled/Preventive maintenance
☐ Breakdown/Corrective maintenance
☐ Others (Specify) ……………………………………….

14. What components are normally maintained/serviced and after how long?

Component (indicate availability as well by ticking)	Duration in months					Key maintenance activities done
	1–3	3–6	6–9	9–12	Other	
Solar modules						
Inverters						
Energy meters						
Batteries						
Diesel generator						
Wind turbine						
Other ___________________						
Other ___________________						
Other ___________________						

15. Who provides maintenance services for the microgrid distribution subsystem?

☐ Locally trained community members
☐ Technicians appointed by microgrid owners
☐ Contracted technicians with required skills
☐ Contracted firm
☐Others (Specify)……………………………………………………………………………

CUSTOMER/DEMAND SIDE

16. Who normally provides maintenance or repair services at the consumers' premises?
    - ☐ Locally untrained community members
    - ☐ Locally trained community members
    - ☐ Technicians from the community but not employed by the operator
    - ☐ Technicians appointed by microgrid owners
    - ☐ A firm contracted by the microgrid operator
    - ☐Others (Specify)……………………………………………………………………………

17. In your opinion, what skills should electrical energy consumers be equipped with so as to support the day to day operation of a microgrid?

    a) ……………………………… e) ………………………………
    b) ……………………………… f) ………………………………
    c) ……………………………… g) ………………………………
    d) ……………………………… h) ………………………………

SDG 7: "Access to affordable, reliable, sustainable and modern energy services" by 2030

18. What would you say a sustainable microgrid is in the East African context?
    …………………………………………………………………………………………………
    …………………………………………………………………………………………………
    …………………………………………………………………………………………………
    …………………………………………………………………………………………………

    Is the microgrid(s) under your administration sustainable?

    ☐ YES ☐ NO

    What are some of the indicators (whether yes or no)?

    a) ……………………………… e) ………………………………
    b) ……………………………… f) ………………………………
    c) ……………………………… g) ………………………………
    d) ……………………………… h) ………………………………

19. What would you say reliable electrical energy is?
    …………………………………………………………………………………………………
    …………………………………………………………………………………………………
    …………………………………………………………………………………………………
    …………………………………………………………………………………………………

    Does the microgrid(s) under your administration provide reliable electrical energy?

    ☐ YES ☐ NO

    What are some of the indicators (whether yes or no)?

    a) ……………………………… c) ………………………………
    b) ……………………………… d) ………………………………

e) ………………………………
f) ………………………………
g) ………………………………
h) ………………………………

20. What would you say affordable electrical energy is?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

Does the microgrid(s) under your administration provide affordable electrical energy?

☐ YES ☐ NO

What are some of the indicators (whether yes or no)?

a) ………………………………
b) ………………………………
c) ………………………………
d) ………………………………
e) ………………………………
f) ………………………………
g) ………………………………
h) ………………………………

21. What are some of the modern energy services/facilities in the microgrid(s) under your administration?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

22. What challenges do you face in the day to day execution of your duties?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

END

Appendix P *Questionnaire for Microgrid Operators (Managers and Engineers who oversee operations)*

Preliminary information

Name of the Microgrid/Organization:
Country:
District:
County/Region:
Sub-county/Ward:
Parish (where applicable):
Village:
Area Classification (Urban=1, Sub-Urban=2, Rural=3, Refugee Settlement=4):
Respondent's Gender (Male or Female) *:
Respondent's Position or responsibility held*:
Respondent's contact: Email*: Telephone*:

* Personal information that a respondent is not comfortable sharing can be ignored.

PRELIMINARY INFORMATION about a microgrid

1. What is the designed capacity of the microgrid? ……………… MW/kW Delete as appropriate
2. What was the installed capacity of the microgrid? ……………… MW/kW Delete as appropriate
3. What is the operating capacity of the microgrid? ……………… MW/kW Delete as appropriate
4. Which of the following energy sources supply to your microgrid and what capacity?
   - ☐ Wind turbines ………………………………… MW/kW Delete as appropriate
   - ☐ Solar photovoltaics …………………………… MW/kW Delete as appropriate
   - ☐ Diesel Generators ……………………………… MW/kW Delete as appropriate
   - ☐ Utility/National Grid …………………………… MW/kW Delete as appropriate.
   - ☐ Battery Storage ………………………………… MW/kW Delete as appropriate
   - ☐ Others (Specify) …………………………………MW/kW Delete as appropriate
5. Is the microgrid connected to any other grid?
   ☐ YES: If yes, select whatever applies: ☐ Another microgrid ☐ National grid
   ☐ NO
6. Is there any planned load-shedding?
   ☐ YES ☐ NO
7. Do you ever experience unplanned operational power outages?
   ☐ YES ☐ NO
8. If yes, what are the causes of the unplanned operational power outages?
   ☐ Technical failure

□ Theft or vandalism of network facilities. Name such facilities ……………………………...
□ Harsh climatic damage of network facilities. Examples ……………………………………..
□ Others (please specify) ……………………………………………………………………….

HUMAN RESOURCE

9. Provide a breakdown of the workforce employed to run the microgrid according to the following categories of specialization:

S/N	**Category of specialization**	**No. of Males**	**No. of Females**	**Total Number**
1	Engineering			
2	Finance & Audit			
3	Business & Marketing			
4	Community Engagement			
5	Research & Development			
6	Others			
	Totals			

10. Provide a breakdown of the **engineering workforce**, as per their highest qualifications, employed to run the microgrid:

S/N	**Highest Qualification**	**No. of Males**	**No. of Females**	**Total Number**	**Remarks, if any.** Full /part-time employment, tasks in brief!
1	PhD				
2	Masters				
3	Bachelors' Degree				
4	Higher/Advanced Diploma				
5	Ordinary Diploma				
6	Advanced certificate				
7	Craft certificate				
8	Casual Workers				
9	Others (Specify)				
	Totals				

KNOWLEDGE AND SKILLS RELATED QUESTIONS

11. Do you normally employ engineering graduates <u>(degree), diploma, certificate</u> holders with no work experience?

□ YES	□ YES	□ YES
□ NO	□ NO	□ NO

*It would be very helpful to get job descriptions of all the engineering positions. Is this possible?

12. (Where applicable): How do the following engineering employee categories meet your expectations on assumption of duty (graduates (degree), <u>diploma, certificate</u> holders)?

Employee category	Rating: To an extremely large extent = 5; To a very large extent = 4; Neutral = 3; Somewhat met expectations = 2; Expectations not met at all = 1; Not applicable = 0
Graduates (degree) holders	□5 □4 □3 □2 □1 □0
Diploma holders	□5 □4 □3 □2 □1 □0
Certificate holders	□5 □4 □3 □2 □1 □0
Others (specify) …………………..	□5 □4 □3 □2 □1 □0

13. (Where applicable): How would you rate the competency of the following engineering employee categories on assumption of duty?

Employee category	Rating: Extremely competent = 5; Very Competent = 4; Competent = 3; Somewhat competent = 2; Not competent at all = 1; Not applicable = 0
Graduates (degree) holders	□5 □4 □3 □2 □1 □0
Diploma holders	□5 □4 □3 □2 □1 □0
Certificate holders	□5 □4 □3 □2 □1 □0
Others (specify) …………………..	□5 □4 □3 □2 □1 □0

14. What are some of the tasks that engineering employees involved in the day to day operation of the microgrid execute?
    a) ………………………………
    b) ………………………………
    c) ………………………………
    d) ………………………………
    e) ………………………………
    f) ………………………………
    g) ………………………………
    h) ………………………………

15. In your opinion, what skills (or competencies) do engineering employees in charge of day to day running of microgrids need to have?
    a) ………………………………
    b) ………………………………
    c) ………………………………
    d) ………………………………
    e) ………………………………
    f) ………………………………
    g) ………………………………
    h) ………………………………

16. What skills, if any, do you find lacking in the engineering employees involved in the day to day operation of the microgrid?
    a) ………………………………
    b) ………………………………
    c) ………………………………
    d) ………………………………
    e) ………………………………
    f) ………………………………
    g) ………………………………
    h) ………………………………

17. What skills should higher institutions of learning consider, for inclusion into their curricula or emphasize, to enable employability of their students in microgrids related environment?
    a) ………………………………
    b) ………………………………
    c) ………………………………
    d) ………………………………
    e) ………………………………
    f) ………………………………
    g) ………………………………
    h) ………………………………

18. Do you provide field tours, practical/internship/industrial training opportunities to students from academic institutions?

    □ YES □ NO

    If yes, indicate the academic institutions that normally benefit from these opportunities

    □ Primary schools
    □ Secondary schools
    □ Technical institutes
    □ Technical colleges
    □ Universities
    □ Others (specify) …………..

19. Do you have any MoUs with institutions that offer training services?

    Academic institutions
    □ YES
    □ NO

    Institutions, agencies or ministries that offer training services?
    □ YES
    □ NO

If yes, indicate the institutions with which you have MoUs

a) ………………………………
b) ………………………………
c) ………………………………
d) ………………………………
e) ………………………………
f) ………………………………
g) ………………………………
h) ………………………………

20. Do you provide or procure continuous professional development or refresher trainings for your employees?
 YES NO

21. How often do your engineering employees attend continuous professional development or refresher trainings?
 Once a year
 Twice a year
 Three times a year
 Four times a year or more
 Never

How do you ensure that engineering employees remain up to date with technology advances?

22. In your opinion, what are some of the skills that engineering personnel in charge of day to day running of microgrids need to receive in form of refresher trainings?

a) ………………………………
b) ………………………………
c) ………………………………
d) ………………………………
e) ………………………………
f) ………………………………
g) ………………………………
h) ………………………………

MAINTENANCE

23. Do you have a maintenance policy?
 YES NO
If yes, can I please get a copy of the maintenance policy? Obtained Not obtained

24. Which one of the following maintenance strategies do you employ?
 Routine/scheduled/Preventive maintenance
 Breakdown/Corrective maintenance
 Others (Specify) ……………………………………….

25. What components are normally maintained/serviced and after how long?

Component (indicate availability as well by ticking)	Duration in months					Key maintenance activities done
	1–3	3–6	6–9	9–12	Other	
Solar modules						
Inverters						
Energy meters						
Batteries						
Diesel generator						
Wind turbine						
Other ___________________						
Other ___________________						
Other ___________________						

26.

a. Are funds always available to carryout repairs?

☐ YES ☐ NO

b. If NO, how long does it normally take to secure funds for repairs? …….. (days)
c. If YES, what are the main sources of these funds? ………………………………

27. Who provides maintenance services for the microgrid distribution subsystem?
☐ Locally trained community members
☐ Technicians appointed by microgrid owners
☐ Contracted technicians with required skills
☐ Contracted firm
☐ Others (Specify)…………………………………………………………………………

CUSTOMER/DEMAND SIDE

28. Which pricing type do you employ in charging consumers and at what per unit rate?
☐ Time of use ………………………
☐ Flat rate …………………………….
☐ Critical peak pricing (additional charges during peak periods) ……………………….
☐ Real time pricing (prices vary over short time intervals) ………………….
☐ Critical peak rebate (incentives for not consuming energy during peak hours) ……………
☐ Others (Specify) ……………….

29. Were prospective electrical energy consumers (community members) trained before project rollout?
☐ YES ☐ NO

30. If yes, who facilitated the training?
☐ Self (microgrid operators)
☐ Contracted a firm to provide the services. Provide the firm name …………………………..
☐ A government agency/Regulator. Provide the agency name ………………………………..
☐ Others (Specify) ……………………………………………………………………..

31. In your opinion, what skills should electrical energy consumers be equipped with so as to support the day to day operation of a microgrid?

a) ………………………………	e) ………………………………
b) ………………………………	f) ………………………………
c) ………………………………	g) ………………………………
d) ………………………………	h) ………………………………

SDG 7: "Access to affordable, reliable, sustainable and modern energy services" by 2030

32. What would you say a sustainable microgrid is in the East African context?
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
Is the microgrid(s) under your administration sustainable?
☐ YES ☐ NO

What are some of the indicators (whether yes or no)?

a) ………………………………	d) ………………………………
b) ………………………………	e) ………………………………
c) ………………………………	f) ………………………………

g) ………………………………… h) …………………………………

33. What would you say reliable electrical energy is?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
Does the microgrid(s) under your administration provide reliable electrical energy?
☐ YES ☐ NO

What are some of the indicators (whether yes or no)?
a) ………………………………… e) …………………………………
b) ………………………………… f) …………………………………
c) ………………………………… g) …………………………………
d) ………………………………… h) …………………………………

34. What would you say affordable electrical energy is?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
Does the microgrid(s) under your administration provide affordable electrical energy?
☐ YES ☐ NO

What are some of the indicators (whether yes or no)?
a) ………………………………… e) …………………………………
b) ………………………………… f) …………………………………
c) ………………………………… g) …………………………………
d) ………………………………… h) …………………………………

35. What are some of the modern energy services/facilities in the microgrid(s) under your administration?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

36. What are some of the challenges that you face as a microgrid operator/owner/installer/engineer?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

37. What are some of the corporate social responsibility activities, if any, that you engage in?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

END