



Strathmore
UNIVERSITY

**A MODEL FOR ASSESSING DIGITAL TECHNOLOGY READINESS IN
MINI GRIDS**

By

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**Submitted in partial fulfilment of the requirements for the Degree of
Master of Science in Sustainable Energy Transitions at Strathmore University**

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February 2024

Declaration

This research proposal is my original work and has not been presented for a degree in any other university. No part of this proposal may be reproduced without the prior permission of the author and/ or Strathmore University. All other sources of information cited herein have been duly acknowledged.


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Abstract

In Sub-Saharan Africa, approximately 0.6 billion people lack access to electricity due to challenges with the centralized grid. Mini grids, seen as a solution for rural electrification, face sustainability issues, including technical limitations with renewable energy, outdated monitoring methods, and scalability matters. To address these challenges and strengthen their value proposition, the integration of current and emerging Digital Technologies, such as AI, IoT, Blockchain, and Cybersecurity, is recommended. This study aimed to address a critical gap in the current understanding of Digital Technology Readiness (DTR) in the context of mini grids in Kenya. Recognizing the necessity of a DTR assessment model tailored to end user preferences and the local environment, this research employed a combination of quantitative methods, inferential analysis, and fuzzy synthetic evaluation (FSE). The research methodology embraced the design thinking process and descriptive analysis to develop the DTR assessment model. Data collection involved the use of online questionnaires, employing purposive and snowball sampling techniques. These instruments sought insights from relevant stakeholders in the mini grid industry. Subsequently, surveys were conducted to validate and test the DTR assessment model, ensuring its validity and efficacy. The study findings, based on responses from diverse industry professionals, were instrumental in identifying 15 critical indicators that collectively contribute to digital technology readiness in the mini grids. Through factor analysis, these indicators were categorized into five main dimensions: Digital Literacy (DL), Digital Technology Usefulness (DTU), Digital Technology Preparedness (DTP), Digital Transformation (DT), and Digital Infrastructure Availability (DIA). The critical index values of these dimensions, in descending order, were as follows: DL (4.443), DTU (4.362), DTP (3.839), DT (3.642), and DIA (3.5). These critical index values serve as a valuable guide, emphasizing the key areas of focus in digital technology readiness. The output of this research was a DTR assessment model for mini grids. The model was tested by mini grid stakeholders and it was found to be valid and effective. The model will be used by the stakeholders to measure DT readiness in mini grids. This will aid in strategic decision-making and enhancing the industry's adaptability to the challenges and opportunities presented by Industry 4.0.

Acknowledgements

I give thanks to the Almighty God for all the blessings and gifts He has bestowed on me. Glory be to Him.

I am deeply appreciative of my supervisor: Prof. Ismail Ateya Lukandu for the patience, wisdom, and dedication he gave me while guiding me through this research.

Special recognition to Dr. Vincent O. Omwenga for the knowledge imparted during the taught lessons in research and Dr. Eng Fenwicks Musonye for being very willing and ready to spend time to offer additional guidance.

Last but not least, my class mates, Laureen Cheruiyot, Isaac Kerina and Joseph Obbo for moral support and active debates to push on.

I dedicate this research to my number one supporters, my wife; Dammarys and my children; Ian, Chebet, Ammara and Leo.

Abbreviations /Acronyms

AI	-	Artificial Intelligence
APS	-	Announced Pledges Scenario
DER	-	Distributed Energy Resources
DT	-	Digital Technologies
DTR	-	Digital Technology Readiness
EPR	-	Extended Producer Responsibility
IEA	-	International Energy Agency
IoT	-	Internet of Things
SHS	-	Solar Home Systems
SSA	-	Sub Saharan Africa
STEP	-	Stated Policies Scenario
PV	-	Photo Voltaics
TOE	-	Technology, Organization, Environment

Definition of Terms

APS	Assumes all long term energy access, emissions objectives, net-zero commitments, will be honored fully and promptly irrespective the policies to deliver them are not developed yet (<i>World Energy Outlook 2022</i>).
DER	A small scale power generator operating locally, is augmented to a bigger power grid on the distribution side. They could be controllable loads, solar PV panels, electric vehicles and tiny natural generators fueled by gas (<i>What Is Distributed Energy Resources (DER)?</i> , 2023).
EPR	Extended-producer-responsibility (EPR) is a methodology that shifts the responsibility for managing a product’s environmental impacts from the public sector to the product’s manufacturer. It was first used in Sweden. The environment is protected since the manufacturer is fully responsible for the environmental effects that the product has throughout its life cycle (Xu et al., 2021).
ICT	The components and infrastructure that facilitate new computing. They are networking hardware, applications and systems that enable interaction with the digital world (<i>ICT - Search Results / WhatIs.Com</i> , 2023).
Mini grid	A set of small electricity generators (10kW-10MW), serving few customers through a distribution grid that can function independently from the central distribution network (Michael Franz et al., 2014).
SHS	A small scale solar energy generation and storage system that supplies electricity to remote communities, small businesses or homes that are off-grid. It is also referred to as a standalone photovoltaic system. (<i>Energypedia</i> , 2022).

STEPS

A projection of the energy sector's future development that considers current initiatives, regulations and policies that are currently in place or being develop (World Energy Outlook 2022, 2022).

Technology

The use of science in engineering, industry, or other fields to solve problem or to invent useful things (*Technology Definition & Meaning / Britannica Dictionary, 2023*)

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Chapter 1: Introduction

1.1 Background

By 2020, in line with the stated policies scenarios (STEPS) viewpoint, the electricity demand in Africa is expected to reach 994 Twh. Renewables are predicted to be responsible for a bigger portion of capacity enhancements. The largest share will go to wind and solar PV with the latter outstripping the other sources of generation. With all this reality, nonetheless, 0.66 billion people around the world will not be connected to the grid and 85% of these individuals will be located in rural Sub-Saharan Africa (SSA) (*World Energy Outlook 2022*, 2022).

In SSA, the energy industry is faced with various challenges including low energy access rates, elevated prices of electricity, unreliable supply and deficit in power output to meet the region's surging demand. Increasing access to state electrical grids is considered the cost-effective way of providing services. However, decentralized power is expected to be a major component of any considerable increase in electricity access, particularly in rural and distant areas. Aspects of Smart Grid technologies can assist both sorts of systems (Welsch et al., 2013).

Decentralized systems are the most economical approach to supply power to over 50% of the people who will gain connectivity by 2030. The key drivers to this achievement are grid-connected electricity from renewable sources coupled with reducing costs of small scale solar photovoltaics (PV) used in standalone systems and mini grids (The Alliance for Rural Electrification (ARE), 2016). This is also supported by Alstone et al. (2015) who assert that the challenge of accessing the grid is especially notable for renters facing intermediary problems and those in remote areas. To overcome these barriers, options like collective connections or small grid systems for cost-efficient solutions in rural regions should be pursued. Furthermore, exploring decentralized power sources not linked to the grid, which may offer lower capacities but are more adaptable and have greater growth potential, is recommended.

Mini grids will have a substantial impact in the future of electrification; they will be the most effective way to supply power to more than 50% of rural residents who currently lack access to power (Michael Franz et al., 2014). In addition, Alstone et al. (2015) emphasized modern technology's importance for energy transition, efficiency, and access. They claimed that decentralized power systems can have distinct equity and climate effects compared to the existing system, thanks to carbon-free, high-efficiency generation supported by ICT connectivity and applications. This challenges the idea that energy access progress and climate change efforts are mutually exclusive. This is consistent with Welsch et al. (2013) who

reckoned that deployment of technology pathway will be different depending on the region and country jurisdiction owing to varying needs and aims of the different markets and societies. Pilot projects will be key to verify the technology pathways and markets.

1.2 Problem Statement

Despite efforts to address the problem of energy access in developing countries through grid expansion, this solution has proven insufficient for sparsely populated areas due to economic constraints. The emergence of mini grids as alternative shows promises in overcoming this accessibility challenge. However, the operation of these mini grid systems still faces challenges, hindering their widespread adoption. Incorporating smart digital technologies could be a viable solution to enhance the efficiency and reliability of mini grid systems.

To effectively leverage digital technologies for mini grids, it is crucial to evaluate the readiness of various stakeholders in the market. Currently, there is a lack of comprehensive information and a DTR assessment model to aid these stakeholders in making informed decisions regarding the deployment of digital technologies in mini grid systems. Therefore, the focus of this thesis is to develop a readiness model that will enable mini grid players to evaluate their preparedness for adopting digital technologies.

1.3 Research Objectives

- i. To identify critical indicators for measuring DT readiness of mini grids.
- ii. To develop a DT readiness model to illustrate mini grids readiness capabilities.
- iii. To validate and test the model.

1.4 Research Questions

- i. What are the critical indicators for measuring DT readiness of mini grids?
- ii. How can a DT readiness assessment model be developed using the identified critical indicators?
- iii. How can the DT readiness assessment model for mini grids be validated and tested?

1.5 Justification

The study's output will be the DTR assessment model. That will be used by the various stakeholders as follows.

1.5.1 Policy Makers

To make business case for DTs, to encourage uptake of DTs, formulate technical and quality standards and legislate data and consumer protections.

1.5.2 Donor agencies and private financiers

To make DTs a standard, to enforce DT usage and increase knowledge on effects of DTs and invest in profitable, sustainable, socially relevant and viable projects.

1.5.3 Technology Developers

To incorporate consumer needs, to incorporate local content in designs, data sharing via open-source platforms and to share return on experiences.

1.5.4 Customers

To make relevant contributions during public participation forums during project implementations and to demand beneficial service levels from developers and operators.

1.5.5 Developers and Operators

To make sound and informed decisions on selection, deployment, operation, and maintenance of mini grids. To have a competitive edge anchored on relevant service delivery.

1.6 Scope and Limitations of the study

The study is centred on the mini grid industry within Kenya. This study aims to develop a DTR assessment model using design thinking methodology and descriptive and inferential analysis. The focus lies on the development and validation of the model for a better understanding and evaluation of DTR. The scope does not include case studies of certain mini grids.

Chapter 2: Literature Review

2.1 Introduction

This chapter explores both the empirical and theoretical aspects of digital technologies. The discourse includes critical analyses of existing literature, theories, and concepts surrounding digital technologies. The first section scrutinizes previous studies pertinent to the development of digital technology readiness (DTR) assessment models. Here, various methodologies and approaches employed in similar investigations were dissevered and evaluated. The subsequent section delved into theories and concepts central to mini grids and the nexus of mini grids, digital technology and digital technology readiness. Fundamental theoretical underpinnings and conceptual frameworks relevant to the study were elucidated. Finally, in the last section, research gaps were identified, the conceptual framework and the operationalization of variables were developed. By and large, through this comprehensive literature review, a robust foundation for subsequent analyses and discussions was gained.

2.2 Empirical Review

This section will cover a critical review of similar studies in the development of Digital Technology Readiness (DTR) Assessment Models.

This work first explores a study by Antony et al. (2021) who researched on exploring and conceptualizing the dimensions of industry 4.0 readiness. The study used the exploratory sequential mixed method approach in UAE and Ireland. Thirty-seven senior managers took part in phase one via a purposive sampling frame. Seventy top managers took part in a web survey during phase two. The study's findings revealed that industry 4.0 readiness was made up of 10 dimensions. The criticality of the dimensions as they relate to various industries and organization types was also advanced. The work partly departs from the others. It has diversity in application rather than being industry specific as was with the rest. The study will aid in assessing the readiness of manufacturing, services, SMEs, and LEs for Industry 4.0.

Chonsawat & Sopadang (2020) aimed to define SMEs' 4.0 Readiness Indicators in Thailand, focusing on key indicators for their preparedness in the fourth industrial revolution. They investigated factors like big data, internet of things, and artificial intelligence integration into SMEs' operations. The study developed a comprehensive framework of readiness indicators to assess preparedness and identify areas for improvement. Significant factors included digital transformation, business model, collaborative robots, cloud manufacturing, and industrial internet, grouped into dimensions like digital technology, data transformation, manufacturing system, infrastructure system, and organizational resilience. The results showed high reliability

and positive correlations in SMEs' readiness, challenging the notion that industry 4.0 is only relevant to non-SME organizations. The research methodology was clear and well-executed.

De Carolis et al. (2017) in Italy aimed to create a maturity model for assessing manufacturing companies' digital readiness during the fourth industrial revolution. The model, based on the CMMI framework's core values, evaluates digital maturity in logistics, maintenance, quality management, production, design, and engineering. The researchers found that manufacturing companies need a certain level of capabilities to succeed and effectively use digital technologies. The research bridged the gap between theory and practical technology implementation for enhancing competitiveness. The tool they developed is pragmatic and relevant.

The study, “Factors affecting the Customer Acceptance of E-Banking” was conducted in Pakistan by Ilyas et al. (2013). Its objective was to assess the client's level of e-banking adoption. TAM was the model that was used. Five hypotheses were created through concentrated group interviews with senior banking management. With 208 responders from two major cities, the model was evaluated. The following step was data analysis using factor analysis with a 65% response rate. Five factors and 17 variables were the results. The results showed that only the amount of data, security and confidentiality affect client behavior. The result demonstrated that clients accept electronic banking because of its security and privacy, and the volume of information was also seen to be a deciding factor. The research was simple and straight forward using only one classic model, TAM. This shows that previous models done years earlier were well thought out and crafted. Hence, they are still relevant with age.

Encouraged by the prospect of 3D technology revolutionizing the building sector, Wu et al. (2018) did a study focusing on coming up with a framework that would encourage the use of 3D technology was done in Australia. Through a thorough literature analysis using the TAM technique, 14 factors affecting the implementation of 3D printing technology were highlighted. A survey was completed by 105 construction sector workers. The top three considerations were not technology but rather human-oriented. The theoretical knowledge was successfully crafted into a functional framework that is relevant at industry level.

Chen et al. (2022) developed a readiness model (TOWExLEi) and an assessment tool for adopting digital technologies in the construction industry in New Zealand. They blended TOE and RWCM frameworks informed by the view that both organizational and people-based elements are crucial in assessing a corporation's technology readiness. The environment dimensions were split into external-Ex and internal-Ei. Their research field was in the

construction industry. They followed the design thinking process to create a technology readiness model and an assessment tool. The resultant mathematical model of their research is as per Equation 2.1 and the model illustration is as depicted in Figure 2.1.

This is a novel study that focused on the construction industry in New Zealand. However, the weakness with this model is that the individual dimensions were hinged on RWCM framework which is anchored on change management. Not all companies are undergoing significant changes on a continuous basis. Change management is triggered by an event such as a merger, buy out, acquisition and so on which necessitates mitigation measures. Hence, unless one of these events has occurred, then RWCM is invalid.

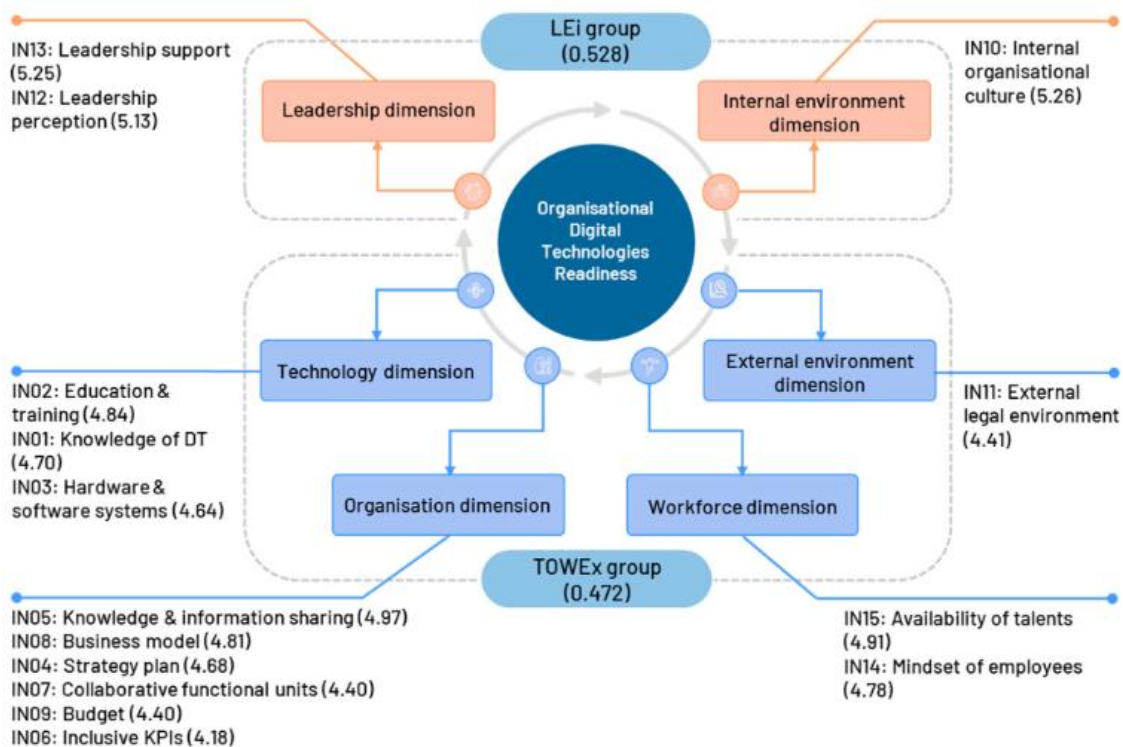


Figure 2.1: TOWExLEi Model

Equation 2.1: TOWExLEi Model

$$DT \text{ Readiness} = (0.528 \times LEi) + (0.472 \times TOWEx)$$

2.3 Theoretical Literature

This section discusses theories on mini grids, digital technologies, and digital technology readiness.

2.3.1 Mini Grids

A mini grid is defined as a set of small electricity generators (10kW to 10MW), serving few customers through a distribution grid that can function independently from the central distribution network (Michael Franz et al., 2014). It consists of different technological components that can be divided into production systems, a distribution system, along with an end-user system as depicted in Figure 2.2. The production systems generate electricity from various sources, including solar PV systems, hydropower systems, diesel generators, geothermal powered generators, biomass powered generators, and wind turbines. The mini grid can be powered by one or multiple energy sources. It also includes inverters that convert alternating current (AC) to direct current (DC), a management system for load monitoring and control, and sometimes storage in the form of batteries.

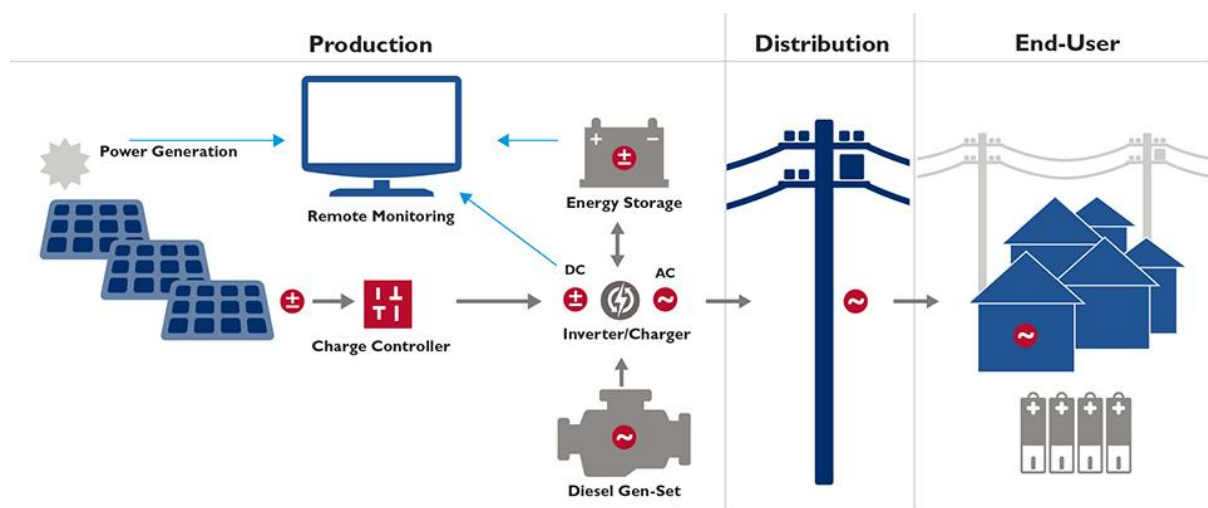


Figure 2.2: Technical components of a mini-grid system

The distribution system of the mini grid comprises transformers, transmission lines, and supporting infrastructure such as poles. Lastly, the end-user system facilitates connections for consumers to access electricity. This system consists of wiring, safety equipment, and meters (USAID, 2018).

There are four types of mini-grid models: utility operator mode, private operator model, community-based model, and hybrid operator models. In the utility operator mode, the national utility company funds and operates the mini grid. In the private operator model, a private entity funds and operates the mini grid, often through private equity, loans, grants, or subsidies. The

community-based model is funded mostly through grants and contributions from the community, and it is operated for the benefit of its members. Lastly, the hybrid operator model combines various aspects of the previously mentioned models (Michael Franz et al., 2014).

The global success of mini-grid adoption is evident, as highlighted by Deshmukh et al. (2013) in various regions. In Brazil, a targeted effort was made to electrify 250,000 families in the remote Amazon. The government provided an 85% capital subsidy, resulting in the establishment of 15 small hydro plants and a solar PV plant within a year, starting in 2010. These mini grids, strategically located in areas beyond the reach of the main grid, were operated by private actors under a Build-Own-Operate arrangement. China demonstrated a strong commitment to eventually connect all mini grids to the main grid. The township electrification program, launched in 2002, successfully connected 1,065 households within three years, integrating with other rural electrification initiatives.

In the Philippines, regulatory adjustments aimed at attracting community initiatives and private sector involvement led to the commissioning of 108 isolated grids managed by 46 operators. Nepal achieved mini-grid success through collaboration between the government and external donors, resulting in the establishment of 317 mini-hydros under the Rural Energy Development Programme and the creation of a Rural Energy Fund.

Recommendations for selecting Photovoltaic Individual Electrification Systems involve simple and cost-effective tests to assess solar PV systems before project selection, utilizing straightforward procedures (*IEC TS 62257-9-6:2019 | IEC Webstore | Rural Electrification, Solar Power, LVDC*, n.d.). The IEEE Recommended Practice for Monitoring Electric Power Quality (1159-2019) assists users, vendors, and equipment manufacturers in understanding techniques to define, measure, quantify, and interpret electromagnetic phenomena in power systems ('IEEE Recommended Practice for Monitoring Electric Power Quality', 2019).

The U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) developed the Quality Assurance Framework for Mini Grids, aiming to establish service levels, accountability, and performance reporting guidelines (Baring-Gould et al., 2016). Additionally, a sustainability model for mini grids proposed by Deshmukh et al. (2013) integrates technical, economic, social, equitable access, environmental impact reduction, and scalability factors.

However, the context differs for most countries in Africa, as outlined by Michael Franz et al. (2014). The challenges faced in most African countries include unreliable electricity demand

data, inaccurate tariff calculations, supply chain failures in spare parts delivery, misappropriation of funds, lack of clarity after a 4-year donor-based project cycle, protracted registration, permission, and licensing procedures, insufficient human capabilities, and a lack of strong legal foundations. Addressing these issues is crucial for successful and sustainable mini-grid adoption in the African context.

In Kenya, while Technology Readiness Assessment Models for mini grids appear to be absent, there are guiding documents available. The Mini Grids Technical Guidelines, proposed by the Energy Petroleum and Regulatory Authority (EPRA), offer recommendations for customer service levels based on operational standards, service availability, and power quality ('Public Participation on the Draft Mini-Grid Regulations 2021', 2021). To enhance interconnectivity between networks, the Kenya's National Grid Code outlines safe, secure, reliable, and efficient procedures for connecting to and utilizing the electrical transmission and distribution system (*Kenya-National-Distribution-Grid-Code-April-2017.Pdf*, n.d.).

2.3.2 Digital Technologies

Digital technologies rely on the transmission of extremely small signals to convey data efficiently. Smart devices possess capabilities akin to those of computers, such as internet connectivity and software usage. These digital systems encompass a variety of technologies, including blockchains, additive manufacturing, augmented and virtual reality, cloud computing, the internet of things, and artificial intelligence (Ciarli et al., 2021). Similarly, the pillars of smart technologies are IoT, big data, digital twin, cyber security, AI simulation, cloud computing and cyber physical systems (Mareschal et al., 2021). The nine pillars of the fourth industrial revolution include additive manufacturing, system integration, simulation, cyber security, augmented reality, big data analytics autonomous and robotics systems, cloud computing and the internet of things. They play vital roles in areas such as sensors, mobile and network technologies, machine learning, artificial intelligence, innovative data exchange models, advanced data analytics, fog and edge computing (Leong et al., 2020).

Artificial intelligence (AI) is described as a process that analyzes situations, facilitates and streamlines choices and implement actions by using logic-based techniques and advanced learning such as machine learning. Blockchains on the contrary are digital ledgers of records, also known as blocks, that are secured using cryptography. Each block contains a unique code, called a "hash," that links it to the previous block, forming a chain of records. Blockchains are decentralized, meaning that they are not controlled by a single entity, and they are transparent, allowing all participants to view and verify transactions. This makes blockchains highly secure

and tamper-proof, as it is difficult for any single participant to alter or delete a block in the chain without the consensus of the network (Swan, 2015).

Big Data refers to a collection of high volume structured and unstructured data sets generated by various sources such as digital transactions, internet of things devices and social media. Characteristics of big data include veracity, variety, velocity and size which make it difficult to analyze and interpret crucial information from it (Costa & Santos, 2017). We further get insights from Yu & Watteyne (2013, as cited in Suresh et al., 2014) who reckoned that IoT is a network of physical objects such as home appliances, vehicles, that are embedded with network connectivity, sensors, software and electronics that allow the objects to gather and exchange information.

Additionally, cybersecurity encompasses collective measures aimed at safeguarding cyberspace to guarantee confidentiality, authenticity, and accessibility. These efforts typically involve addressing three key components: targets, threats, and preventive actions, as highlighted by Kavak et al., (2021). Moreover, as described by Zhang et al., (2010), cloud computing represents a model for delivering hosted services via the internet. This approach centralizes data management, storage, and processing, offering users convenient access to a wide array of computing resources, including analytics, databases, intelligence, servers, software, and storage. These resources are accessible over the internet and typically come with a structured pricing model.

Wang et al., (2020), contributed to the knowledge of Machine Learning (ML) as a branch of computer science and AI focused on using algorithms and data to build systems that improve performance or mimic the way humans learn based on the information consumed. On the other hand, the link between computational and physical systems is referred to as Cyber Physical Systems (CPS). CPS can control the intricate coordination of numerous systems. Sensors and real-time embedded systems are employed in real-time data acquisition systems to gather signals from the physical world (Jamaludin & Rohani, 2018).

Augmented and Virtual Reality are technologies aimed at enhancing the way humans interact and experience the world around them. Augmented reality is focused on integrating digital information such as video sound of graphics into the physical world in real time. Virtual reality on the other hand entails the use of computer simulation and modelling allowing an individual to interact with a visual that is in three dimensions (*Gartner IT Glossary*, 2022). Digital twin is different altogether. Grieves and Vickers (2017), as cited in Sharma et al., (2022) define the

digital twin as a virtual representation of a physical object or system designed using information gathered from simulations, sensors and other sources.

While Autonomous and Robotic Systems are better explained individually. Autonomous systems use advanced technologies such as machine learning and artificial intelligence to perform tasks, make decisions and interact with their surroundings based on rules and algorithms that have already been preprogrammed. Robotic systems are made up of a physical robot equipped with control systems, actuators and sensors that allow it to perform tasks. Consequently, an autonomous robotic system can be referred to as a machine that uses AI, exists in the actual world and interacts with it (Luckcuck et al., 2019).

Simulation is an important tool in the fourth industrial revolution landscape that enables organizations to create virtual models of complex systems to enhance operations, design and decision-making. In addition, simulations assist organizations to assess and implement industry 4.0 by evaluating a wide range of possibilities (de Paula Ferreira et al., 2020). Conversely, a technology or software platform that allows information between different processes, applications and systems to be exchanged seamlessly is an Integration system (*Gartner IT Glossary*, 2022). The final one considered in this study would be Additive Manufacturing (AM) described as the creation of three dimensional objects through printing by depositing, joining or solidifying material usually in layers Stampfl and Hatzenbichler (2014, as cited in Gardan, 2016).

2.3.3 Technology Readiness and Acceptance Theories

The word readiness can sometimes be replaced by the word acceptance. It means a measure of an individual's or organization's inclination to adopt digital technology. Several theories related to technology readiness have been proposed. The ones considered to be relevant in advancing the thought process in this study are the Technology Acceptance Model (TAM), Technology-Organization-Environment (TOE) Framework, and The Readiness for Workplace Change Management (RWCM). TAM is a model which suggests that an individual's decision to adopt and use technology is based on perceived ease of use and perceived usefulness (Davis et al., 1989). The illustration is as shown in Figure 2.3.

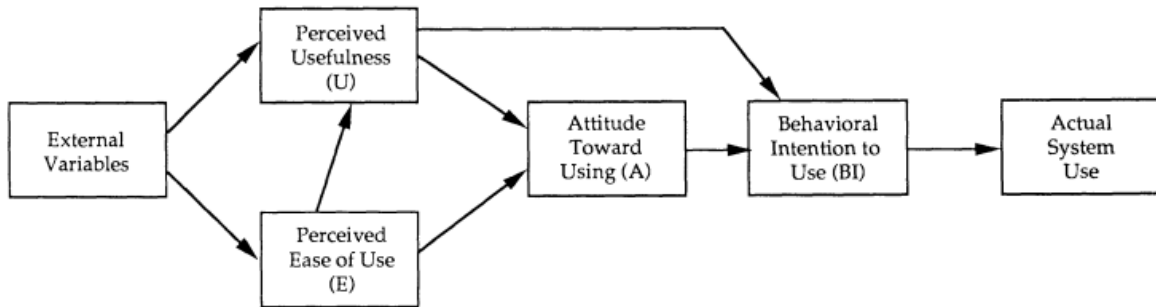


Figure 2.3: Technology acceptance Model (TAM)

Advanced by (Tornatzky & Fleischer, 1990), the Technology-Organization-Environment (TOE) framework is a widely accepted framework used to analyze technology acceptance levels at organizational level. The illustration is as Figure 2.4. The Readiness for Workplace Change Management (RWCM) framework by Becker (2005) is another important theory that focuses on leadership and workforce in workplace change management.

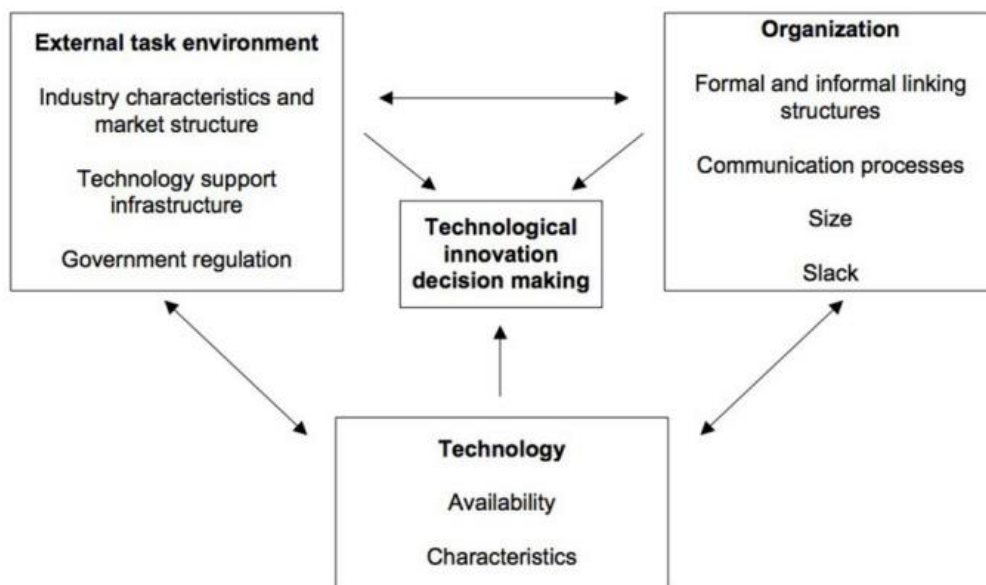


Figure 2.4: Technology-Organization-Environment Framework

2.3.4 Digital Technologies in Mini Grids ecosystem

The stakeholders in the mini grids ecosystem are customers, including households, social institutions, or small and medium enterprises (SMEs), public utilities, private developers and operators, and private financiers. As explained by Michael Franz et al. (2014), they have diverse interests that can be summarized as follows. Customers expect electricity at a reasonable price and quality to the extent that if the tariff is higher, they will agree to gain access. Public utilities have no interest to run small highly decentralized units unless the

government requires of them to run diesel generation units as a stop gap measure before the grid arrives. Private developers will only invest where there is a legal framework for generation-distribution-consumption of electricity, there is a profitable tariff and there is a designated operating zone for mini grids and protection in case the grid arrives before the end of the agreed term.

In the nexus of DT and mini grids, there are two possible areas that can be tapped into. The first area involves technical functionalities and system balancing, covering all the components such as generation with or without storage, transmission, and end-user demand-side management. The second area encompasses the mini grid value chain, which includes the productive use of electricity, design, planning, customer management, finance, and maintenance. Digital technologies offer significant benefits, such as enhanced efficiency, timesaving, cost reduction, and improved service levels for customers. These technologies have shown immense potential in addressing emerging needs and consumer demands. To harness the power of DT in mini grids, all the stakeholders in this ecosystem require a high level of collaboration to develop enabling frameworks that promote the uptake of digital technologies. These stakeholders include policy makers, donor organizations, and technology developers (Fritzsche et al., 2019). Their individual mandates are showcased in Table 2.1.

Table 2.1: DT-Mini Grids stakeholders' contribution

Stakeholder	Mandate	Reason
Policy Makers	Provide long term plans	Make business case for DTs
	Provide incentives and subsidies	To encourage uptake of DTs
	Craft regulatory frameworks	Develop specifications and standards for technical and quality aspects
	Develop legal structures	Enact laws and regulations for data privacy and consumer protection.
Donor organizations	Include DT specifications in tenders	To make DTs a standard
	Incentivize or mandate sharing of data from funded projects	To enforce DT usage
	Nurture collaboration between communities, innovators, and researchers	Increase knowledge on effects of DTs
Technology Developer	Take a design thinking approach	To incorporate consumer needs
		To incorporate local content
	Industry collaboration	Data sharing via open-source platforms
		Share return on experiences

Note: Researchers own table based on literature from (Fritzsche et al., 2019)

Policy makers play a crucial role in the mini grids industry by advocating for the adoption of Digital Technologies (DTs) and formulating supportive policies and regulations. By making a compelling business case for DTs and legislating data and consumer protections, policy makers create an enabling environment for technology adoption, fostering trust and confidence among stakeholders. Donor organizations and private financiers contribute significantly by establishing DTs as standard requirements for funding, thereby incentivizing mini-grid projects to integrate technological advancements. Their investments in profitable, sustainable, and socially relevant projects, along with efforts to increase knowledge on the positive effects of DTs, drive innovation and progress in the industry.

Meanwhile, technology developers play a pivotal role by incorporating consumer needs into design, embracing local content, and facilitating data sharing through open-source platforms,

ensuring that digital solutions are user-friendly, inclusive, and interoperable. Their collaboration with policy makers and financiers, coupled with a commitment to sharing experiences and lessons learned, accelerates the adoption and impact of digital technologies in the mini grids industry.

Sustainability and relevance of mini grids depend on meeting critical criteria, which can be achieved through the incorporation of digital technologies. Fritzsche et al. (2019) conducted research and identified these requirements. Firstly, mini grids should be powered by Renewable Energies (RE), necessitating the use of DTs to manage the intermittency of renewable sources effectively. Secondly, mini grids must consider the socio-economic context and be held accountable for it, requiring the application of digital planning and design tools. Thirdly, ensuring equity and affordability in electricity costs within mini grids calls for big data utilization for planning and intelligent management and operating tools. Moreover, mini grids need to provide reliable electricity services, which can be achieved through demand estimation and sizing using DTs.

Additionally, to foster productive use, DTs should integrate potential productive equipment to enhance their efficiency. The adaptability of mini grids is essential, and DTs play a crucial role in ensuring scalability and accommodating new trends, such as prosumers (consumers who also produce electricity). Besides, DTs enable transparency and consumer protection by addressing data protection and shared platforms. Finally, mini grids should strive to minimize their ecological footprint, requiring the implementation of predictive maintenance, longevity, and effective e-waste management, all of which can be facilitated through DTs. By fulfilling these criteria and embracing digital technologies, mini grids can continue to thrive and contribute to sustainable energy solutions.

Figure 2.5 illustrates the nexus DT and mini grids that covers both technical and value chain.

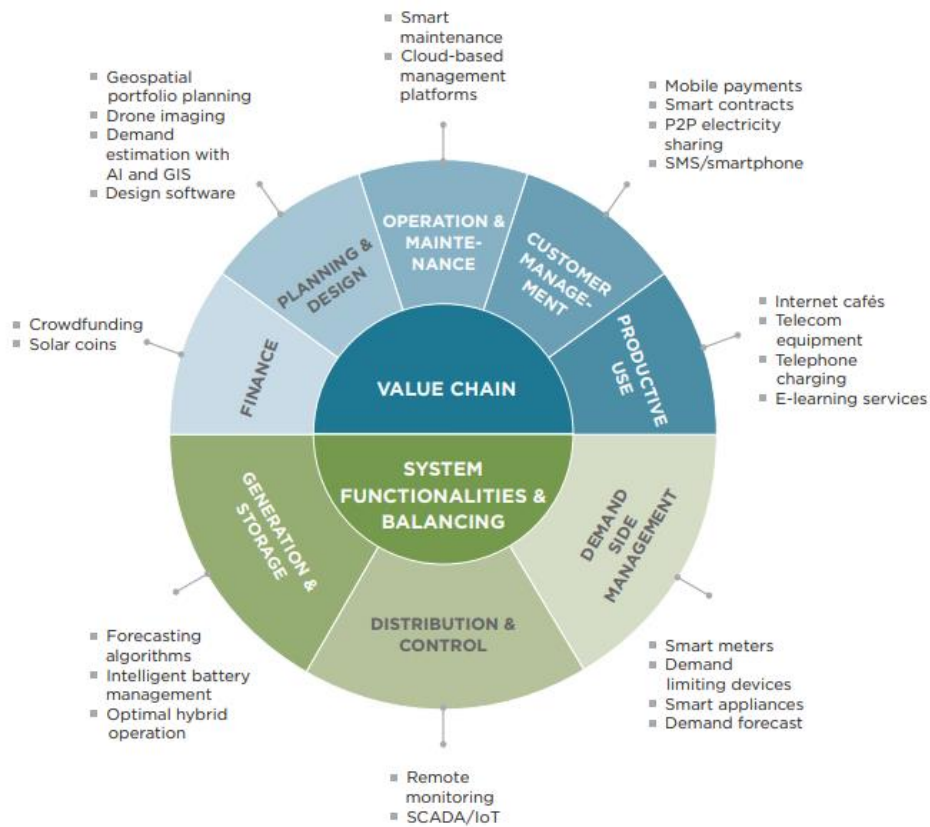


Figure 2.5: Digital Technologies in mini grids

2.4 Research Gaps

According to the available, researched, and analyzed literature, Digital Technology Readiness models and assessment tools have been developed for industries other than energy. Further, the TOWExLEi readiness model which is the foundation of this study was done in the construction industry in New Zealand. I adopted the research design albeit with changes to the contributing frameworks. The TOWExLEi model is a blend of TOE Model and RWCM framework which are based on organizational and individual dimensions and that is fine. While I agree with TOE adoption, I do not think RWCM is fully representative of businesses on a going concern. It is based on change management, which is not always the case unless a company has experienced an event that necessitates intervention. Hence, I decided to use TOE Model and TAM frameworks instead. TAM is grounded on perceived usefulness (PU) and Perceived ease of use (PEOU) which are very personal to users.

2.5 Conceptual Framework

Figure 2.6 shows the relationships between the variables. The inputs are DTR dimensions and indicators processed via scientific methods. The output is a DTR assessment model.

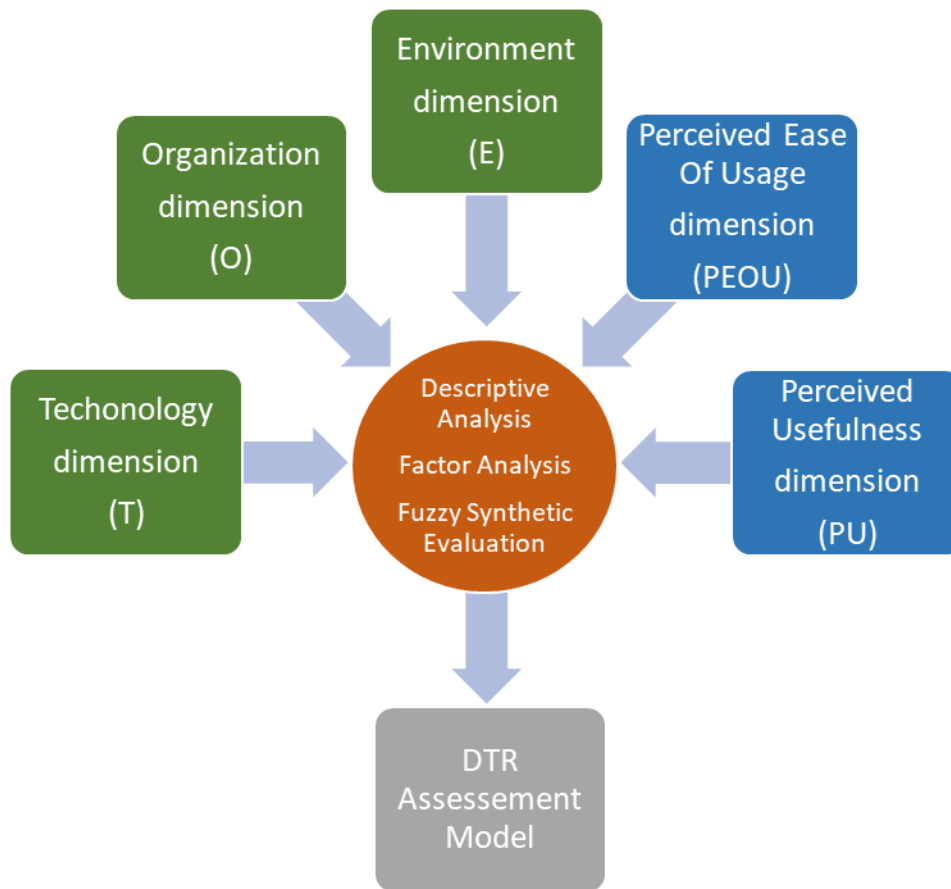


Figure 2.6: Conceptual Framework: DTR assessment model for mini grids

Through FSE modeling, the resultant mathematical model will be a function of the variables as illustrated by Equation 2.2.

Equation 2.2: FSE Model Framework

$$\text{MG-DTR } m = f(T, O, E, \text{PEOU}, \text{PU})$$

2.6 Operationalization of variables

The concept is Digital Technology Readiness, split into 5 dimensions; Technology, Organization, Environment, Perceived Ease of Use and Perceived Usefulness. The first three are from TOE framework and the last two are from TA Model. Each of those dimensions were assessed using specific measurable variables expressed as statements in a questionnaire. The statements embody indicators based on literature. The indicators were measured using a Likert scale.

Table 2.2: Operationalization of variables

1 Concept				
Digital Technology Readiness				
5 Dimensions				
Technology	Organization	Environment	Perceived Ease	Perceived Usefulness
15 Variables				
T1: Knowledge	O1: Strategy	E1: Culture	PE1: Understanding	PU1: Speed
T2: Education	O2: Model	E2: Governance	PE2: Learning	PU2: Performance
T3: Infrastructure	O3: Budget	E3: Collaboration	PE3: Difficulty	PU3: Helpful
15 Questionnaire Statements/ Indicators				
T1: Information on new digital technologies and areas of application is well understood	O1: Digital Technology adoption strategy within the organization is clear	E1: The organizational culture embraces digital technology innovation and implementation	PE1: I would be able to understand and interact with digital technology clearly	PU1: I could complete jobs faster if I used digital technologies
T2: Employees are educated and trained to be technologically competent	O2: The model of the organization supports using emerging digital technologies	E2: There are adequate legal and ethical regulations governing technology adoption	PE2: Learning to operate digital technology would be easy for me	PU2: My performance at work would increase if I used digital technology
T3: Infrastructure for adopting digital technologies are in place	O3: Digital technologies implementation is budgeted for	E3: Cross functional collaboration to initiate and utilize digital technology is at the desired level	PE3: Digital technology would be easy for me to use	PU3: Using digital technologies would make my work easier
Source				
Chen et al. (2022)	Chen et al. (2022)	Chen et al. (2022)	Ilyas et al. (2013)	Ilyas et al. (2013)
Wu et al. (2018)	Becker (2005)	Wu et al. (2018)	Heijden (2000)	Gefen & Straub, 1997
Tornatzky & Fleischer, 1990	Tornatzky & Fleischer, 1990	Tornatzky & Fleischer, 1990	Davis et al. (1989)	Davis et al. (1989)

Operationalization of variables for Digital Technology Readiness in Mini Grids is summarized in Table 2.2. The concept is assessed through a set of 15 indicators, each designed to measure specific aspects of readiness. The operationalization involves employing a 5-point Likert scale, where respondents are asked to rate each indicator on a scale from 1 to 5. The Likert scale ranges from 1 (Strongly Disagree) to 5 (Strongly Agree), allowing participants to express their level of agreement with each statement associated with the indicators.

The 15 indicators served as key variables, and the Likert scale responses facilitated a quantitative measurement of the perceived readiness of mini grids in adopting digital technology. Operationalization ensured a structured and standardized approach to data collection, enabling the researcher to analyze and quantify the extent of agreement or disagreement across the indicators. The Likert scale provided a nuanced understanding of the participants' perspectives on the various dimensions of digital technology readiness in mini grids, contributing to a comprehensive assessment of the research objectives.

Chapter 3: Methodology

3.1 Introduction

This chapter presents the methods employed to achieve the objectives of the study. The first section gives an overview of the research design. The second section describes the process of performing fuzzy synthetic evaluation then the specifics of the field setting, study population and determination of the sample size. The last section provides detailed insights into the instruments and methods utilized for data collection and analysis. Furthermore, this chapter addressed additional considerations crucial to the research process; aspects related to research and data quality, dissemination, utilization of results and finally the ethical considerations that were adhered to throughout the study were explained. In conclusion, the comprehensive methodologies outlined in this chapter not only lay the foundation for achieving the study's objectives but also underscore the meticulous attention paid to research integrity, data quality, and ethical standards throughout the entire research process.

3.2 Research design

This study adopted the method suggested by (Chen et al., 2022) to meet the objectives of the study. It is illustrated in Figure 3.1.

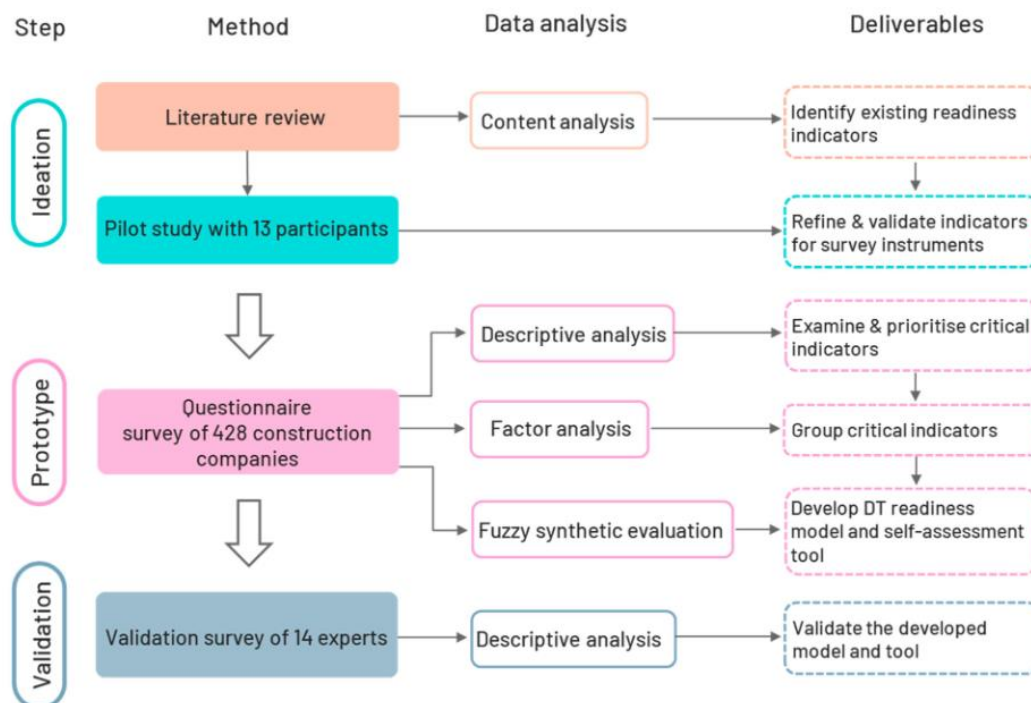


Figure 3.1: A DTR Model for construction industry

This research followed the design thinking methodology as follows.

Ideation

- a) Literature review to identify existing DTR dimensions and indicators.
- b) Draft a Questionnaire based on identified DTR dimensions and indicators.
- c) Pilot study with a few stakeholders to refine and validate the indicators.

i) Prototype

Questionnaire survey with more stakeholders to

- d) Examine and prioritize critical indicators.
- e) Group critical indicators.
- f) Propose a DTR assessment model.

ii) Validation

- g) To check the validity and efficacy of the proposed DTR assessment model.

3.3 Implementation of the Fuzzy Synthetic Evaluation (FSE)

Fuzzy synthetic evaluation, also referred to as fuzzy synthetic judgment or fuzzy evaluation, is a decision-making and evaluation technique designed to address the challenges posed by complex, uncertain, or imprecise data. This approach is grounded in the principles of fuzzy logic, a mathematical methodology capable of managing vagueness and ambiguity in data through the representation of fuzzy sets (Goguen, 1973).

The FSE steps used in this study is as follows (Oppong et al., 2021);(Osei-Kyei et al., 2017):

- 1) Set up of the basic set of indicators as $\Pi = \{p_1, p_2, p_3, p_4 \dots p_m\}$, where m is the number of indicators
- 2) Define the set of grade alternatives of the measurement scale as $F = \{f_1, f_2, f_3, f_4, \dots f_n\}$ with f_n representing the alternatives of the adopted 5-point Likert scale (f_1 = strongly disagree, f_2 = disagree, f_3 =neutral, f_4 =agree, and f_5 = strongly agree).
- 3) Calculate the weighting vectors (WV) for individual indicators or groups from the mean scores (MS) in the survey data using **Equation 3.1**:

Equation 3.1: Weighting Vectors

$$WV_i = MS_i / \sum_{i=1}^7 MS_i, 0 \leq WSi \leq 1 \sum WSi = 1$$

- 4) Determine the fuzzy evaluation matrix $R_i = (r_{ij})_{m \times n}$, where r_{ij} is the extent to which alternative f_j satisfies the criterion p_i

5) Establish the ultimate evaluation matrix D_i by using **Equation 3.2**:

Equation 3.2: Evaluation Matrix

$$D_i = W_i \circ R_i$$

where \circ denotes the fuzzy composition operator.

6) Determine the overall criticality index by normalizing D_i using **Equation 3.3**:

Equation 3.3: Critical Index Calculation

$$\text{Criticality index} = \sum_{i=1}^7 D_i \times F$$

3.4 Field Setting

The field setting of this research was the mini grid industry in Kenya.

3.5 Targeting Population

By June 2022, EPRA had approved 100 mini grids in Kenya. Sixty were privately owned while 41 were public utilities controlled by the Kenya Power and Lighting Company. Mini grids that were privately owned have a total installed capacity of 22MW and 91 % were powered by solar photovoltaics. The Public utilities were 31MW thermal, 2.26MW solar photovoltaics and 0.55MW wind generated ('Energy & Petroleum Statistics Report for the Financial Year Ended 30th June 2022', 2023). The study used purposive sampling.

Purposive sampling is a non-probabilistic sampling technique in which the researcher relies on their judgement to select a sample that will be a part of the study ('Purposive Sampling', 2023). This is supported by Black (2019) who stated that purposive sampling is a non-probability sampling technique that is achieved when the respondents of the study are selected based on the researcher's judgement. Researchers who select this technique prefer it because they believe that using their sound judgement will assist them in obtaining a representative sample that saves time and money.

The specific profiles that were targeted were the executive, finance, operations, engineering, and other personnel with technological implementation responsibility. Once the developers and operators were engaged, they nominated relevant individuals from their partners drawn from consumers, donors, financiers, and technology developers to participate.

3.6 Sampling Size

The study targeted 80 respondents from a population of 100. The number of 100 respondents was based on an assumption that one stakeholder per mini grid is sufficient to articulate the situation of the mini grid. The sample size was determined using the Yamane (1967) sampling method, with a 95% confidence level.

Yamane's formula is explained in **Equation 3.4** as:

Equation 3.4: Yamane sample size equation

$$n = \frac{N}{1 + Ne^2}$$

where:

- n is the sample size,
- N is the population size (number of mini grids, i.e., 100 with one technical expert each),
- e is the margin of error (expressed as a proportion, in this case, 0.05 for a 95% confidence level).

Calculation:

$$n = \frac{100}{1 + 100 \times (0.05)^2}; n = \frac{100}{1 + 100 \times 0.0025}; n = \frac{100}{1 + 0.25}; n = \frac{100}{1.25}; n = 80$$

Therefore, the calculated sample size based on the Yamane's formula was 80. The Yamane 1967 sampling method provided a systematic and statistically sound approach to determine an appropriate sample size for the study. By employing this method, the researcher sought relevant information from 80 stakeholders, ensuring a representative and reliable dataset for analysis.

3.7 Data Collection/Instrumentation

3.7.1 Primary Data

The primary data for this study was collected using online Questionnaires. A draft Questionnaire was used in the pilot study. The aim was to present the proposed DTR indicators to a few stakeholders to validate their relevance, enhance and clarify the survey. The output was a survey Questionnaire which was used in the research survey. The purpose of the survey was to collect data from a wider audience drawn from the stakeholders to examine and prioritize critical indicators. The output was research data.

The consent form and the draft questionnaire used for the pilot study are presented in Appendix A and Appendix B respectively.

3.7.2 Secondary Data

Secondary data refers to data that has been collected and analyzed by someone other than the researcher for a different purpose. It involves using existing data from various sources, such as research articles, reports, or datasets, to address new research questions or objectives. Zotero's suitability for bibliometric analysis and secondary data management has also been acknowledged by experts in the field of bibliometrics and scientometrics. In their work, van Eck & Waltman, (2014) underscored the importance of using dedicated bibliometric software tools like Zotero to enhance the accuracy and efficiency of bibliometric analysis. They particularly highlighted the benefits of such tools in identifying key trends, seminal works, and influential authors within a specific research domain. In the context of this study, secondary data utilized was from previously published literature, such as academic papers and studies, to identify and analyze existing DTR theories, models, dimensions, and indicators.

3.8 Data Analysis Methods

Data was analyzed at various levels of the research. Content analysis was carried out during literature review while descriptive and inferential data analysis was undertaken on the questionnaire survey using Statistical Package for the Social Sciences (SPSS) software. This was done to find the critical indicators for DTR. The analysis involved factor analysis, t-test, reliability test and fuzzy synthetic evaluation (FSE). FSE output was the mathematical model depicting the relationship between the variables. Cronbach's alpha was used to measure the reliability test, interrelating, and reducing the number of indicators was carried out using factor analysis while the indicator's relative contribution levels and their categories was qualified and determined using FSE.

3.8.1 Research Quality and Data Quality

The pilot study targeted 10% of the sample size (8/80). The questionnaire survey targeted the sample size of 80 respondents out of the possible population of 100 respondents. Saunders et al., (2019) recommend a 95% confidence level with an error margin positive or negative 3% to 5%. He also recognizes that getting a 100% response is rare. The pilot survey results were used to fine tune the Questionnaire to ensure there are no misunderstandings and to make it relevant. The online Questionnaires were sent either via official emails, via LinkedIn or via WhatsApp. Integrity and fidelity to the processes was observed as follows: literature review, pilot survey, Questionnaire survey, model design and model calibration, and validation by the stakeholders. To ensure data quality the Questionnaire was tested in advance for reliability using Cronbach Alpha. It should have a minimum score of 0.7 (Salkind, 2010).

3.8.2 Utilization of results

These results of the study will be used to advance rural electrification in Kenya, by leveraging Digital Technologies to improve mini grid performance and sustainability. The Digital Technology Readiness (DTR) assessment model will guide mini grid operators, policymakers, and stakeholders in the energy sector on how to prioritize the DTR dimensions and to make strategic decisions based on that. The DTR model assesses current technological capabilities and identifies areas for improvement, enabling informed decisions about integrating AI, IoT, Blockchain, Cybersecurity, and other digital innovations into mini grid systems. Policymakers and regulatory authorities can use the findings to develop policies and incentives that promote the integration of Digital Technologies in mini grid projects. The research outcomes facilitate knowledge exchange and capacity-building among stakeholders, raising awareness of the benefits and challenges associated with integrating Digital Technologies. This will empower decision-makers to make informed investments, collaborate effectively, and optimize mini grid project performance.

3.8.3 Dissemination of results

To effectively communicate the outcomes, the study employed various visualization tools including frequency tables, pie charts, and graphs. Dissemination was through diverse channels such as formal meetings, official emails, conferences, social media platforms, and both journal and conference paper publications. Dissemination of research findings plays a crucial role in bridging the gap between research and practical implementation. According to Wilson et al., (2010), research dissemination involves a deliberate process through which the results or conclusions derived from experiments, studies, and research are shared and made accessible to a broader audience. The targeted audience was mini grid stakeholders.

3.8.4 Ethical considerations

The research was carried out in line with ethical standards prescribed by Strathmore University policy and guidelines. A University letter indicating the purpose and objective of the study was provided. Before answering the Questionnaires, participants were requested to give their consent. The respondents were informed of the study's nature and purpose. For reasons of secrecy, the Questionnaire had the fields of the names of organizations, people, and contacts optional. Google Forms online application instruments for gathering data, did not gather any system data, including the computers' IP addresses of the responders. The National Commission for Science, Technology, and Innovation (NACOSTI) and Strathmore University

gave prior consent for the study, providing the researcher access to the designated respondents to gather the necessary data.

Chapter 4: Results

4.1 Introduction

This chapter presents the findings of the study structured into three sections. The first section examines the results of the pilot study, offering insights into the preliminary findings gathered during the initial phase of the research regarding the data collection instruments. The second section presents both descriptive and inferential statistics, encompassing a comprehensive analysis that includes t-test and fuzzy synthetic evaluation (FSE). The output of the FSE is presented using a mathematical model, illustrating the relationship between the various dimensions of the 15 indicators under study. Lastly, the third section expounds the outcomes of the model validation process conducted by experts, alongside the testing of the Digital Technology Readiness (DTR) assessment model; this involved the assessment of the DTR model's efficacy using data gathered from 10 mini-grid companies operating within the country. In summary, this chapter delivers a thorough examination of the study's findings, ranging from the initial pilot study insights to the comprehensive statistical analyses, culminating in the validation of the DTR assessment model through rigorous expert evaluation and real world application within the context of mini grids in the country.

4.2 Questionnaire Tests

4.2.1 Pilot Test

There was validity and reliability test for the data collection instruments to assess authenticity of the instrument used to collect the data. The study used Cronbach Alpha test for the purposes of reliability test analysis while the instrument validity test was conducted using expert opinion in the rating of the data collection instrument. The researcher used 10% of the sample size which is 8 respondents, selected at random for the pilot study. The researcher used purposive sampling in identifying the respondents for the pilot test where only those who had been in the industry for more than 5 years were given chance to participate in the validation of the data collection instruments.

4.2.2 Reliability Test

The researcher used the Cronbach Alpha test in the reliability analysis where any Alpha value above 0.7 was regarded as valid indicating that the data collection instrument had good internal consistency and could be replicated on a different population.

Table 4.1: Reliability Results

Reliability Statistics	
Cronbach's Alpha	N of Items
.873	8

The value obtained as shown in the

Table 4.1 indicates that the data collection instrument was reliable as given by the Cronbach's Alpha value of 0.873 which is above 0.7. The findings indicated that the data collection tools are consistent and can be relied upon for a repeat result of the same output from different cohorts. The number of items of 15 are the number of questionnaires that were used by the researcher in measuring the study objectives. The 0.7 value for reliability test is supported by (Shemwell et al., 2015) who indicated that a scale that result in an Alpha of at least 0.7 are considered reliable for any kind of test. It gives a good internal consistency of the data collection instruments thus indicating that they can be relied upon for data collection and analysis of the results.

4.2.3 Validity Test

The 8 experts that participated in the validation of the data collection instruments had a minimum of 5 years of experience in the mini grid systems in Kenya. They consisted of 4 engineers, 2 operation managers, 1 researcher and 1 consultant. The mean score rating for the validation of the data instruments is as presented in the Table 4.2.

Table 4.2: Validation Results

Validation Statement (N=8)	Mean	P-value
The 1-5 rating scale used is reasonable and applicable to assess the digital technology readiness (DTR) in mini grids	4.2	0.03
The identified indicators are enough to assess DTR in mini grids	3.8	0.02
The identified indicators are practical and relevant for the study	4.5	0.01
The questions asked are objective and clear with respect to the DTR assessment	4.0	0.04
The questions asked are very comprehensive and ready to understand with regards to the DTR assessment	4.3	0.02

*Two-tailed

A rating scale of 1-5 was used where the respondents were asked to state the extent to which they rate the instruments with 1 being the lowest and 5 being the highest. The ratings were as given in Table 4.2 which indicates that all the ratings had a mean greater than 3 which was a high score for the data collection instrument. The Wilcoxon signed rank test that was conducted to establish whether there existed a difference between the actual means score of 3 and the theoretical mean score obtained. Testing at 95% confidence level, the p-values obtained were all significant, indicating that the mean values obtained were significantly higher than 3 which is the actual mean. The validation results indicated that the data collection tool indicators were predictable and relevant for the study.

4.3 Data Analysis Results

4.3.1 Response Rate

The study targeted 80 respondents who received the online questionnaire for data collection.

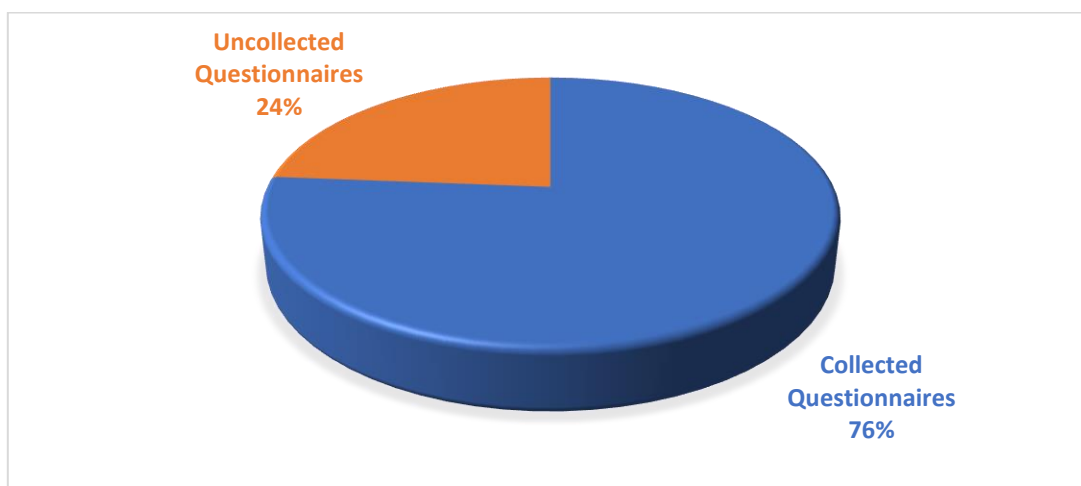


Figure 4.1: Response rate (%)

As indicated in **Figure 4.1**, the response rate for the study was at 76% where 61 out of the 80 respondents filled and submitted the online questionnaire. A response rate of above 70% is a good response for any study as given out by (Creswell, 2003).

The study finding in Table 4.3 gives the description of the respondents with respects to designation of the respondents, role played in the mini grid industry and years of experience of the respondents.

Table 4.3: Descriptive Statistics

Indicators	Frequency	Percentages
Designation of the Respondents		
CEO	5	8.2
Operations Manager	5	8.2
Engineer	18	29.5
Senior Manager	11	18.0
Consultant	4	6.6
Others	18	29.5
Total	61	100.0
Role in the Mini-Grid Industry		
Technology Developer	20	32.8
Operator	9	14.8
Finance Lender	1	1.6
Research Institution	4	6.6
Others	27	44.3
Total	61	100.0
Years of Experience		
Below 5	15	24.6
Between 5-10	26	42.6
Between 11-15	11	18.0
Between 16-20	5	8.2
Over 20	4	6.6
Total	61	100.0

4.3.2 Designation of the respondents

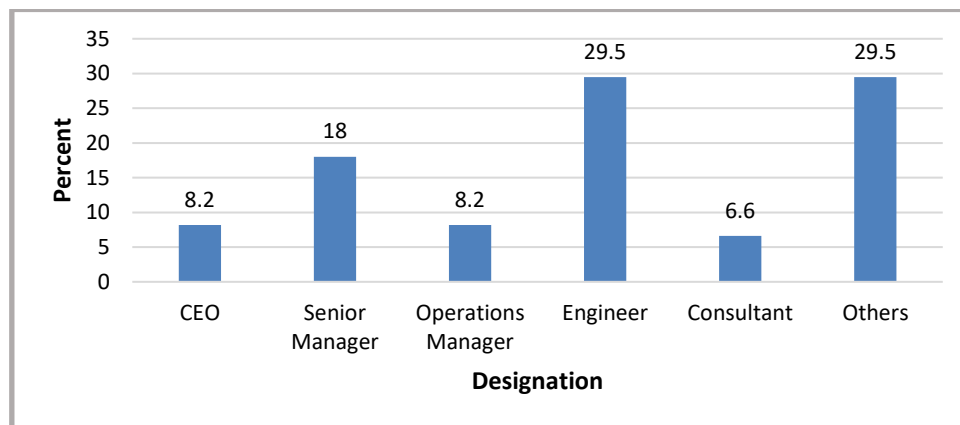


Figure 4.2: Designation of the respondents

Figure 4.2 shows that majority of the respondents in the study were engineers at 29.5% followed by senior managers at 18% and 8.2% as operations manager. 8.2% of the respondents were chief executive officers while 6.6% were consultants. Other roles reported by the

respondents include business development, technical officers, accounting, and other management roles.

4.3.3 Role of the mini grid industry stakeholders

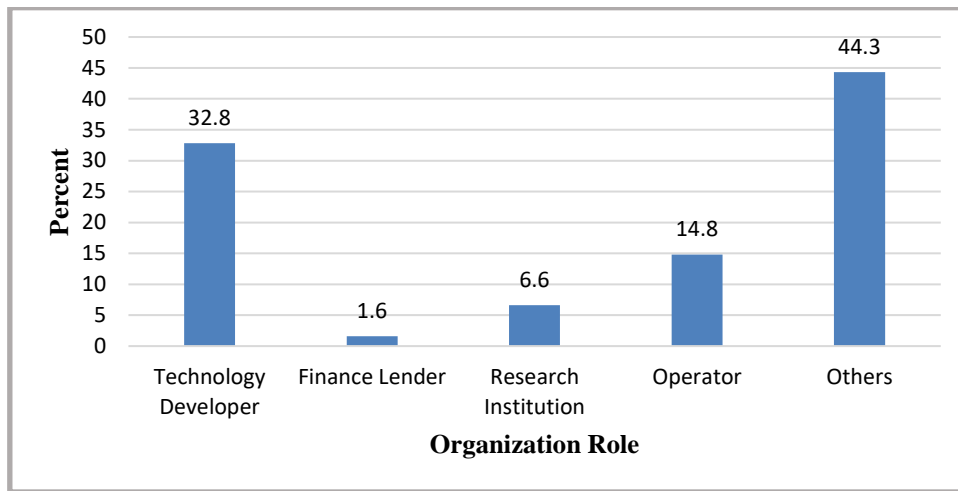


Figure 4.3: Role of organizations

The mini grids industry stakeholders played various roles as depicted in Figure 4.3. Approximately 33% were technology developers while 14.8%, 6.6% and 1.6% were operators, researchers and financial lenders respectively. A significant proportion played other roles such as policy and advocacy, and legal.

4.3.4 Years of experience

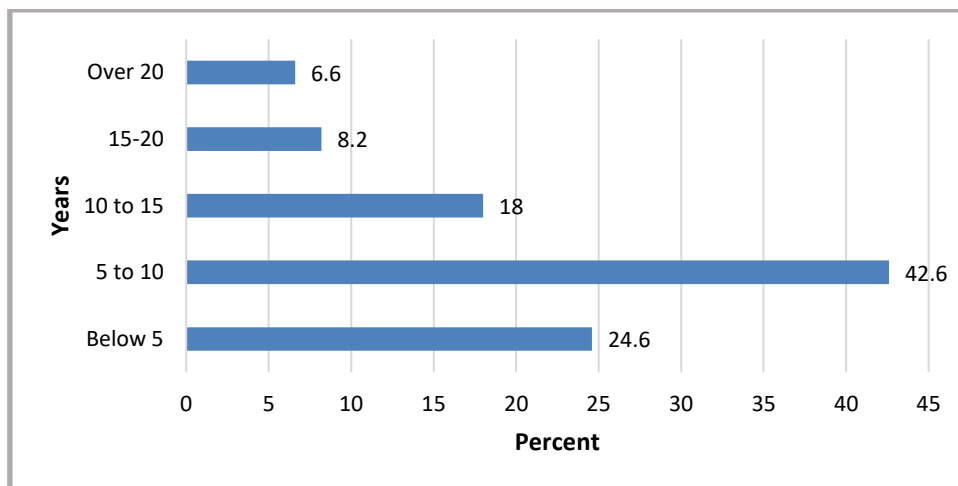


Figure 4.4: Years of experience

Majority of the respondents had 5-10 years of experience at 44.3% indicating a cohort that has good experience in the mini grids industry in Kenya. This is seen in Figure 4.4.

4.3.5 Ranking of the Indicators

Table 4.4: Ranking of the Indicators

Ref.	Indicator	Mean	SD	T-value	P-value	Ranking
PE3	Digital technology would be easy for me to use	4.525	0.62	19.14	0.000	1
PE2	Learning to operate digital technology would be easy for me	4.475	0.67	17.11	0.000	2
PU1	I could complete jobs faster if I used digital technologies	4.377	0.82	13.12	0.000	3
PU3	Using digital technologies would make my work easier	4.377	0.86	12.51	0.000	4
PE1	I would be able to understand and interact with digital technology clearly	4.344	0.70	14.90	0.000	5
PU2	My performance at work would increase if I used digital technology	4.328	0.87	11.92	0.000	6
E1	The organizational culture embraces digital technology innovation and implementation.	3.885	1.20	5.77	0.000	7
O2	The model of the organization supports using emerging digital technologies	3.820	0.99	6.45	0.000	8
T2	Employees are educated and trained to be technologically competent	3.770	0.80	7.48	0.000	9
O1	Digital Technology adoption strategy within the organization is clear.	3.689	1.04	5.16	0.000	10
O3	Digital technologies implementation is budgeted for	3.639	1.10	4.56	0.000	11
T3	Infrastructure for adopting digital technologies are in place	3.492	1.03	3.74	0.000	12
E3	Cross functional collaboration to initiate and utilize digital technology is at the desired level	3.475	1.01	3.68	0.001	13
E2	There are adequate legal and ethical regulations governing technology adoption	3.344	1.18	2.28	0.026	14
T1	Information on new digital technologies and areas of application is well understood	3.197	1.05	1.47	0.147	15

The 5-point Likert measurement of the 15 items was reliable at 5% significance level with a Cronbach's Alpha of 0.891. The mean score and the ranking results for all the indicators are presented in Table 4.4 above giving the top five variables in descending order as the PE3, PE2, PU1, PU3 and PE1. Testing at 5% two tailed test, the mean results for one sample t-test was significant as all the p-values except T1 were less than 0.05. The mean scores of all the

indicators were significantly higher than the neutral value of 3.0 indicating that the indicators that are critical for the remaining stages of analysis.

4.3.6 Factor Analysis Results

Table 4.5: KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.785
Bartlett's Test of Sphericity	Approx. Chi-Square	670.470
	df	105
	Sig.	.000

KMO and Bartlett tests are seen in Table 4.5. The KMO test examines how the factors (variables) explain each other. KMO values closer to 1.0 are considered ideal while those below 0.5 are unacceptable. A value of 0.785 is greater than the acceptable value of 0.7 as given by (Kaiser, 1974) which is an indication that the data can produce valid factor analysis results. The KMO measure of 0.785 indicates a strong partial correlation between the variables thereby ideal for factor analysis.

The Bartlett's Test of Sphericity tests the null hypothesis that the correlation matrix is an identity matrix. Correlation matrix refers to unrelated variables which are not ideal for factor analysis. The significant test ($p < 0.001$) indicates that the correlation matrix is not an identity matrix, therefore, we reject the null hypothesis.

Table 4.6: Factor Loadings and Eigenvalues of the Principle Indicators

INDICATOR	COMPONENTS				
	1	2	3	4	5
E1	0.838				
O2	0.824				
O3	0.797				
E3	0.635				
E2	0.573				
PE1		0.922			
PE2		0.901			
PE3		0.869			
PU2			0.918		
PU3			0.895		
PU1			0.737		
T1				0.923	
O1				0.571	
T2				0.498	
T3					0.86
Eigenvalue	6.437	2.05	1.469	1.208	1.009
Variance explained (%)	42.916	13.668	9.793	8.054	6.725
Cumulative variance explained (%)	42.916	56.583	66.377	74.431	81.156

Extraction method: Principle Component Analysis

The KMO and BTS demonstrated that the results were factorable as per Table 4.6. The Principle Component Analysis (PCA) generated 5 groups based on eigenvalues greater than 1. The five components accounted for 81.2% of the total variation with Factor 1 explaining approximately 43% of the variation. The factor loadings of 0.5 and above indicate a strong correlation between the variable and the factor as supported by (Oppong et al., 2021).

4.3.7 Fuzzy Synthetic Evaluation Results

Table 4.7: Fuzzy Synthetic Evaluation Results

Indicators	Weights		Membership function		Criticality Index
	Individual	Group	Individual	Group	
G1		0.376		(0.06, 0.11, 0.19, 0.43, 0.21)	3.642 (0.184)
E1	0.205		(0.1, 0.03, 0.08, 0.46, 0.33)		
O2	0.203		(0.03, 0.08, 0.15, 0.51, 0.23)		
O3	0.198		(0.06, 0.08, 0.2, 0.46, 0.2)		
E3	0.198		(0.03, 0.15, 0.26, 0.43, 0.13)		
E2	0.197		(0.06, 0.2, 0.25, 0.31, 0.18)		
G2		0.205		(0.00, 0.00, 0.1, 0.35, 0.55)	4.443 (0.225)
PE1	0.360		(0.00, 0.00, 0.13, 0.39, 0.48)		
PE2	0.323		(0.00, 0.00, 0.1, 0.33, 0.57)		
PE3	0.317		(0.00, 0.00, 0.07, 0.34, 0.59)		
G3		0.189		(0.03, 0.00, 0.05, 0.42, 0.5)	4.362 (0.220)
PU2	0.340		(0.03, 0.00, 0.07, 0.41, 0.49)		
PU3	0.332		(0.03, 0.00, 0.05, 0.39, 0.53)		
PU1	0.328		(0.03, 0.00, 0.02, 0.46, 0.49)		
G4		0.176		(0.03, 0.16, 0.18, 0.5, 0.13)	3.839 (0.194)
T1	0.339		(0.05, 0.25, 0.23, 0.41, 0.07)		
O1	0.337		(0.03, 0.13, 0.15, 0.49, 0.2)		
T2	0.324		(0.00, 0.10, 0.16, 0.61, 0.13)		
G5		0.054		(0.03, 0.15, 0.26, 0.41, 0.15)	3.5 (0.177)
T3	1.000		(0.03, 0.15, 0.26, 0.41, 0.15)		

As detailed in Table 4.7, Individual and group weights of the variables were calculated based on the mean scores calculated in Table 4.4. The membership functions (MFs) for both individual factors and groups were also generated. The MFs were based on respondents' ratings of each indicator, for instance, 10% of the respondents rated E1 as strongly disagree, 3% as disagree, 8% as neutral, 46% as agree and 33% as strongly agree. Therefore, the MF for E1 was expressed as (0.1, 0.03,0.08,0.46,0.33). The MFs for the 5 groups were also generated based on the average rating for each group. For instance, for Group 1 indicators which assess Organizational Digital Transformation Readiness (DTR), 6% of the respondents strongly disagree, 11% disagree, 19% neither agree nor disagree, 43% agree while 21% strongly agree. Therefore, the MF for Group 1 was expressed as (0.06,0.11,0.19,0.43,0.21). The Critical Indices (CI) were then calculated for each group.

4.3.8 The DT Readiness Assessment Model

4.3.8.1 Mathematical equation

The 5 groups were abbreviated based on what the indicators measure. Group 1 consisting of (E1, O2, O3, E2, E3) measured Digital Transformation (DT) at the organizational level was abbreviated as DT. Group 2 (PE1, PE2, PE3) assessed digital literacy (DL) and was abbreviated as DL. Group 3 (PU1, PU2, PU3) assessed digital technology usefulness and was abbreviated as DTU. Group 4 (T1, O1, T2) assessed digital technology preparedness and abbreviated as DTP. Group 5 (T3) measured availability of digital infrastructure and abbreviated as DIA. The critical index (CI) for DT, DL, DTU, DTP and DIA were calculated as 3.642, 4.443, 4.362, 3.839 and 3.5 respectively. The CIs were normalized to 0.184, 0.225, 0.220, 0.194 and 0.177 respectively to give a sum of unity (1). Based on the normalized CIs, the DT readiness model was expressed as shown in Equation 4.1.

Equation 4.1: DTR Assessment Model Equation

$$\text{DTR model} = (\text{DT} \times 0.184) + (\text{DL} \times 0.225) + (\text{DTU} \times 0.22) + (\text{DTP} \times 0.194) + (\text{DIA} \times 0.177)$$

4.3.8.2 DTR Assessment model template

Explained in Table 4.8, the DTR Assessment model template was developed based on Equation 4.1 for practitioners to self-assess their mini grids' DT readiness. The maximum criticality index score for DT readiness is computed as a sum of the product of maximum score and group criticality index. The model allows users to rate themselves on a 5-point scale (1=strongly disagree, 2=disagree, 3=neutral, 4=agree, 5=strongly agree). Lower scores of an indicator signifies poor readiness, therefore, that indicator is an obstacle to technology transformation.

Table 4.8: Organizational DTR Assessment Model template

Indicator	Statement	Participant Rating	Weighted Rating	Group Max score	Criticality Index
Group 1	Digital Transformation (DT)			5	0.184
E1	The organizational culture embraces digital technology innovation and implementation.	X	0.205*X		
O2	The model of the organization supports using emerging digital technologies	X	0.203*X		
O3	Digital technologies implementation is budgeted for	X	0.198*X		
E3	Cross functional collaboration to initiate and utilize digital technology is at the desired level	X	0.198*X		
E2	There are adequate legal and ethical regulations governing technology adoption	X	0.197*X		
Group 2	Digital Literacy (DL)			5	0.225
PE1	I would be able to understand and interact with digital technology clearly	X	0.360*X		
PE2	Learning to operate digital technology would be easy for me	X	0.323*X		
PE3	Digital technology would be easy for me to use	X	0.317*X		
Group 3	Digital Technology Usefulness (DTU)				0.22
PU2	My performance at work would increase if I used digital technology	X	0.340*X		
PU3	Using digital technologies would make my work easier	X	0.332*X		
PU1	I could complete jobs faster if I used digital technologies	X	0.328*X		
Group 4	Digital Technology Preparedness (DTP)			5	0.194
T1	Information on new digital technologies and areas of application is well understood	X	0.339*X		
O1	Digital Technology adoption strategy within the organization is clear	X	0.337*X		
T2	Employees are educated and trained to be technologically competent	X	0.324*X		
Group 5	Digital Infrastructure Availability (DIA)			5	0.177
T3	Infrastructure for adopting digital technologies are in place	X	1.000*X		
	Maximum possible score				5
	DT Readiness Total Calculated Score (TCS)				TCS
	DTR Level (% to Maximum Possible Score)				(TCS/5) %

The calculated score, computed as a percentage of the maximum possible score, serves as a measure of technological readiness for each assessed mini grid. A score falling below 60% indicates a poor level of technological readiness within the mini-grid. Scores ranging between 60% and 80% suggest a moderate level of readiness, albeit with notable areas requiring significant improvements. Conversely, a score above 80% signals a high level of overall digital technology readiness for the mini grid under assessment as shown in Figure 4.5.

DTR LEVELS	
<60%	Not ready
60-80%	Somewhat ready
>80%	Ready

Figure 4.5: DTR Levels

Chapter 5: Discussion

5.1 Introduction

In this chapter, key indicators crucial for evaluating technology readiness within the mini grids industry as per the results of the study are explained. Through the application of factor analysis, the 15 identified indicators have been categorized into five main dimensions: Digital Transformation (DT), Digital Literacy (DL), Digital Technology Usefulness (DTU), Digital Technology Preparedness (DTP), and Digital Infrastructure Availability (DIA). Notably, the descending order of Index Values for these indicators reveals DL as the highest-ranking indicator (4.443), followed by DTU (4.362), DTP (3.839), DT (3.642), and DIA (3.5). These Index Values serve as pivotal metrics, guiding attention towards the primary areas necessitating focus in assessing technology readiness within the mini grids industry. To sum up, this chapter offers an extensive examination of the five critical indicators identified, providing valuable insights into their implications and significance within the contemporary technological landscape of mini grids.

5.2 Digital Literacy (DL): Group 2

As seen in Table 4.6, the group explained 13.668% of the total variance and the loadings of the three indicators were 0.922, 0.901 and 0.869. The DL group had a higher impact on technology readiness compared to the other 4 groups with normalized critical index of 0.225 as per Table 4.7. Digital literacy was measured by the ability of key stakeholders to understand (PE1), learn (PE2) and use (PE3) digital technologies in the mini grids industry. The three indicators which assessed individual digital literacy had mean scores of 4.344, 4.475 and 4.525 and were ranked 5th, 2nd and 1st respectively in Table 4.4. Of the three indicators, PE1 had a higher impact on technology readiness owing to its higher loading factor. The emergence of new technologies and the current industry 4.0 transition has led to increased demand for technological knowledge and skills especially in tech-oriented sectors such as the energy industry (Reddy et al., 2020). The ability and ease at which individuals learn, understand and interact with digital technologies is an important indicator of DT adoption.

The three indicators in this group align with the framework proposed by Martin & Grudziecki, (2006) specifically corresponding to the first level of digital literacy as depicted in the **Figure 5.1**. At Level I, digital competency is encapsulated, encompassing not only knowledge and skills but also attitudes and awareness regarding digital technologies, as elucidated by (Reddy et al., 2020). The practitioners within the mini grids industry demonstrated a robust understanding and awareness of digital technologies, thereby establishing a foundation of

strong digital competence. This competence, in turn, facilitates the utilization and operation of digital technologies. The findings of this study align with existing literature emphasizing the critical role of digital literacy in shaping technology readiness and the success of technology-driven industries such as the mini grids sector (Farias-Gaytan et al., 2022; Kateryna et al., 2020).

Notably, low levels of digital literacy emerge as a significant impediment to the Industry 4.0 transformation, particularly within the socio-economic context of emerging economies. Recognizing the challenges posed by low digital literacy, (Radovanović et al., 2020) underscore the pivotal role of community tech hubs in enhancing digital literacy, especially in regions with limited connectivity, such as sub-Saharan Africa. The study further advocates for the implementation of comprehensive digital literacy programs that incorporate both text and vocal communication, as well as online and offline content.

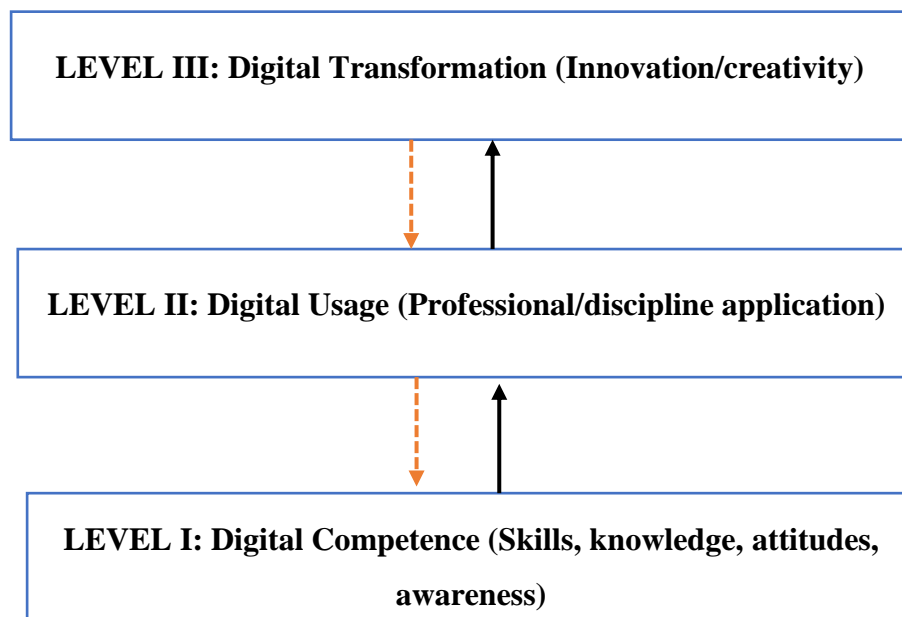


Figure 5.1: Levels of Digital Literacy

5.3 Digital Technology Usefulness (DTU): Group 3

The result as per Table 4.6 indicate that the group of indicators explained 9.8% of the total variation, with loadings of 0.918, 0.895, and 0.737 for the three indicators. Among these, Digital Technology Usefulness (DTU) emerged as a significant factor in technology readiness, following Digital Literacy (DL), with a normalized critical index of 0.22 as seen in Table 4.7. This emphasizes the substantial impact of understanding and effectively utilizing digital technology on the overall readiness of stakeholders in the mini grids industry.

The assessment of the three indicators (PU2, PU3, and PU1) focused on the usefulness of digital technology, with mean scores of 4.328, 4.377, and 4.377, respectively as per Table 4.4. These indicators ranked 6th, 4th, and 3rd, indicating their importance in evaluating the readiness of technology. Notably, PU2 had the highest loading, suggesting that its assessment is crucial in determining how digital technology can enhance the performance of key stakeholders in the mini grids industry.

The findings emphasize the interconnectedness of digital literacy and digital usefulness, highlighting the dependence of the latter on the former. This relationship involves the practical application of digital tools to process data, identify problems, and find solutions. The alignment of these indicators with the second level (Level II) of Martin & Grudziecki (2006) digital literacy framework, focusing on digital usage, further supports the relevance of these assessments in the context of technology readiness.

In summary, the results underscore the significance of Digital Technology Usefulness (DTU) and its associated indicators in shaping the technology readiness landscape for mini grids. The emphasis on digital literacy and practical application aligns with established frameworks, providing valuable insights for stakeholders aiming to enhance their readiness for digital transformation in the mini grids industry.

5.4 Digital Technology Preparedness (DTP): Group 4

In Table 4.6 the Digital Technology Preparedness (DTP) group in the mini grids industry, as indicated by its 8.1% contribution to the total variation, plays a significant role in shaping the industry's readiness for digital technology adoption. The factor loadings of 0.923, 0.571, and 0.498 for the three indicators (T1, O1, and T2) underscore the importance of these dimensions in assessing the industries' preparedness. The mean scores for the individual indicators, with T1 at 3.197, O1 at 3.689, and T2 at 3.77, as per Table 4.4 provide insight into their perceived importance, ranking 15th, 10th, and 9th, respectively. These scores indicate that, while Digital Technology Preparedness is recognized as significant, there is room for improvement in specific areas identified by these indicators.

The normalized index of 0.194 for DTP, as seen in Table 4.7 reaffirms the relevance of this group in evaluating technology preparedness. Notably, T1, with the highest loading among the three indicators, emerges as a critical dimension. This suggests that understanding new digital technologies and their application is a key determinant of technology preparedness in the mini grids industry. The results imply that stakeholders in the mini grids industry need to focus on

enhancing their understanding and proficiency in new digital technologies. This may involve investing in training programs, fostering collaboration with technology developers, and staying abreast of emerging digital trends. The prioritization of T1, as indicated by its high loading, emphasizes its central role in shaping the overall readiness of the industry for the digital transformations unfolding in the broader technological landscape.

In conclusion, the results related to Digital Technology Preparedness highlight specific areas within the mini grid industry that require attention and improvement. Addressing the aspects outlined by T1, O1, and T2 will contribute to enhancing the industries' overall preparedness for the evolving challenges and opportunities associated with digital technology adoption.

5.5 Digital Transformation (DT): Group 1

The group consisting of 5 indicators explained 42.9% of the total variation with factor loadings ranging from 0.838 to 0.573 as seen in Table 4.6. The indicators were ranked as per Table 4.4 as follows E1 7th, O2 8th, O3 11th, E3 13th and E2 14th respectively. The indicators under DT were institutional or organizational indicators of digital technology readiness with a normalized index of 0.184 as per Table 4.7. Of the 5 indicators, organizational culture (E1) had the strongest correlation to organizational digital transformation. This is consistent with the work done by Edwards et al. (2002) who concluded that an organization's ability to innovate is reliant on its culture. Organizational culture refers to the customs, values and beliefs within a working environment which impact productivity, innovation and performance. Key components of organizational culture include core values and shared beliefs, work ethic and communication, leadership styles, and adaptability (continuous learning and innovation). Understanding and managing organizational culture is a critical determinant of digital transformation in the mini grids industry.

These findings imply that the successful integration of digital technologies in the mini grids industry goes beyond technological aspects; it is intrinsically linked to the cultural fabric of organizations within the industry. The emphasis on organizational culture reflects the acknowledgment that a positive and adaptive workplace culture is vital for fostering innovation and effectively navigating the complexities of digital transformation.

In the mini grids industry, where the dynamics of Industry 4.0 are actively shaping operations, recognizing the importance of organizational culture becomes a strategic imperative. Leaders and stakeholders must prioritize cultivating an organizational culture that values continuous learning, embraces innovation, and adapts to the evolving digital landscape. This approach not

only enhances digital technology readiness but also positions organizations within the mini grids industry to thrive in the era of digital transformation

5.6 Digital Infrastructure Availability (DIA): Group 5

The Digital Infrastructure Availability (DIA) group in the mini grid industry is represented by a single indicator, demonstrating its significance in the context of digital technology. This indicator has an index value of 0.177, as per Table 4.7 with a substantial factor loading of 0.86 as seen in Table 4.6, indicating a high correlation with the overall technology readiness in the industry.

Digital infrastructure, as defined in the study, encompasses interconnected technologies, networks, and systems used for the storage, processing, and transmission of digital information, involving both hardware and software elements. The presence of robust digital infrastructure is considered a prerequisite for the effective adoption and integration of digital technologies within any industry, including the mini grids industry. The index value and high factor loading of the DIA indicator underscore the critical role that digital infrastructure plays in shaping the readiness of the mini grids industry for digital transformation. It signifies that the availability and quality of digital infrastructure significantly contribute to the industry's capacity to leverage and implement digital technologies.

The study's acknowledgment of the importance of digital infrastructure aligns with the broader trends in Africa, where there has been a gradual increase in digital infrastructure development. However, the pace of progress in this area is noted to be comparatively slower than in other regions (Calderon & Cantu, 2021). This observation emphasizes the need for concerted efforts to accelerate the development of digital infrastructure in the mini grids industry, ensuring that it keeps pace with the demands of Industry 4.0.

In conclusion, the DIA group's single indicator highlights the centrality of digital infrastructure availability in determining the mini grid industries' readiness for digital technology adoption. Stakeholders in the industry must prioritize investments and initiatives that enhance digital infrastructure to create an environment conducive to the successful integration and utilization of digital technologies. This will not only foster innovation but also contribute to the industries' overall resilience and competitiveness in the rapidly evolving landscape of digital transformation.

5.7 Validation of the model

The survey results and DT Readiness model were validated by 15 experts composed of engineers, senior managers, operations managers, and a CEO. The results tabulated below in Table 5.1 indicate higher mean scores ranging from 4.20 to 4.73 with an average score of 4.47. The P-values of the 7 statements were significant at 1% confidence level. In conclusion, the experts strongly agreed that the DTR assessment model was practical, applicable, and replicable in assessing digital technology readiness in the mini grids industry.

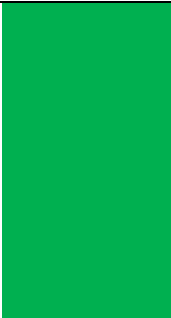


Table 5.1: Validating the model (N=15)

	Validation Statement	Mean	P-Value
Q1	The indicators are practical	4.27	<0.001
Q2	The categories are adequate	4.73	<0.001
Q3	The 1-5 rating scale is reasonable	4.47	<0.001
Q4	The research methodology used in replicable	4.67	<0.001
Q5	The DTR model is useful and practical	4.60	<0.001
Q6	The DTR model is applicable in the mini grid industry	4.33	<0.001
Q7	The model is objective and reliable for assessing DT Readiness in mini grids	4.20	<0.001

5.8 Testing the DTR Assessment model

To further confirm its effectiveness in the field, the DTR assessment model was deployed to assess the readiness of 10 select mini grids. The results are as shown in Table 5.2;

Table 5.2: Results for Testing DTR

Company	Mini Grid Ownership	County	DTR score	DTR level
A	Multinational Private	Nairobi	92%	
B	Local Parastatal	Homabay	87%	
C	International Private	Kisii	86%	
D	Local Private	Meru	86%	
E	International Advisory	Mandera	86%	
F	Local Private	Nairobi	84%	
G	Local Parastatal	Garissa	76%	
H	Local Parastatal	Wajir	66%	
I	Local Parastatal	Tharaka Nithi	57%	
J	Local Parastatal	Turkana	57%	

In the context of the study, the deployment of the Digital Technology Readiness model aimed to assess the readiness of ten selected mini-grid companies. The results indicate a noteworthy finding: 80% of the assessed mini grids demonstrated technological readiness. This majority comprises predominantly private and international companies, suggesting that entities with private and international affiliations tend to be more technologically prepared for the digital landscape within the mini grids industry.

Conversely, the study found that 20% of the assessed mini grids were not technologically ready. Strikingly, this mostly minority consists of public entities, indicating that companies under government ownership face challenges or gaps in technological readiness when compared to their private and international counterparts. A significant factor contributing to their lower readiness levels was the absence of essential digital infrastructure. This deficiency in infrastructure specifically tailored for digital technology deployment and utilization highlights a critical gap within these entities, potentially hindering their ability to effectively integrate and leverage digital tools and solutions within their operations.

These results shed light on the varying levels of digital technology readiness within the mini grids industry, emphasizing a potential correlation between ownership structure (private/international vs. public) and technological preparedness. Further exploration into the specific factors influencing this divide could offer valuable insights for policymakers, stakeholders, and industry participants to address potential barriers and enhance overall technology readiness in the industry.

Chapter 6: Conclusion and Recommendations

6.1 Conclusion

In summary, the study successfully identified and categorized 15 critical indicators for assessing technology readiness in the mini grids industry. Utilizing factor analysis, these indicators were consolidated into five dimensions and ranked accordingly as listed: Digital Literacy (DL), Digital Technology Usefulness (DTU), Digital Technology Preparedness (DTP), Digital Transformation (DT), and Digital Infrastructure Availability (DIA). The derived index values for these dimensions, with DL having the highest value (4.443) and DIA the lowest (3.5), provide a clear hierarchy of importance.

Digital Literacy (DL) emerged as the top priority, with a high index value of 4.443, emphasizing the significance of understanding, learning, and using digital technologies among key stakeholders. This aligns with the global shift towards Industry 4.0, where proficiency in digital literacy becomes a crucial factor in technology adoption. Digital Technology Usefulness (DTU) follows closely, with an index value of 4.362, highlighting the practical application of digital tools in processing data and finding solutions. The interconnectedness of digital literacy and usefulness underscores the dependence of effective technology utilization on a strong foundation of digital literacy.

Digital Technology Preparedness (DTP) is identified as a key area for improvement, with an index value of 3.839. The emphasis on understanding new digital technologies, as indicated by the highest loading factor (T1), suggests that stakeholders need to enhance their proficiency through training programs and collaboration with technology developers. Digital Transformation (DT), focusing on organizational indicators, holds substantial importance with an index value of 3.642. Organizational culture, represented by E1, is identified as a critical determinant of digital transformation in the mini grids industry. This highlights the need for a positive and adaptive workplace culture to facilitate innovation and navigate digital complexities.

Digital Infrastructure Availability (DIA), represented by a single indicator, emphasizes the crucial role of robust digital infrastructure with an index value of 3.5. The result underscores the need for accelerated efforts to develop digital infrastructure in the mini grids industry, aligning with broader trends in Africa. These findings hold significant implications for stakeholders in the mini grids industry during the ongoing transition to Industry 4.0. The prioritization of digital literacy, technology usefulness, preparedness, transformation, and infrastructure availability offers valuable insights into key areas that demand attention and

investment. By focusing on these critical indicators, industry players can enhance their technology readiness and adapt more effectively to the demands of the evolving landscape.

The developed model not only serves as a comprehensive framework for assessing technology readiness but also acts as a practical auditing template for decision-makers and stakeholders. As the mini grids industry navigates the complexities of Industry 4.0, the insights provided by this study can guide strategic planning, resource allocation, and policy formulation. Ultimately, the research contributes to a deeper understanding of the digital dynamics within the mini grids industry, fostering informed decision-making and sustainable development in the era of technological advancement.

6.2 Recommendations

Based on the findings, the study makes the following recommendations:

i) Policy Makers:

Formulate and advocate for policies that make a strong business case for the adoption of Digital Technologies (DTs) in the mini grids industry. Encourage stakeholders by showcasing the potential benefits of DTs in enhancing efficiency, sustainability, and overall readiness for the industry's digital transformation.

ii) Donor Agencies and Private Financiers:

Establish and enforce the adoption of DTs as a standard requirement for funding mini grid projects. Invest in initiatives that are not only profitable but also socially relevant, sustainable, and viable. Promote knowledge dissemination on the positive impacts of DTs to enhance understanding and encourage broader adoption.

iii) Technology Developers:

Incorporate consumer needs into the design of digital technologies for the mini grids industry, ensuring user-friendly solutions that address specific challenges. Embrace local content in designs to promote inclusivity and relevance. Facilitate knowledge exchange through open-source platforms and share experiences to contribute to a collective understanding of successful technology implementations.

iv) Customers:

Actively engage in public participation forums during mini grid project implementations to provide valuable insights and feedback. Demand beneficial service levels from developers and

operators, emphasizing the importance of customer satisfaction and positive technology impacts on their experience.

v) Developers and Operators:

Make informed decisions throughout the mini-grid project lifecycle, from selection and deployment to operation and maintenance. Prioritize relevant service delivery to stay competitive and aligned with the evolving needs and expectations of customers in the digital era. Foster a culture of continuous learning and innovation within the organization to maintain a competitive edge in the rapidly advancing technological landscape.

6.3 Future Work

The insights derived from this study are grounded in the perspectives of professionals within the mini grids industry. It is important to note that the specificity of the industry context may limit the applicability of the findings to other industries within the broader energy landscape. Consequently, future studies could;

- i) replicate similar studies across diverse energy related domains to facilitate the formulation of a universally applicable model for assessing technology readiness in the broader energy landscape.

or,

- ii) research on case studies of certain mini grids to practically implement the model and make necessary adjustments if any that can only be realised through experimentation.

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Appendices

Appendix A: Consent form

PARTICIPANT INFORMATION AND AGREEMENT FORM

SECTION 1: PARTICIPANT DETAILS

1.1: Study Overview

Research Title: Designing a readiness model and self-assessment tool for adopting digital technologies in mini grids.

1.2: Investigator

Principal Investigator: Ken Korir. K

1.3: Institutional Affiliation

Affiliated Institution: Strathmore University

SECTION 2: ABOUT THE RESEARCH

2.1: Research Purpose

Objective of the Investigation: The objective of this research is to design a readiness model and self-assessment tool for adopting digital technologies in mini grids

2.2: Voluntary Participation

Voluntary Participation: Your participation is entirely voluntary, and the decision to partake is entirely up to you.

2.3: Eligible Organizations

Eligible Organizations: This study is open to stakeholders in mini grids industry, including regulators, policymakers, technology developers, funding agencies, operators, financial institutions, and research bodies.

2.4: Eligible Participants

Eligible Participants: We welcome professionals with responsibilities related to technology application in mini grids, including but not limited to CEO, IT Manager, Operations Manager, Engineer, Machine Operator, Finance Manager, Senior Manager, Consultant, and Researcher.

2.5: Ineligible Participants

Ineligible Participants: Individuals without responsibilities related to technology application in mini grids.

2.6: Participation Process

Participation Process: If you agree to participate and comprehend the study's objectives, you will be invited by the lead researcher or an assigned enumerator. Your involvement will involve signing this informed consent form followed by a questionnaire.

2.7: Risks and Benefits

Risks and Benefits: Your involvement poses no risks. Your provided information will be treated confidentially and will not be utilized without your explicit consent. Your contribution will contribute to advancing energy accessibility through the adoption of digital technologies in mini grids.

2.8: Data Confidentiality

Data Confidentiality: All research records will be securely stored and accessible only to authorized personnel. Any data stored in our database will be encrypted and password protected. Your confidentiality will be strictly upheld.

2.9: Data Storage

Data Storage: The collected data will be de-identified and made available in a public repository for research purposes.

2.10: Contact Information

Contact Information: For further inquiries, you can contact Ken Korir at ken.korir@strathmore.edu or (0725 633 536). You can also reach out to Prof. Ismail Ateya, your research supervisor, at the Strathmore School of Computing and Engineering Sciences, Nairobi, or via email at iateya@strathmore.edu.

By signing below, you acknowledge that you have read and understood the information provided and have had your questions addressed satisfactorily. You retain the right to change your mind at any point.

Participation Agreement:

I AGREE to participate in this research.

I DO NOT AGREE to participate in this research.

Questionnaire Data Storage:

I AGREE to have my completed questionnaire stored for future data analysis.

I DONT AGREE to have my completed questionnaire stored for future data analysis.

Participant's Details:

Name: _____ Date: _____

Signature: _____

I, _____ [Name of person taking consent], affirm that I have followed the prescribed procedure, provided comprehensive information about the study to the participant, addressed their questions satisfactorily, and obtained their voluntary agreement to participate.

Researcher's Details:

Name: _____ Date: _____

Signature: _____

Appendix B: Draft questionnaire for DTR pilot study

Kindly mark ‘X’ appropriately:

- I have informed consent to participate in this study:

True False

- My organization is a stakeholder in the mini grid industry as a:

Technology Developer Regulator Policy Maker Operator Developer

Donor agency Finance Lender Research institution

- I hold the following position in my organization:

CEO IT Manager Operations Manager Engineer Machine Operator

Finance Manager Senior Manager Consultant Researcher

Specify other Technical: _____

- I have the following years of experience:

Below 5 Between 5-10 Between 10-15 Between 15-20 Over 20

- I am willing to participate in the validation survey for this study in future:

True False

Please mark ‘X ‘ to indicate the level in which you agree or disagree with each of the following statements associated to Digital Technology Readiness (DTR).

Item	Code	Research Statement	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
			1	2	3	4	5
1	T1	Information on new digital technologies and areas of application is well understood	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	T2	Employees are educated and trained to be technologically competent	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	T3	Infrastructure for adopting digital technologies are in place	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	O1	Digital Technology adoption strategy within the organization is clear.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5	O2	The model of the organization supports using emerging digital technologies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6	O3	Digital technologies implementation is budgeted for	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7	E1	The organizational culture embraces digital technology innovation and implementation.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8	E2	There are adequate legal and ethical regulations governing technology adoption	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9	E3	Cross functional collaboration to initiate and utilize digital technology is at the desired level	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10	PE1	I would be able to understand and interact with digital technology clearly	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11	PE2	Learning to operate digital technology would be easy for me	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
12	PE3	Digital technology would be easy for me to use	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
13	PU1	I could complete jobs faster if I used digital technologies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
14	PU2	My performance at work would increase if I used digital technology	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
15	PU3	Using digital technologies would make my work easier	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>