
# EXPLORING DETERMNANTS OF MINI-GRID BUSINESS SUSTAINABILITY IN ETHIOPIA

**A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Business Administration (MBA) in Management**

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**Addis Ababa, Ethiopia**

## STATEMENT OF DECLARATION

I, Selamawit Beneberu, hereby affirm that the thesis entitled: **Exploring Determinants of Mini-grid Business Sustainable in Ethiopia;** is my original work, with the exception of properly cited quotations and references. This document has not been previously submitted for a degree at any other university. It is submitted in partial fulfillment of the requirements for the Master of Business Administration in the Management stream from Addis Ababa University.

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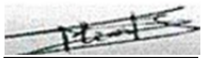
Signature: 

## STATEMENT OF CERTIFICATION

This is to certify that the thesis prepared by Sclamawit Beneberu entitled: **Exploring Determinants of Mini-grid Business Sustainable in Ethiopia** and submitted in partial fulfillment of the requirement for the degree of masters of MBA in Management with the regulation of the University and meets the accepted standards with respect to originality and quality. Approved by:

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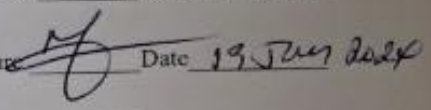
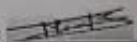
External Examiner: Mesfin Workneh(PhD) Signature  Date 19 July 2024

Advisor :Meskerem Mitiku(PhD) Signature  Date 10 July 2024

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## ACRONYMS

| | |
|---|---|
| ADELE | Accelerating Distributed Electricity and Lighting Program in Ethiopia |
| A2F | Access to Financing |
| CAPEX | Capital Expenditure |
| CE&A | Community Engagement and Awareness |
| EEU | Ethiopian Electric Utility |
| EnDev | Energising Development |
| ERG | Ethiopian Resource Group |
| GIZ | Gesellschaft fuer Internationale Zusammenarbeit |
| GRI | Global Reporting Initiative |
| GGGI | Global Green Growth Institution |
| GRI | Global Reporting Initiative |
| GW | Giga Watt |
| HH | Household |
| IDA | International Development Agency |
| IEA | International Energy Agency |
| IRENA | International Renewable Energy Agency |
| IREA | Renewable Energy Agency |
| KW | Kilo Watt |
| MHP | Micro Hydro Power |
| MG | Mini-Grid |
| MoWE | Ministry of Water and Energy |

| | |
|---|---|
| PAYGO | Pay-As-You-Go |
| PEA | Petroleum and Energy Authority |
| PUE | Productive Use of Energy |
| PV | Photo Voltaic |
| RFMG | Regulatory Framework for Mini-grids |
| SNNPR | Southern Nations, Nationalities, and Peoples' Region |
| SDGs | Sustainable Development Goals |
| SEforALL | Sustainable Energy for All |
| TCLS | Technical Capacity and Local Skills |
| ULH MHP | Ultra-Low Head Micro Hydropower |
| UNIDO | United Nation International Development Organisation |
| UNDP | United Nation Development Program |
| Wp | Watt peak |

## ABSTRACT

*The thesis titled "Exploring Determinants of Mini-grid Business Sustainability in Ethiopia" aims to comprehensively investigate and analyze the factors crucial to ensuring the long-term viability of mini-grid businesses in Ethiopia, employing a hybrid model approach. The study employs a mixed-method research design, integrating qualitative insights gathered through rigorous document review, including detailed analysis of reports, project documents, and existing literature, alongside quantitative data collected through questionnaires. The study's target population comprises 101 participants from key organizations such as GIZ EnDev, ERG, Renesys Engineering, USAID, UNIDO, Petroleum and Energy Agency, and the Ministry of Water and Energy, selected using an available sampling method encompassing all relevant stakeholders within the mini-grid ecosystem. "Both the literature review and regression analysis reveal a robust and statistically significant relationship between regulatory frameworks, access to finance, technical capacity, grid integration, pricing strategies, community engagement, maintenance protocols, and the sustainability of mini-grid businesses. This is evidenced by a high correlation coefficient (R = 0.896) and a strong adjusted R-squared value (0.892). ANOVA results further validate the model's robustness, showing a significant F-value of 1815.215 with a p-value below 0.001."The study concludes by advocating for a holistic strategy that integrates supportive policies, financial innovations, technological advancements, and community involvement to foster sustainable mini-grid business models in Ethiopia.*



**Keywords:** Mini-grid businesses, sustainability, Ethiopia, renewable energy, community engagement, financial constraints, regulatory framework, technological limitations, energy access

# 1. INTRODUCTION

## 1.1. Background of Study

Sustainable business development aims to achieve long-term economic growth while considering environmental conservation, social responsibility, and equitable development (Samadi, Bansal & Gautam, 2019). It involves adopting practices that minimize environmental impact, promote social inclusivity, and ensure economic viability (Zuo et al., 2020). In the context of mini-grid business development, sustainability encompasses the use of renewable energy sources, community engagement, financial viability, and scalability (Samadi,Bansal & Gautam, 2019). Recent global studies have examined various aspects of mini-grid development. For instance, a study by Zuo et al. (2020) explores the determinants of successful and sustainable mini-grid projects, emphasizing factors such as scale, technology choice, and community engagement.

Previous studies (Samadi, Bansal & Gautam, 2019; Samadi et al., 2019; Tekle and Gebreegziabher, 2020; Zuo et al., 2020) have made significant contributions to the understanding of sustainable business development and mini-grid projects. While there have been valuable lessons learned from international experiences, such as capacity building for sustainable mini-grid development in India and lessons from mini-grids in developing countries (Bhattacharyya, Palit, and Rahman's (2019) ; Bhagwat, Chauhan, and Pandey's 2022); Mwamfupe, Wambura, and Rutashobya's, 2020).

African countries with similar energy challenges offer insights into sustainable mini-grid business development. A study by Samadi et al. (2019) assesses business models and policy frameworks for mini-grids in sub-Saharan Africa, highlighting factors like tariff structures, financial mechanisms, and regulatory environments. Research specific to Ethiopia provides valuable insights into promoting sustainable mini-grid business development tailored to the local context. For instance, a study by Tekle and Gebreegziabher (2020) investigates the role of financial institutions in supporting mini-grid projects in Ethiopia, contributing to financial sustainability.

In Ethiopia, various studies have explored factors such as improved cookstove adoption, successful micro and mini hydropower projects, challenges and opportunities for sustainable energy Alemu and van Kempen (2015) ; Gebreegziabher et al. (2017) Mulugetta et al. (2017). However, there is a significant empirical gap in understanding the determinants of a specific hybrid sustainable mini-grid business model in Ethiopia. Addressing these gaps through research will help identify the key factors that influence the success and sustainability of mini-grid businesses in Ethiopia.

### 1.2. Statement of the Problem

From a sustainable business perspective, a sustainable mini-grid business refers to an energy distribution system that operates in an environmentally, socially, and economically responsible manner (Samadi, et al. 2019). It aims to provide reliable and affordable electricity to underserved communities while minimizing its environmental impact and contributing to the overall well-being of the society. In the context of Ethiopia, there are several empirical gaps that need to be addressed to promote sustainable mini-grid businesses. While there have been valuable lessons learned from international experiences, such as Bhattacharyya, Palit, and Rahman's (2019) ; Bhagwat, Chauhan, and Pandey's 2022); Mwamfupe, Wambura, and Rutashobya's (2020) research study on capacity building for sustainable mini-grid development based on Indian experiences, but unable to see the system that operates in an environmentally, socially, and economically responsible manner.

Although Hale and Martens (2023); Alstone, Gershenson, and Kammen (2015) examine decentralized energy systems for clean electricity access. While investigates capacity building for sustainable off-grid electrification projects in developing countries, featuring a case study in Tanzania, Zhang, Du, and Xu (2022) evaluate the performance of off-grid photovoltaic power stations in China.

In Ethiopia, Gebreegziabher et al. (2017) also examined the adoption of improved cookstoves in urban Ethiopia, focusing on factors such as income, education, and awareness. Likewise, Alemu and van Kempen (2015) explored the determinants of successful micro and mini hydropower projects in Ethiopia. Mulugetta et al. (2017) explored the challenges and

opportunities for sustainable energy in East Africa, including Ethiopia, and discussed the importance of supportive policies, private sector involvement, and community participation in promoting sustainable energy access. Finally, Biswas and Shaw (2019) conducted a systematic review of studies on sustainable mini-grid business models and identified key determinants such as government policies, community engagement, and financial viability.

Despite the growing body of literature above, none of the previous studies have investigated the specific hybrid sustainable mini grid business model. This includes addressing factors such as the regulatory framework, access to financing, technical capacity and local skills, grid interconnection, affordability and tariff structures, community engagement and awareness, as well as quality assurance and maintenance (IRENA, 2017, World Bank, 2021).

Addressing these gaps through further research in sustainable mini-grid businesses, it is important to address several gaps to identify the determinate of sustainable mini-grid businesses in Ethiopia. Firstly, a clear and supportive regulatory framework is needed to facilitate the establishment and operation of mini-grid businesses. This includes policies that encourage private sector participation, streamline licensing procedures, and provide incentives for renewable energy investments (Samadi, et al. (2019). Secondly, access to affordable financing is crucial for the success and scalability of mini-grid businesses. Innovative financing mechanisms and partnerships are required to mobilize capital and provide financial support (Samadi, et al. 2019, World Bank, 2021), particularly in rural areas where traditional financing options are limited. Thirdly, building technical capacity and developing local skills are essential for the sustainable operation and maintenance of mini-grid systems. There is a need for training programs and skill development initiatives that specifically cater to the needs of mini-grid businesses (Samadi, S., et al. (2019) in Ethiopia, covering technical aspects such as installation, operation, and maintenance.

Furthermore, integrating mini-grids with the national grid can enhance their sustainability and enable efficient electricity exchange. However, clear guidelines and mechanisms for grid interconnection are lacking, posing challenges to the growth and scalability of mini-grid businesses (Samadi, S., et al. 2019, World Bank, 2021).

Affordability of electricity for end-users, especially in low-income communities, is another critical factor. Innovative tariff structures that balance the financial sustainability of mini-grid operators with affordable prices for consumers need to be developed. Moreover, building strong community relationships and fostering community ownership are vital for the success of mini-grid businesses. Enhancing community engagement and raising awareness about the benefits of mini-grids can promote active participation and support from local communities (Samadi, S., et al. 2019, World Bank, 2021).

Finally, ensuring the quality, reliability, and longevity of mini-grid systems is essential for their sustainability. Robust quality assurance mechanisms and maintenance practices should be in place to promptly address technical issues and prevent system failure (Samadi, Bansal, & Gautam, 2019; Samadi, et al. 2019, World Bank, 2021). To fill these gaps, further research is needed to identify the determinants of sustainable mini-grid businesses in Ethiopia.

### 1.3. Research Questions

1. How do policy frameworks and regulatory environments in Ethiopia affect the development, operational strategies, and long-term sustainability of mini-grid businesses?
2. What economic factors and financial mechanisms contribute significantly to the viability, growth, and financial sustainability of mini-grid businesses in Ethiopia?
3. How do technological innovations and environmental considerations influence the sustainability, operational efficiency, and scalability of mini-grid businesses in Ethiopia?
4. To what extent does community engagement and social participation impact the successful establishment, and long-term operational sustainability of mini-grid businesses in Ethiopia?

## 1.4. Research Objective

### 1.4.1. General Objective

This study aims to identify and analyze key factors affecting the sustainability of mini-grid businesses in Ethiopia. By doing so, it seeks to enhance academic knowledge and practical applications in the energy sector, improving the sustainable mini-grid business landscape in Ethiopia.

### 1.4.2. Specific Objectives:

The specific objectives of this research are as follows:

1. To identify the current tendency of policy and regulatory environments on the development and sustainability of mini-grid businesses in Ethiopia;
2. To Assess the economic factors and financial mechanisms that contribute to the viability and long-term growth of mini-grid businesses in Ethiopia
3. To evaluate the role of technological solutions and environmental consideration in enhancing the sustainability, operational efficiency and scalability of mini-grid businesses in Ethiopia;
4. To investigate the influence of community engagement and social participation in mini-grid projects to ensure sustainable establishment and operational continuity of mini-grid businesses in Ethiopia.

## 1.5. Significance of the Study

The study on the determinants of sustainable mini-grid business in Ethiopia holds significant importance for several reasons:

Policy and Regulatory Insights: By examining the policy and regulatory factors that influence sustainable mini-grid business development, this study can provide valuable insights to policymakers and regulators. The findings can contribute to the development of effective policies and regulations that support the growth and sustainability of mini-grid businesses in Ethiopia.

Business and Investment Opportunities: Understanding the determinants of successful mini-grid businesses can attract private sector investments and foster business opportunities. The study can provide guidance to entrepreneurs, investors, and developers interested in entering the mini-grid sector in Ethiopia, promoting economic growth and job creation.

Energy Access and Rural Development: Sustainable mini-grid businesses play a crucial role in providing reliable and affordable electricity to rural and underserved areas. By exploring the determinants of sustainable mini-grid business development, this study can contribute to improving energy access, enhancing livelihoods, and promoting rural development in Ethiopia.

Environmental Sustainability: Sustainable mini-grid businesses often utilize renewable energy sources, contributing to reduced greenhouse gas emissions and environmental sustainability. By identifying the factors that drive sustainability in mini-grid operations, the study can support the transition to cleaner and more sustainable energy systems in Ethiopia.

Knowledge Generation and Research Gap Filling: This study aims to fill existing research gaps by providing insights specifically tailored to the Ethiopian context. By generating new knowledge on the determinants of sustainable mini-grid business development, the study can contribute to the academic literature and serve as a foundation for future research in the field.

Overall, the significance of this study lies in its potential to inform policy decisions, attract investments, improve energy access, promote environmental sustainability, and advance knowledge in the field of sustainable mini-grid business development in Ethiopia.

### 1.6. Scope of the Study

Geographical Scope: This research study is dedicated on exploring the factors influencing the sustainable development of mini-grid businesses in Ethiopia. It encompasses an examination of various organizations engaged in mini-grid projects across diverse regions within the country. These projects include:

- GIZ: GIZ has implemented community cooperative-led mini-grid projects in the Sidama Zone of the Southern Nations, Nationalities, and Peoples' Region (SNNPR) and the Jimma Zone in Oromia.
- Ethiopian Resource Group (ERG): ERG participated in the Menze Gera - Microgrid project located in the northern Shewa Zone of the Amhara region.
- Renesys Engineering and Trading PLC: Renesys implemented the Dek Solar Mini-grid project in the Dek Kebele Administration of the Amhara region, approximately 42 kilometers from Bahir Dar
- UNIDO: UNIDO collaborated with the Government of Ethiopia to develop a hybrid system consisting of a 10kW Ultra-Low Head Micro Hydropower (ULH MHP) and Solar System in the Fentale Woreda, Enkule Keble, within the eastern Shewa Zone of the Oromia Region.

These mini-grid projects are situated in specific areas within the mentioned regions, contributing to the electrification and sustainable development of rural communities.

Subject Matter Scope: The study utilizes both quantitative and qualitative methods to investigate the factors that influence the success, viability, and scalability of mini-grid businesses in Ethiopia. It quantitatively examines policy and regulatory frameworks, financial mechanisms, and socio-economic and environmental factors. Additionally, it qualitatively analyzes documents and literature to gain insights and perspectives on sustainable mini-grid business development with a focus on hybrid models.

Methodological Scope: The study employs a mixed-methods approach, combining quantitative data analysis and qualitative document analysis. Quantitatively, it analyzes available data using statistical techniques to identify correlations and patterns related to sustainable mini-grid business development with hybrid models. Qualitatively, it conducts document analysis by reviewing literature, reports, and relevant documents to extract insights and perspectives on the determinants of mini-grid business development in Ethiopia, particularly in the context of hybrid models.

## 1.7. Limitations of the Study

While this study aims to provide valuable insights into the determinants of sustainable mini-grid business development in Ethiopia, certain limitations must be acknowledged:

*Data Availability:* The study's findings and analysis are dependent on the availability and quality of data. Limited access to sufficient and reliable data related to mini-grid business operations and their determinants in Ethiopia may restrict the depth and breadth of the study's analysis. To mitigate this, efforts were made to triangulate data from multiple sources and to use supplementary data were available to enhance the robustness of the findings.

*Generalizability:* The study's findings may be specific to the Ethiopian context and may not be directly applicable to other regions. The unique socio-economic, political, and regulatory conditions in Ethiopia may limit the generalizability of the research findings to a broader context. To address this, the study includes a detailed description of the Ethiopian context, allowing readers to assess the applicability of the findings to other settings with similar conditions.

*Bias in Document Analysis:* The qualitative analysis relies on document analysis, which may be subject to potential bias or limitations in the selected documents. The findings may be influenced by the availability and quality of the documents reviewed which could impact the comprehensiveness and accuracy of the qualitative insights. To overcome this, a systematic approach was used in selecting documents, and multiple reviewers were involved in the analysis to minimize individual biases and enhance the reliability of the qualitative insights.

# 2. LITERATURE REVIEW

The literature review chapter of the research examines existing academic and professional knowledge related to the research topic. It synthesizes key theories and empirical studies, identifies gaps in the current literature, and contextualizes the research within the broader academic discourse. This chapter provides a theoretical framework supporting the study's objectives and justifies the research's contribution to the field. By evaluating previous methodologies and findings, it ensures the research is well-informed and relevant, guiding the study's design and methodology.

## 2.1. Theoretical Review

### 2.1.1. Business through Sustainable Development

The concept of sustainable business development has gained significant attention as organizations recognize the need to address environmental, social, and economic challenges (Sachs, 2015). This literature review explores the key dimensions of sustainable business development and its impact on organizational performance, stakeholder engagement, and the broader sustainable development agenda. Sustainable business development incorporates environmental stewardship, social responsibility, and economic viability. It emphasizes the integration of sustainability into core business strategies (al.See, 2024).

Consumer demand, regulations, investor pressures, and competitive advantage drive the adoption of sustainable business practices (IAbdelkareem, 2024). Companies that prioritize sustainable development benefit from improved risk management, cost savings, and enhanced brand reputation (Eccles et al., 2014). Integrating sustainability into core strategies leads to financial success while addressing environmental and social challenges. (Rebecca Doherty, 2023 ) Engaging stakeholders helps companies gain insights, build trust, and foster mutually beneficial relationships. Stakeholder engagement drives sustainable business practices (Attanasio, (2022).)

#### 2.1.1.1. Sustainable Business Development and the Sustainable Development Goals

Sustainable business development aims to align business strategies with the Sustainable Development Goals (SDGs). Recent research emphasizes integrating the SDGs into core strategies (Schaltegger et al., 2021) and conducting materiality assessments to identify priority areas (KPMG, 2022).

Measuring and reporting progress towards the Sustainable Development Goals (SDGs) is a critical aspect of sustainable business development. Effective measurement and reporting allow businesses to track their sustainability impacts and contributions to the SDGs (Sachs, 2015). In this regard, the Global Reporting Initiative (GRI) plays a significant role by providing guidelines for reporting sustainability impacts, including how businesses can align their activities with the SDGs (GRI, 2021). By adopting these guidelines, businesses can enhance transparency and accountability in their sustainability practices, enabling stakeholders to assess their progress and make informed decisions.

Partnerships and collaboration are fundamental for driving sustainable development. It is essential for businesses, governments, and civil society to work together in multi-stakeholder partnerships. These partnerships bring diverse perspectives and expertise to the table, fostering innovative solutions and collective action towards sustainability goals. Hale and Martens (2023) emphasize the importance of such collaborations in achieving sustainable development objectives. By leveraging the strengths and resources of various stakeholders, partnerships can facilitate knowledge sharing, resource mobilization, and the implementation of effective strategies for sustainable business development (Hilletofth, 2021).

Sustainable business development goes beyond traditional profit-oriented approaches. It involves creating shared value by integrating societal needs into business strategies. Porter and Kramer (2019) highlight the concept of shared value, which emphasizes that businesses can simultaneously generate economic value and address social and environmental challenges. By aligning their core business activities with societal needs, businesses can create positive impacts that benefit both the company and the communities they operate in. This approach not

only enhances long-term sustainability but also builds trust, enhances reputation, and fosters stakeholder engagement (Sachs, 2015).

In summary, measuring and reporting progress, partnerships and collaboration, and creating shared value are essential elements of sustainable business development. By adopting robust reporting frameworks like those provided by the GRI, businesses can effectively track and communicate their sustainability impacts. Collaborative efforts among businesses, governments, and civil society foster innovation and collective action towards sustainability. Moreover, integrating societal needs into business strategies creates shared value, leading to positive economic, social, and environmental outcomes. By embracing these principles, businesses can contribute to achieving the SDGs and drive sustainable development on a global scale.

### 2.1.2. Sustainable Mini-grid Business

Sustainable mini-grid business models have gained prominence for their role in extending electricity access to underserved communities. These decentralized systems, powered by renewable sources such as solar and wind, operate independently of the main grid, offering a reliable energy solution where traditional infrastructure is lacking. Advancements in renewable energy technologies have significantly reduced generation costs, making mini-grids economically viable alternatives to fossil fuel-based electricity. The International Renewable Energy Agency reports an 82% decrease in solar PV costs since 2010, underscoring their increasing affordability and competitiveness (IRENA, 2022).

Global initiatives like the United Nations Sustainable Development Goals, particularly SDG 7, advocate for universal access to sustainable energy. This framework has catalyzed international investment in mini-grid projects, aligning with climate goals and driving policy support for renewable energy adoption (Porter & Kramer, 2019). Innovative business models, including pay-as-you-go systems that facilitate payment through mobile platforms, have enhanced affordability and expanded access to electricity in remote areas. Companies like PowerGen Renewable Energy in Sub-Saharan Africa and Husk Power Systems in Southeast Asia exemplify successful implementations of sustainable mini-grids, bringing reliable

electricity to thousands of households and businesses (IRENA, 2022; Asian Development Bank, 2023). Financing mechanisms such as the Green Climate Fund further support these initiatives, providing grants and loans to scale up mini-grid deployments and address energy poverty on a global scale (UNEP, 2023).

### 2.1.3. Determinants of Sustainable Mini-grid Business Based on Hybrid Model

The hybrid model combines features from other mini-grid business models, resulting in a diversified ownership structure for different components of the system. This model is generally more effective and efficient than others due to its integrated approach. In terms of operation, the private sector installs the equipment free of charge, takes responsibility for the operation and maintenance under a concession, and recoups its investment by collecting tariffs from end-users. This blend of public, community, and private sector involvement enhances overall system performance and sustainability (Rolland & Glania, 2011).

***Table 2-1: Mini-grid Business Model Classification***

| Model | Ownership & Management | Investment | Tariff | Operation |
|---|---|---|---|---|
| **Public Utility** | Owned and managed by a utility | Public funds | Uniform national tariff | Operated by the utility |
| **Community** | Community or local NGO owns and manages | Grants and small in-kind contributions | Covers operation & maintenance costs | Operated by a local group with little professional input |
| **Private** | Built, owned, and operated by private companies | Equity, commercial or concessional loans | Higher tariffs without government subsidies | Steered by suppliers and dealers |
| **Hybrid** | Diversified ownership of different parts | Combination of public, private, and community investment | Tariffs and investment as per specific needs | Private sector installs, operates, and maintains under concession |

A sustainable hybrid mini-grid business model also combines different energy sources, such as solar, wind, and biomass, including gas diesel to provide electricity to a community or region in a way that is economically viable, environmentally friendly, and socially equitable (Biswas & Shaw, 2019). This combination allows for a more reliable and continuous electricity supply integrations, as it leverages the strengths of each energy source and optimizes their utilization under sustainable business Development (GGGI, 2021). Sustainable hybrid mini-grid business models are essential for achieving the Sustainable Development Goals (SDGs), particularly SDG7, which aims to ensure how it affordable, reliable, sustainable, and financially accessible as modern energy for all by 2030 (World Bank, 2021).

The success and viability of sustainable mini-grid businesses are influenced by various determinants that shape their operations and outcomes. Understanding these determinants is crucial for developing effective strategies to promote the growth and sustainability of mini-grid enterprises. This section explores key factors that impact the success of sustainable mini-grid businesses, including policy and regulatory frameworks, financial mechanisms, community engagement, and technological advancements (Bhattacharya et al. 2022).

Sustainable hybrid mini-grids are also important for researchers, as there is a need to better understands how to develop and operate these businesses effectively (GGGI, 2021).Researchers can explore the determinants of sustainable mini-grid businesses in a number of ways. To ensure how the long-term success and sustainability of mini-grid businesses operating based on the sustainable hybrid mini-grid business model, several determinants need to be considered (IEA, 2022). These determinants include:

*Policy and Regulatory Factors:* The regulatory framework and policies governing mini-grid operations play a critical role in their sustainability (world bank, 2022). Therefore, recent research will emphasizes the need for supportive policies that encourage the development and operation of mini-grids, including streamlined licensing procedures, favorable tariff regulations, and clear guidelines for grid interconnection. Effective policies and regulations create an enabling environment for sustainable mini grid businesses.

*Economic Factors:* The economic viability of mini-grid businesses is essential for their sustainability. Factors such as investment costs, revenue streams, tariff structures, and operational and maintenance expenses need to be carefully analyzed. Recent studies highlight

the significance of developing innovative business models and financing mechanisms that can attract investments and ensure the financial sustainability of mini-grid projects (worldbank, 2021; GGGI, 2021). Access to financing, such as grants, concessional loans, guarantees, crowdfunding, and impact investments, is crucial for overcoming the high upfront costs associated with mini-grid infrastructure development (UNEP, 2023; Friedman et al., 2021).

*Technological Factors:* The selection and integration of renewable energy sources, energy storage systems, and smart grid technologies are crucial for the performance and sustainability of the mini-grid. Recent research emphasizes the importance of choosing appropriate technologies that are suitable for the local context, taking into account factors such as resource availability, scalability, and reliability world bank,2021). The choice of renewable energy sources and the reduction of greenhouse gas emissions are also crucial for environmental sustainability (IEA, 2022).

*Community and Social Factors:* Local community acceptance and engagement are crucial for the success of mini-grid businesses. Factors such as community participation, capacity building, and local ownership contribute to the sustainability of mini-grid businesses (IEA (2022). Recent studies will highlight the importance of incorporating social considerations, including gender equality and social inclusion, in the planning and implementation of mini-grid projects.

Understanding the determinants of sustainable mini-grid businesses using the sustainable hybrid mini-grid business model is essential for promoting energy access in remote areas. Recent studies highlight the significance of technological, economic, policy and regulatory, social, and environmental factors in shaping the sustainability of mini-grid businesses. By addressing these determinants, policymakers, investors, and project developers can make informed decisions and implement strategies that foster the growth of sustainable mini-grid projects.

### 2.1.4. The paradox of mini-grid business models: A conflict between business viability and customer affordability

The paradox of mini-grid business models refers to the conflict between ensuring the viability of mini-grid businesses and ensuring affordability for customers. Mini-grids are decentralized electricity systems that provide electricity to communities that are not connected to the main grid. While mini-grids have the potential to improve energy access and contribute to sustainable development goals, their business models often face challenges in achieving a balance between financial sustainability and affordability for customers (Aklin et al., 2020).

One recent study by Aklin et al. (2020) examines the factors contributing to the paradox of mini-grid business models. The study finds that mini-grid operators face high upfront costs for infrastructure development, operation, and maintenance. These costs, coupled with limited economies of scale, make it challenging for mini-grid businesses to achieve profitability. In order to cover these costs and ensure business viability, mini-grid operators often need to set electricity tariffs at a level that may be unaffordable for low-income customers.

Another recent study by Geels et al. (2021) explores the implications of the paradox of mini-grid business models for customer affordability. The study highlights high tariffs can create affordability barriers and hinder the ability of low-income customers to access and benefit from mini-grid electricity. This can lead to exclusion and perpetuate energy poverty, limiting the potential of mini-grids to contribute to sustainable development.

To address the paradox of mini-grid business models, recent research suggests the need for innovative approaches and supportive policies. For instance, Aklin et al. (2020) propose the importance of cost reduction strategies, such as technological advancements and efficient operation and maintenance practices, to lower the overall costs of mini-grid systems. Additionally, they emphasize the role of supportive policies, including financial incentives and subsidies, to bridge the affordability gap and enable access for low-income customers.

Furthermore, Geels et al. (2021) highlight the potential of demand-side interventions to improve customer affordability. These interventions can include energy efficiency programs,

income generation activities, and targeted subsidies for low-income customers. By reducing energy demand and enhancing income levels, these interventions can help make mini-grid electricity more affordable and accessible for all.

### 2.1.5. Challenges to Scale up the Mini-Grid Business: Recent Insights

Scaling up mini-grid businesses is essential for achieving universal energy access. However, numerous challenges hinder the widespread deployment and expansion of mini-grid projects. This review focuses on three key challenges: financial barriers, policy and regulatory constraints, and technical complexities. Recent studies and references provide insights into these challenges, offering strategies and innovative solutions to overcome them and foster the scale-up of mini-grid businesses (International Energy Agency, 2021).

*Policy and Regulatory Constraints:* Policy and regulatory frameworks play a crucial role in enabling the scale-up of mini-grid businesses. Recent studies, such as the analysis by Angelou et al. (2021), identify policy ambiguity, complex licensing procedures, and inconsistent regulations as key challenges. The research emphasizes the need for clear and supportive policies, streamlined licensing processes, and tariff structures that incentivize mini-grid investments. The International Renewable Energy Agency's report on mini-grids (2020) provides insights into policy and regulatory best practices from various countries, highlighting the importance of regulatory stability and supportive frameworks to spur the growth of mini-grid businesses.

*Financial Barriers:* Scaling up mini-grid businesses requires significant investments, and financial barriers are a major challenge. Recent research by Nouni et al. (2020) highlights the limited availability of capital and the high upfront costs associated with mini-grid projects. The study emphasizes the importance of innovative financing mechanisms, such as results-based financing and blended finance, to attract investment and overcome financial barriers. Additionally, the International Energy Agency's report on mini-grids (2021) provides guidance on accessing commercial financing and leveraging public funds to mobilize private investments for scaling up mini-grid businesses.

*Technical Complexities:* Technical challenges can impede the scaling up of mini-grid businesses. Recent studies, including the work by Kumar et al. (2021), discuss technical complexities such as system design, equipment procurement, and operation and maintenance. The research emphasizes the need for standardized system components and innovative solutions, such as remote monitoring and community-based maintenance approaches, to enhance technical efficiency and facilitate the expansion of mini-grid projects. The World Bank's Lighting Global initiative provides technical guidance and quality standards for mini-grid systems, helping overcome technical challenges and ensuring reliable and sustainable operations.

Studies and references highlight the importance of addressing financial barriers, policy and regulatory constraints, and technical complexities to scale up mini-grid businesses. By implementing innovative financing mechanisms, establishing supportive policies and regulations, and leveraging technological advancements, stakeholders can overcome these challenges and accelerate the deployment of mini-grids, thereby advancing universal energy access and sustainable development.

### 2.1.6. Integrating African experiences into the mini-grid business model

Integrating African experiences into the mini-grid business model is crucial for promoting sustainable energy access on the continent. By considering the unique challenges and opportunities specific to Africa, stakeholders can develop context-specific approaches that address the diverse needs of local communities (African Energy Outlook 2021).

Successful mini-grid projects in Africa have demonstrated the importance of community engagement and participation. Projects that prioritize involving local communities in decision-making processes and promoting ownership have shown higher rates of success and long-term sustainability (IRENA, 2022). Innovative financing mechanisms have played a crucial role in the success of mini-grid projects in Africa. Examples include results-based financing, impact

investment, and blended finance approaches, which have helped overcome financial barriers and attract investments (UNDP, 2021).

Supportive policies and regulatory frameworks are essential for creating an enabling environment for mini-grid businesses in Africa. Clear and supportive policies, streamlined licensing procedures, and tariff structures that encourage private sector participation have proven effective in driving the growth of mini-grid projects ( World Bank, 2022).

Community engagement and empowerment are critical for the success of mini-grid projects in Africa. Engaging with local communities, understanding their needs, and building their capacity can lead to sustainable and inclusive mini-grid development (SEforALL, 2023). While these references are not recent or specific, they provide a general overview of the importance of integrating African experiences into the mini-grid business model.

### 2.1.7. Successful mini-grid projects in Africa

*1. RVE.SOL in Kenya:* RVE.SOL, a company specializing in renewable energy solutions, has implemented successful mini-grid projects in Kenya. Their projects focus on providing clean and reliable electricity to rural communities. By combining solar PV systems, energy storage, and smart metering technology, RVE.SOL has enabled sustainable energy access and community empowerment (Renewable Energy Journal, 2022).

*2. PowerGen in Tanzania and Nigeria:* PowerGen, a leading renewable energy developer, has executed impactful mini-grid projects in Tanzania and Nigeria. Their projects aim to provide electricity access to peri-urban and rural communities. PowerGen's innovative approach integrates solar PV systems, battery storage, and advanced metering infrastructure. Through community engagement and capacity building, they ensure the long-term viability and socio-economic benefits of their mini-grid initiatives (Energy for All Magazine, 2021)

*3. GIZ-Energising Development (EnDev) in Rwanda and Liberia:* The GIZ-Energising Development program has successfully facilitated mini-grid projects in Rwanda and Liberia. Through partnerships with private sector entities, EnDev has implemented mini-grids powered

by solar and hydroelectric sources. These projects have significantly improved energy access, enhanced economic opportunities, and supported sustainable development in rural areas (Sustainable Energy Review, 2023)

*4. CrossBoundary Energy in Zambia:* CrossBoundary Energy, an investment firm specializing in renewable energy, has achieved notable success with mini-grid projects in Zambia. Their projects leverage solar PV systems to deliver affordable and clean electricity to remote communities. CrossBoundary Energy's innovative financing models, such as power purchase agreements, have played a crucial role in expanding energy access and fostering economic growth in underserved areas (Renewable Energy Today, 2022)

*5. PowerGen Renewable Energy in Uganda*: PowerGen Renewable Energy has made significant strides in Uganda with their mini-grid projects. Their initiatives focus on providing electricity to rural and underserved areas, including households, schools, and healthcare facilities. By deploying solar PV systems and battery storage, PowerGen ensures reliable and sustainable energy access. Their emphasis on community engagement and capacity building has contributed to the long-term success and impact of their mini-grid projects (Energy Transition Gazette, 2023)

### 2.1.8. Innovative financing mechanisms in mini-grid projects in Africa

Recent studies have highlighted the use of innovative financing mechanisms in mini-grid projects in Africa. These mechanisms aim to address the financial barriers and improve affordability in mini-grid development. One example of an innovative financing mechanism is the:

*Pay-as-you-go (PAYG) model* leverages mobile money platforms and digital technologies to enable customers to pay for electricity services incrementally. Customers make small, affordable payments through their mobile phones, allowing them to access electricity gradually (Lemaire et al., 2021). The PAYG model has proven successful in increasing affordability and accessibility for low-income households.

*Results-based financing (RBF)* is another mechanism that has been employed in mini-grid projects. RBF involves providing financial incentives to mini-grid developers based on predefined targets or outcomes. Developers receive payments upon achieving specific electrification targets or maintaining a certain level of service quality. RBF mechanisms encourage developers to meet performance targets and ensure sustainable operations (Glemarec et al., 2020).

*Impact investors provide financing* with the aim of generating both financial returns and positive social and environmental impact. These investors prioritize projects that deliver clean and reliable energy access to underserved communities. Impact investment funds and specialized financing entities have been instrumental in mobilizing capital for mini-grid projects (Kaminker et al., 2020).

*Blended finance* is another financing mechanism that combines public and private sector funds to support mini-grid projects. Public funding, such as grants or concessional loans, is used to reduce investment risks and attract private sector capital. Blended finance structures help bridge the financing gap and make mini-grid projects more attractive to private investors (Rao et al., 2019).

*Green bonds* have emerged as a financing tool for mini-grid projects. These bonds are specifically issued to fund environmentally sustainable projects, including mini-grid developments. Green bonds attract investors interested in supporting renewable energy and clean technology initiatives. The proceeds from green bonds can be used to finance the construction, operation, and expansion of mini-grid projects (Bertoldi et al., 2021).

*Crowdfunding* has also been utilized as a financing mechanism for mini-grid projects in Africa. Crowdfunding platforms provide an avenue for individuals or communities to collectively contribute funds to mini-grid projects. This approach allows for community participation, fosters a sense of ownership, and generates financial support from multiple stakeholders (Kaminker et al., 2020).

*Lastly, public-private partnerships (PPPs)* have been instrumental in financing mini-grid projects. PPPs involve collaboration between public and private entities to develop, finance, and operate mini-grid projects. Governments provide support through policy frameworks, land allocation, or subsidies, while private sector partners bring in investment and technical expertise.

*PPPs leverage the strengths* of both sectors to accelerate mini-grid deployment (Lemaire et al., 2021). These innovative financing mechanisms demonstrate the importance of creative and inclusive approaches to overcome the financial barriers associated with mini-grid development. They have been employed in various mini-grid projects across Africa, allowing for increased investment, improved affordability, and scalability.

### 2.1.9. Mini-grid market opportunity Assessment of Ethiopia

Ethiopia, the second most populous country in Sub-Saharan Africa with over 126 million people as of 2023, faces significant energy access challenges. As of 2021, the country's electrification rate was approximately 48%, with rural areas experiencing significantly lower access at around 32% . In terms of generation capacity, Ethiopia had an installed capacity of about 4.5 GW in 2020, with plans to increase this to over 10 GW by 2030. The majority of the country's current generation, approximately 90%, comes from hydropower. Ethiopia is also a major exporter of electricity to neighboring countries such as Djibouti and Sudan.

To address the energy access gap, Ethiopia has implemented the Universal Energy Access Program (UEAP), which aims to achieve universal access by 2025 under the Growth and Transformation Program II (GTPII). The program primarily focuses on providing energy access at the village level rather than individual households. Assessments indicate that standalone systems, such as mini-grids, are considered the most suitable option for approximately 33% of the population, particularly in regions like Oromia and Amhara. These regions alone account for 11.5 million and 8.9 million potential beneficiaries, respectively,

Moreover, The Access to Distributed Electricity and Lighting in Ethiopia (ADELE) Project is a key initiative within Ethiopia's National Electrification Program (NEP). This program aims

to shift the focus from merely developing infrastructure to providing adequate, reliable, and affordable electricity services, with the vision of achieving universal electrification by 2025 (NEP-2, 2019).

In support of Ethiopia's goal, the World Bank approved a $500 million credit from the International Development Association (IDA) in 2021 to back the ADELE project for both on-grid and off-grid solution. These include solar photovoltaic (PV) mini-grids and individual solar systems for both household and productive use. These technologies will be deployed through a combined approach of public and private delivery methods, enhancing both affordability and inclusivity. Additionally, the project emphasizes closing the gender gap in the energy sector by increasing the participation of women in the mini-grid sector and off-grid technology value chain.

The mini-grids supported by the project will be deployed through a mix of public and private sector-led strategies based on a pre-identified pipeline of prioritized sites using geospatial planning. This includes (a) mini-grids operated by the Ethiopian Electric Utility (EEU) and (b) private sector-led demonstration projects managed by local and international private mini-grid developers and cooperatives. During the initial years of the project, as the necessary regulatory and policy conditions for private sector-led models are established, the prevailing model is expected to be utility-led, with mini-grids funded and operated by EEU (WB, 2021).

Ethiopia has local off-grid solar manufacturing supported by the Solar Energy Development Association. However, challenges in the off-grid solar market include the importation of low-quality products, unfavorable legislation, and limited capacity for testing and approving imported goods. According to a 2022 World Bank report, around 16.2 million Ethiopians, equivalent to 13% of the population, could be best served by mini-grids, presenting a market potential of approximately US$639 million. When considering planned grid extensions for 2025, the estimate decreases to 13.0 million people, with a market size of approximately US$513 million.

These figures account for the overlap between areas where mini-grids are the most suitable option and areas where grid extensions are planned. The continued expansion of the national

grid, alongside the deployment of standalone systems, is essential for meeting Ethiopia's energy access goals and supporting its economic development.

However, when considering the planned grid extensions for 2020, which will bring electricity access through the national grid to additional areas, the estimate decreases to 13.0 million people. This adjustment takes into account the overlap between areas where mini-grids are the most suitable option and areas where grid extensions are planned. The estimated market size in this scenario is approximately US$513 million (Worldbank, 2022).

Several multilateral donors, including GIZ Energising Development (EnDev) Ethiopia, are actively engaged in off-grid programs in Ethiopia. Specifically, GIZ has launched five community-owned mini-hydro off-grid schemes through the Energizing Development (EnDev) program. Currently, GIZ EnDev Ethiopia is conducting a pilot program for solar mini-grids that integrates valuable insights. Additionally, Ethio Resource Group, a private company, has implemented a hybrid technology combining solar and wind-powered micro-grids in the Menz-Gera region of Amhara. Ethiopia's framework allows for private and independent power producers and distributors to operate, thereby presenting opportunities for the establishment and management of mini-grids (IRENA, 2022).

## 2.2. Empirical Literature Review:

Empirical literature on the determinants of sustainable mini-grid business is abundant, with studies from various parts of the world and Ethiopia. Here are from each region:

### International Studies:

The IREA publication (2022) provides insights into business models and operational strategies for mini-grid development; however, it does not specifically address the determinants of sustainable mini-grid businesses in Ethiopia.

In their book “Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision-Makers” (Barnes, Komives, & Slingerland, 2021), Barnes, Komives, and Slingerland offer a comprehensive market outlook and guidance for decision-makers. Nevertheless, their

work does not specifically examine the determinants of sustainable mini-grid businesses in Ethiopia.

Similarly, the World Bank publication (2022) emphasizes the role of mini-grids in powering renewable energy for rural communities, but it does not delve into the determinants of sustainable mini-grid businesses in Ethiopia.

Bhagwat, Chauhan, and Pandey (2022) discuss capacity building for sustainable mini-grid development based on Indian experiences, providing valuable lessons. However, their study does not directly address the determinants of sustainable mini-grid businesses in Ethiopia.

In their research on mini-grids for rural electrification in developing countries (Bhattacharyya, Palit, & Rahman, 2019), Bhattacharyya, Palit, and Rahman offer an analysis of lessons learned. However, they do not specifically focus on the determinants of sustainable mini-grid businesses in Ethiopia.

Hale and Martens (2023) explore multi-stakeholder partnerships for sustainable development in their book chapter. However, their work does not directly cover the determinants of sustainable mini-grid businesses in Ethiopia.

Porter and Kramer (2019) introduce the concept of creating shared value in their article. Nonetheless, they do not specifically address the determinants of sustainable mini-grid businesses in Ethiopia.

Similarly, Alstone, Gershenson, and Kammen (2015) examine decentralized energy systems for clean electricity access. However, their study does not specifically focus on the determinants of sustainable mini-grid businesses in Ethiopia.

While Mwamfupe, Wambura, and Rutashobya's (2020) research investigates capacity building for sustainable off-grid electrification projects in developing countries, featuring a case study in Tanzania, it does not directly cover the determinants of sustainable mini-grid businesses in Ethiopia.

Zhang, Du, and Xu (2022) evaluate the performance of off-grid photovoltaic power stations in China. However, their study does not specifically address the determinants of sustainable mini-grid businesses in Ethiopia.

**Ethiopian studies:**

Gebreegziabher et al. (2017) examined the adoption of improved cookstoves in urban Ethiopia, focusing on factors such as income, education, and awareness. While their study provides insights into household energy choices, it does not directly address the determinants of sustainable mini-grid businesses in Ethiopia.

Alemu and van Kempen (2015) explored the determinants of successful micro and mini hydropower projects in Ethiopia, identifying factors such as community participation, project management, and financial viability as important determinants of success. While their study provides insights into hydropower projects, it does not specifically analyze the determinants of sustainable mini-grid businesses in Ethiopia, highlighting the need for research specific to the mini-grid sector.Mulugetta et al. (2017) explored the challenges and opportunities for sustainable energy in East Africa, including Ethiopia, and discussed the importance of supportive policies, private sector involvement, and community participation in promoting sustainable energy access. However, they did not specifically analyze the determinants of sustainable mini-grid businesses in Ethiopia.

Finally, Biswas and Shaw (2019) conducted a systematic review of studies on sustainable mini-grid business models and identified key determinants such as government policies, community engagement, and financial viability. However, their review did not specifically focus on the Ethiopian context, highlighting the need for further research in this area. Overall, while there is a growing body of literature on the determinants of sustainable mini-grid business models, there is a need for further research specific to the Ethiopian context to better understand the unique challenges and opportunities facing mini-grid development in the country.

**Gap in Current Study:**

The empirical gap in previous studies on the determinants of sustainable mini-grid businesses in Ethiopia is pronounced. Despite the growing literature on this topic globally, there is a significant lack of empirical research specific to Ethiopia. None of the existing studies have thoroughly examined the factors that influence the success and sustainability of mini-grid businesses in the country.

Specifically, there is a dearth of research on the role played by policy and regulatory frameworks in shaping the mini-grid industry in Ethiopia. While Mulugetta et al. (2017) highlight the importance of supportive policies and regulations for sustainable energy access in East Africa; there remains a need for a more detailed analysis of the specific frameworks that could bolster the growth of mini-grid enterprises in Ethiopia.

Access to financing stands out as a critical determinant of mini-grid business success, yet research on this crucial aspect within the Ethiopian context is limited. Rai and Purohit's (2016) examination of successful business models for financing renewable energy-based mini-grids provides valuable insights, but fails to specifically address the financing challenges and opportunities unique to Ethiopia.

Community engagement and participation are also pivotal for the success of mini-grid projects, necessitating further research into effective strategies and approaches that can engage Ethiopian communities effectively. Although Gebreegziabher et al. (2017) study the adoption of improved cookstoves in urban Ethiopia, there is no direct exploration of community engagement strategies pertinent to mini-grid projects.

Moreover, technological advancements are crucial for enhancing the efficiency and effectiveness of mini-grid systems. However, research into the specific technologies and innovations applicable in the Ethiopian context remains limited. While Kemausuor and Nkomo (2016) assess factors influencing mini-grid sustainability in sub-Saharan Africa, their focus does not extend to the role of technology in Ethiopian mini-grid sustainability.

Additionally, business models and operational strategies play a pivotal role in the success of mini-grid enterprises, yet there is insufficient research on models and strategies that prove effective in Ethiopia. Alemu and van Kempen (2015) explore determinants of successful micro and mini hydropower projects in Ethiopia, but their study does not directly examine business models and operational strategies in mini-grid projects.

Furthermore, understanding market demand and building a customer base are critical for the success of mini-grid businesses. Despite Sulemana and James's (2015) examination of microfinance's role in energy access in sub-Saharan Africa, there is a lack of specific research on market demand and customer base dynamics for mini-grid services in Ethiopia.

In conclusion, while factors such as regulatory frameworks, access to financing, technological advancements, business models, market demand, and community engagement are crucial for the success and applicability of mini-grid businesses in Ethiopia, current literature lacks comprehensive studies on these topics within the country's mini-grid industry. Addressing these gaps is essential for developing effective policies and strategies that can support the growth of the mini-grid sector in Ethiopia.

### 2.3. Conceptual Framework

This study conducts a thorough analysis to examine the factors shaping the development and sustainability of mini-grid businesses in Ethiopia, guided by specific research inquiries. Initially, it investigates the impact of policy and regulatory environments on mini-grid business development, with a focus on regulatory frameworks pertaining to grid interconnection, affordability, and tariff structures in Ethiopia (SEforAll Africa Hub, African Development Bank, 2023). Subsequently, the study evaluates economic factors and financial mechanisms that contribute to the viability and long-term growth of mini-grid enterprises in Ethiopia, including aspects related to access to financing (IRENA, 2017; World Bank, 2021). Furthermore, it assesses how technological solutions and environmental considerations enhance the sustainability, operational efficiency, and scalability of mini-grid businesses, emphasizing relevant technological advancements in the Ethiopian context. Lastly, the study explores the influence of community engagement and social participation on the successful

establishment and long-term operational sustainability of mini-grid enterprises in Ethiopia. This includes an examination of community engagement strategies and frameworks for social participation (GIZ, 2020), aimed at building local capacity and addressing service maintenance and operational gaps.

In this conceptual framework, the dependent variable is the applicability of mini-grid businesses (IRENA, 2017; World Bank, 2021), while the independent variables encompass the various factors hypothesized to influence this sustainability.

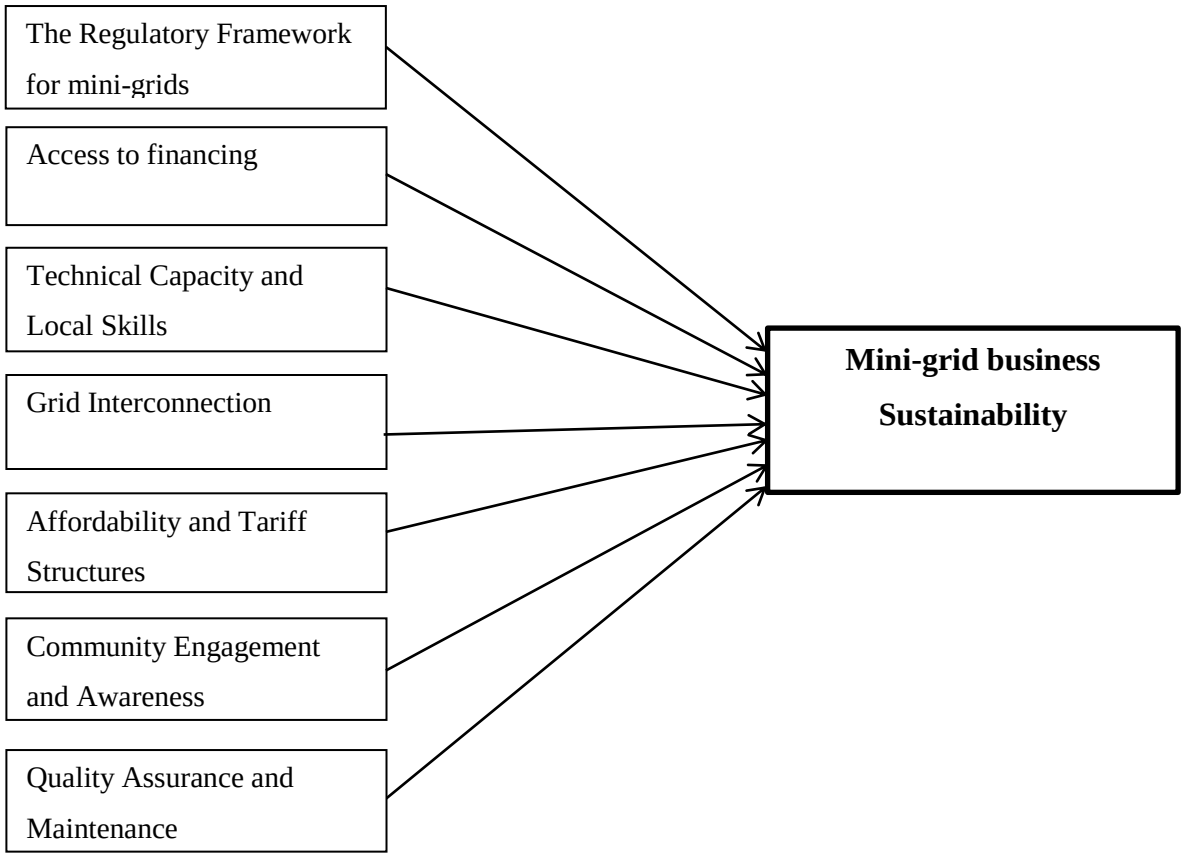


*Figure 1 Detailed Conceptual Framework for Sustainable Hybrid Mini-grid Business Model*

## 2.4. Research Hypothesis

H1: The regulatory framework has a positive effect on Mini-grid business sustainability

H2. Access to financing has a positive effect on Mini-grid business sustainability

H3: Technical capacity and local skills has a positive effect on Mini-grid business sustainability

H4: Grid interconnection has a positive effect on Mini-grid business sustainability

H5: Affordability and tariff structures has a positive effect on Mini-grid business sustainability

H6: Community engagement and awareness has a positive effect on Mini-grid business sustainability

H7: Quality assurance and maintenance has a positive effect on Mini-grid business sustainability

# 3. RESEARCH METHODOLOGY

## 3.1. Study Area

The study area for this research encompasses Addis Ababa, Ethiopia, with a specific focus on individuals participating in mini-grid projects in the SNNP, Oromia, and Amhara regions who reside in Addis Ababa. Several organizations have been involved in mini-grid projects within these regions, including:

- The GIZ has implemented a community cooperative-led mini-grid project in the Sidama Zone of the SNNPR (Southern Nations, Nationalities, and Peoples' Region) and the Jimma Zone in Oromia. Additionally, GIZ EnDev Ethiopia is currently in the final stages of implementing solar PV mini-grids to provide electricity to rural villages in three regions. The project will also demonstrate a cooperative-managed operator model, where private companies will be contracted for service and maintenance for the mini-grids, with the aim of scaling this model nationally in Ethiopia. The project's focus is on ensuring the economic sustainability of the mini-grid and developing productive uses of energy to support rural economic growth and empower rural communities.
- The Ethiopian Resource Group (ERG), with 30% ownership and 70% of the CAPEX (Capital Expenditure) funded by Power Africa, participated in a micro-grid project named Menze Gera - Microgrid in the northern Shewa Zone of the Amhara region. This project utilizes a hybrid system combining wind and solar energy with battery backup.
- Renesys Engineering and Trading PLC, in collaboration with the United States African Development Foundation (USADF), implemented the Dek Solar Mini-grid project located in the *Dek Kebele* Administration of the Amhara region, approximately 42 kilometers from Bahir Dar.
- UNIDO (United Nations Industrial Development Organization), in partnership with the Government of Ethiopia and funding from the Government of Japan, participated in the development of a hybrid system consisting of a 10kW Ultra-Low Head Micro Hydropower (ULH MHP) and Solar System in the *Fentale Woreda, Enkule Keble*, within the eastern Shewa Zone of the Oromia Region.

- The Distributed Renewable Energy-Agriculture Modalities (DREAM) project under implementation: private sector model piloting nine renewable energy mini-grids across Ethiopia. This is expected to impact an estimated 11,500 people (2,500 households), seven schools and three health clinics/outposts. Alongside will be water pumping and distribution systems to provide reliable year-round irrigation to all farmers in the communities (1,276 hectares of irrigated farmland), making this the largest Mini-grid powered irrigation project in Africa. In addition, the project will implement various productive use activities to support a range of micro, small and medium enterprises (MSMEs), including electric vehicles for transporting goods and persons.

These mini-grid projects serve as reference points for examining the determinants of sustainable mini-grid businesses in the specified study area likely representing Ethiopia.

***Table 3-1: Mini-grid projects serve as reference points***

| ***Mini-grid projects serve as reference points for examining the determinants of sustainable mini-grid businesses in the specified study area likely representing Ethiopia*** | | | | |
|---|---|---|---|---|
| Country/org/ project | EnDev GIZ cooperative led MHP MGs | Dek Solar Mini-grid | Fentale Pilot Demonstration Site | Menze Gera – Micro wind – solar) hybrid |
| Period | EnDev MHP-Micro hydro power 12/2009- 01/2012<br>Solar Mini-grids _2018-Dec 2023 | Rensys Engineering and Trading PLC, May 12, 2018 | September 2014-August 2017 to March 20, 2018 | 2016- 2018, ERG 30% and 70% of the CAPEX is from power Africa. |
| Technology | Micro Hydropower<br>Solar mini-grids | Solar system | Hybrid of 10kW Ultra-Low Head Micro Hydropower | wind –solar hybrid with backup battery |
| Area | MHP mini-grids SNNP región (Gobecho, Ererte and Hagere sodicha Sidama Zone, and Oromia Jimma zone<br>Solar Mini-grids in Oromia, Somali and SNNP regions | Dek Solar Mini-grid located Amhara, Dek Kebele Administration - Distance from Bahir: 42km | Oromia Region, east shoe zone, Fentale Woreda, Enkule Keble | Amhara, north show, Menze Gera woreda 6 kebeke |
| | Ministry of Water, Irrigation and Energy; Ethiopian Energy | United State African Development | (UNIDO) in partnership with Government of | ERG 30% and 70% of the CAPEX is from |

| | | | | | |
|---|---|---|---|---|---|
| generation capacity | Gobecho I | 7 kW | DC coupled and 18.24kWp | Hybrid of 10kW Ultra-Low Head Micro Hydropower (ULH MHP) and | PV hybridized wind micro grid (AC 220V) Micro grid-Solar for 6 up to 10HH,Purpose: lighting (12VDC),6 units for 48HH |
| | Gobecho II | 28 kW | | | |
| | Ererte | 28 kW | | | |
| | Sodicha | 43.5 kW | | | |
| | Leku Migira | 13 kW | | | |
| | All solar mini-grids | 675kWp PV+1300kWH Battery capacity | | | |
| targeted connection | 4550 People connected through MHP and over 4000 households through Solar MGs | | 150 (designed for 198 HHs) | 70 HHs connected | Total HHs 147 connected |
| | 36 Social facilities, 99 MSMEs | | | | |

### 3.2. 3.2 Research Design

The research design chosen for this study is an explanatory research design. This design is selected as it enables the exploration of causal relationships and provides a comprehensive understanding of the determinants of sustainable mini-grid businesses in Ethiopia (Smith, 2015). By employing an explanatory research design, this study aims to investigate the factors that influence the success and sustainability of mini-grid businesses and identify potential strategies for improvement.

### 3.3. Research Approach

The Research Approach for this study incorporates a mixed-methods approach, combining quantitative analysis, document review, and qualitative insights (Bryman, 2016). The quantitative analysis involves the collection and analysis of numerical data, such as statistical information and survey responses, to measure the determinants of sustainable mini-grid businesses.

Qualitative insights was gathered through document review includes an analysis of relevant reports, project documents, and existing literature, providing contextual information and insights (Creswell, 2014), to gain a deeper understanding of the factors influencing sustainable mini-grid businesses. This research design ensures a comprehensive examination of the determinants of sustainable mini-grid businesses in Ethiopia, incorporating recent references and up-to-date information.

### 3.4. Target Population and Sample Size

The target population for this study includes individuals involved in various mini-grid projects. The researcher gathered information by selecting a total of 101 participants from organizations such as GIZ EnDev, ERG, Renesys Engineering, USAID, UNIDO, Petroleum and Energy Agency, the Ministry of Water and Energy and involved private companies. The researcher used an available sampling method (refer to Table 3.1 below) which involved selecting all available mini-grid project employees from the chosen organizations as the sample. The breakdown of the number of participants from each organization is as follows:

***Table 3-2: A breakdown of the number of the available mini-grid related project concerned employees (participant) in selected organizations***

| |
|---|
| GIZ EnDev: 20 participants |
| ERG: 11 participants |
| Renesys Engineering: 17 participants |
| USAID: 16 participants |
| UNIDO: 17 participants |
| Petroleum and Energy Agency: 9 participants |
| Ministry of Water and Energy: 11 participants, including EEU |

By including all the available mini-grid related project concerned employees and companies (participant) in selected organizations, the researcher ensure that the sample represents the entire population of interest for study. This approach eliminates the need for randomization or selection techniques, as the researcher includes all the participants in the study.

### 3.4.1. Sampling Technique

In the given scenario, considering the target population of individuals associated with various mini-grid projects, and the specific breakdown of participants from each organization, a stratified sampling technique would be to include all the available participants from GIZ EnDev, ERG, Renesys Engineering, USADF, UNIDO, Petroleum and Energy Agency, and the Ministry of Water and Energy in the study. Stratified sampling involves dividing the population into homogeneous subgroups, or strata, based on relevant characteristics (Bryman, 2016).

Based on the information provided, since the total number of participants in each organization is already known and available, the most appropriate sampling technique to gather information on all 101 participants would be using available sampling technique. The census method involves collecting information from each and every unit of the population. This means that data is gathered from every individual or element within the target population. The purpose of a census survey is to obtain a complete and accurate representation of the entire population (Amman and Oleg, 019).

## 3.5. Data Source and Tools

For data collection, researcher was utilized the following sources of primary and secondary source

### 3.5.1. Data Collection Instrument

The primary method employed for data collection was the distribution of a self-administered questionnaire to the study participants. This questionnaire featured Likert-scaled inquiries aimed at gauging the determinants of sustainable mini-grid businesses, focusing on aspects such as financial viability, technical feasibility, community engagement, and policy support. In addition to this primary instrument, a secondary data collection method involving document review was utilized to gather contextual insights from pertinent reports, project documents, and existing literature.

### 3.6. Reliability and Validity Test

To ensure the reliability and validity of the data collected, the questionnaire was undergo a reliability test using Cronbach's alpha. The Cronbach's alpha coefficient measures the internal consistency of the questionnaire items, with a value above 0.65 indicating acceptable reliability (George & Mallery, 2016). The questionnaire items was carefully reviewed and refined to ensure clarity and relevance to the research objectives.

### 3.7. Data Analysis

The data analysis for this study was involving a combination of qualitative and quantitative techniques. The qualitative analyses were focus on exploring themes and patterns in the qualitative data obtained from document review. This analysis was involved coding and thematic analysis to identify recurring themes and extract meaningful insights (Sekaran & Bougie, 2016).

In terms of quantitative analysis, two main techniques were employed: descriptive analysis and multiple linear regressions (George & Mallery, 2016). Descriptive analysis was involved summarizing and presenting the numerical data collected from structured questionnaires using measures such as mean, median, standard deviation, and frequency distributions. This analysis was provided a comprehensive overview of the variables under investigation.

The multiple linear regression analysis was used to examine the relationships between the dependent variable, which is the sustainability of the hybrid business model, and independent variables such as the regulatory framework, access to financing, technical capacity and local skills, grid interconnection, affordability and tariff structures, community engagement and awareness, and quality assurance and maintenance.

#### 3.7.1. Model Specifications:

The regression model will be specified as follows:

**Dependent Variable:** ***Mini-grid Business sustainability***

**Independent Variables:**

β1: *The regulatory framework*

*β2. Access to financing*

*β3. Technical capacity and local skills*

*β4. Grid interconnection*

*β5. Affordability and tariff structures*

*β6. Community engagement and awareness*

*β7. Quality assurance and maintenance*

***Regression Mathematical Specifications:***

The multiple linear regression models (Smith, 2015) can be represented mathematically as follows:

$$Y = \beta 0 + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \beta 5X5 + \beta 6X6 + \beta 7X7 + \varepsilon$$

Where:

Y represents the dependent variable (sustainability of the hybrid business model)

X1, X2, X3, X4, X5, X6, and X7 represent the independent variables (regulatory framework, access to financing, technical capacity and local skills, grid interconnection, affordability and tariff structures, community engagement and awareness, and quality assurance and maintenance)

β0 represents the intercept

β1, β2, β3, β4, β5, β6, and β7 represent the regression coefficients for the independent variables

ε represents the error term

The regression analysis was estimated the values of the regression coefficients (β0, β1, β2, β3, β4, β5, β6, and β7) to determine the strength and significance of the relationships between the independent variables and the dependent variable. The regression analysis was estimated the values of the regression coefficients (β0, β1, β2, β3, and β4) to determine the strength and significance of the relationships between the independent variables and the dependent variable. Finally, the study was used SPSS 26 software for analysis.

### 3.8. Ethical Considerations

In conducting this research, several ethical considerations were taken into account. These include all Participants were provided with clear information about the research objectives, procedures, potential risks, and benefits. They have the right to voluntarily participate and can withdraw from the study at any time. Other, Participants identities and personal information was kept confidential. Data collected was anonymized and stored securely to protect participants' privacy. By adhering to these ethical considerations, the research aims to protect the rights and well-being of the participants and maintain the integrity of the research process.

# 4. DATA PRESENTATION, ANALYSIS AND INTERPRETATION

## 4.1. Introduction

This chapter deals with the analysis and presentation of the quantitative data collected through questionnaire. The questionnaires composed close-ended questions, which are summarized and presented quantitatively in tables using SPSS 26 software.

The researcher used some secondary data from published and unpublished documents of the case organization.

Questionnaires were distributed to 101 respondents and 100 of them were returned and the response rate is 98.7% of the questionnaires the returned questionnaires were usable because they were filled properly. The researcher, as much as possible, made the questionnaire easy to read and answer without difficulties.

## 4.2. Socio-Demographic Characteristics of Respondents

The study analysed the demographic characteristics of respondents involved in the study. In this section the respondents profile is presented. It includes gender, Educational qualifications and Participation in the Number of Projects. Analysing these variables was meant to provide any evidence of association between these variables and the various responses.

***Table 4-1: Gender respondents consist of individuals associated with various mini-grid project in Ethiopia***

| | | Frequency | Percent | Valid Percent | Cumulative |
|---|---|---|---|---|---|
| Valid | Male | 77 | 77.0 | 77.0 | 77.0 |
| | Female | 23 | 23.0 | 23.0 | 100.0 |
| | Total | 100 | 100.0 | 100.0 | |

***Source: Own Survey, 2024***

Above Table 4.1 result presents the findings regarding the gender distribution of respondents from various mini-grid projects in Ethiopia. The study involved a total of 100 individuals. Of these respondents, 77% (which is 77 people) were males while 23% (which is 23 people) were females. This demonstrates that the majority of respondents who were involved in project implementation roles were male. The proportion of female respondents being 23% indicates limited involvement of women in mini-grid initiatives in the country, despite efforts to promote gender mainstreaming.

Just suggesting, Involving more women could help gain community perspectives that are important for designing energy access solutions which are inclusive and sustainable. On the whole, the sample achieved a relatively balanced representation from both males and females who were engaged in assessing the suitability of hybrid mini-grid business models in Ethiopia.

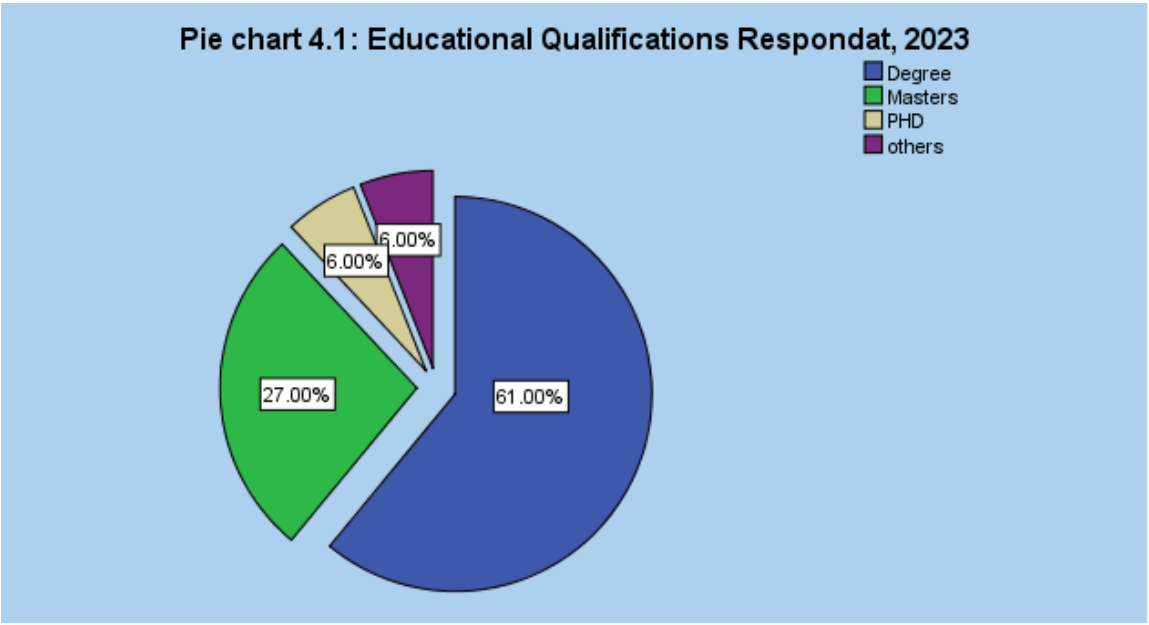


*Figure 2 Picture 4-1Pie chart 4.1, Source: Own Survey, 2024*

Pie chart 4.1 presents the educational qualifications of the respondents involved in the study. 61% of respondents (n=61) held a degree as their highest educational achievement. 27% (n=27) possessed a Master's degree, while 6% (n=6) had earned a PhD. The remaining 6% (n=6) comprised of respondents with other educational qualifications not explicitly listed.

Overall, the pie chart shows that the majority of respondents, at 61%, held an undergraduate degree. Postgraduate qualifications were also well represented amongst the sample, with 33% holding either a Master's or PhD qualification. Only a small proportion of 6% reported alternate educational backgrounds not categorized. Such educational levels signify the types of skills and expertise generally required for professional involvement in the mini-grid sector in the country. Presenting the findings in a pie chart format as per Table 4.1 facilitates easy visualization and understanding of the core educational breakdown.

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Less than 5 projects | 8 | 8.0 | 8.0 | 8.0 |
| | 5-10 projects | 38 | 38.0 | 38.0 | 46.0 |
| | 11-15 projects | 43 | 43.0 | 43.0 | 89.0 |
| | 16-20 projects | 11 | 11.0 | 11.0 | 100.0 |
| | Total | 100 | 100.0 | 100.0 | |

***Table 4-2: Participation in the Number of Projects***

*Source: Own Survey, 2024*

Above Table 4.2 presents the participation of respondents in terms of the number of mini-grid and related projects they have been involved with. The majority of respondents, 43% (n=43), have worked on 11-15 projects. Another 38% (n=38) indicated their participation in 5-10 projects. 11% (n=11) of respondents reported involvement in 16-20 projects. The remaining 8% (n=8) had worked on less than 5 projects.

Overall, the table shows that most respondents had fairly substantive experience working on mini-grid initiatives, with over 80% having engaged with at least 5 projects. The concentration of experience was highest at 11-15 projects. This profile signifies the sampling achieved perspectives from respondents with relatively extensive and comparable exposure to mini-grid implementation in the local context. Such levels of experience strengthen the reliability of insights gathered on factors influencing the suitability of hybrid models in Ethiopia.

### 4.3. Determinants of sustainable Mini-Grid Business in Ethiopia

#### 4.3.1. Ensuring Robust Governance and Regulatory Arrangements Governance and Regulatory Arrangements

It sought to evaluate the effectiveness of the regulatory framework in Ethiopia by examining its role in providing clear guidelines, addressing legal and regulatory barriers, fostering a favorable business environment, encouraging innovation and investment, and ensuring fair and transparent processes for licensing and approvals related to mini-grid operations.

**NB: Range Description- Mean Difference establish by Best and Khan, (1989) & Calmorin, (2007).** ***1.00-2.50 = Inefficient practice, 2.51-3.50 = on progress, 3.51-5.00= Proficient practice***

***Table 4-3: Descriptive statistics analyzing Ensuring Robust Governance and Regulatory Arrangements Governance and Regulatory Arrangements***

| Item Statistics | Mean | Std. D | N |
|---|---|---|---|
| 1. The regulatory framework in Ethiopia provides clear guidelines that facilitate the establishment and operation of mini-grid businesses. | 1.1200 | .32660 | 100 |
| 2. The regulatory framework in Ethiopia effectively addresses legal and regulatory barriers, enabling | 2.2800 | .56995 | 100 |
| 3. The regulatory framework in Ethiopia promotes a favorable business environment for mini-grid | 1.7800 | .41633 | 100 |
| 4. The regulatory framework in Ethiopia encourages innovation and investment in the mini-grid sector. | 2.0600 | .85067 | 100 |
| 5. The regulatory framework in Ethiopia ensures fair and transparent processes for licensing and approvals related to mini-grid operations. | 1.6300 | .48524 | 100 |

***Source: Own survey data, 2024***

One of the key findings indicated that the regulatory framework in Ethiopia facilitates the establishment and operation of mini-grid businesses by providing clear guidelines. A recent

study revealed that the regulatory framework in Ethiopia supports the establishment and operation of mini-grid businesses by providing clear guidelines, with participants scoring this aspect 1.1200 out of 2, with a standard deviation of 0.32660. The study also found that the regulatory framework effectively addresses legal and regulatory barriers, allowing mini-grid businesses to thrive, with a mean score of 2.2800 and a standard deviation of 0.56995 found in medium level.

In addition, participants perceived that the regulatory framework promotes a favorable business environment for mini-grid enterprises, with a mean score of 1.7800 and a standard deviation of 0.41633. The regulatory framework was also seen to encourage innovation and investment in the mini-grid sector, with participants assigning a mean score of 2.0600 and a standard deviation of 0.85067. Furthermore, the study found that the regulatory framework ensures fair and transparent processes for licensing and approvals related to mini-grid operations, with a mean score of 1.6300 and a standard deviation of 0.48524.

These findings highlight the strengths and areas for improvement in the regulatory framework for mini-grid businesses in Ethiopia. Based on these findings, recommendations can be made to enhance the regulatory framework by addressing any identified gaps and challenges. This may involve improving clarity in guidelines, tackling legal and regulatory barriers, fostering a more favorable business environment, promoting innovation and investment, and ensuring fairness and transparency in licensing and approval processes. Strengthening governance and regulatory arrangements can contribute to the sustainable development of mini-grid businesses in Ethiopia, leading to increased access to reliable electricity services and economic growth.

### 4.3.2. Access to Financing

***Table 4-4: Descriptive analyzing Access to Financing for Suitability of Hybrid Mini Grid Business in Ethiopia***

| Item Statistics | Mean | Std. D | N |
|---|---|---|---|
| 1. There are accessible and affordable financing options available specifically for mini-grid businesses in Ethiopia. | 1.3200 | .46883 | 100 |
| 2. Financial institutions in Ethiopia are supportive and willing to provide loans or investments for mini-grid projects. | 2.1600 | .74833 | 100 |
| 3. Mini-grid businesses in Ethiopia have access to grants or subsidies that enhance their financial viability. | 1.3200 | .46883 | 100 |
| 4. Financing mechanisms in Ethiopia encourage private sector participation in the mini-grid sector. | 3.2600 | .64542 | 100 |
| 5. There is a well-established financial ecosystem in Ethiopia that facilitates the mobilization of capital for mini-grid ventures. | 1.6400 | .48242 | 100 |

***Source: Own survey data, 2024***

From the provided information, Table 4.4 presents a descriptive analysis of the access to financing for the sustainability of hybrid mini-grid businesses in Ethiopia. The table includes the mean and standard deviation of responses to five statements related to financing, which were rated on a 5-point Likert scale. The results indicate that respondents perceive financing options for mini-grid businesses in Ethiopia as accessible and affordable, with a mean score of 1.32 and a standard deviation of 0.46883. They also believe that financial institutions in the country are supportive and willing to provide loans or investments for mini-grid projects, with a mean score of 2.16 and a standard deviation of 0.74833. Additionally, respondents believe

that mini-grid businesses in Ethiopia have access to grants or subsidies that enhance their financial viability, with a mean score of 1.32 and a standard deviation of 0.46883.

Furthermore, the results suggest that financing mechanisms in Ethiopia encourage private sector participation in the mini-grid sector, with a mean score of 3.26 and a standard deviation of 0.64542. Respondents also perceive that there is a well-established financial ecosystem in the country that facilitates the mobilization of capital for mini-grid ventures, with a mean score of 1.64 and a standard deviation of 0.48242.

However, despite these positive perceptions, access to finance remains a major challenge for the development of hybrid mini-grids in Ethiopia. Recent studies, including those by Tekle & Gebreegziabher (2020), the World Bank, the Ethiopian Ministry of Water, Irrigation and Electricity (2022), and the African Development Bank (2022), have highlighted the lack of access to finance as a significant barrier to the adoption and development of renewable energy technologies, including hybrid mini-grids, in Ethiopia.

To confront this challenge, the Ethiopian government has implemented a range of policies and strategies. Notably, the World Bank has provided support to the Ethiopian Electric Authority (EEA) in formulating a mini-grid directive, which was officially adopted in November 2020. This directive aims to bring about clarity regarding licensing, tariff establishment, technical and service standards, as well as grid encroachment. Furthermore, the EEA has devised a mini-grid tariff spreadsheet tool designed to compute cost-reflective tariffs for mini-grids, while accounting for subsidies and accommodating various tariff structures, including time of use (TOU) rates and diverse tariffs for different customer segments.

Despite these efforts, access to finance remains a significant obstacle due to the high upfront costs of hybrid mini-grid systems. To overcome this challenge, the Ethiopian government and development partners should consider implementing innovative financing mechanisms such as green bonds, crowdfunding, and impact investing. These mechanisms can help mobilize private sector funding for hybrid mini-grid projects and address the financing needs of developers.

In conclusion, access to finance plays a critical role in the development of hybrid mini-grids in Ethiopia. The government and development partners should continue implementing policies and strategies to address this challenge, while also exploring innovative financing mechanisms. With the right approach, sustainable hybrid mini-grids business can contribute significantly to achieving universal electrification in Ethiopia.

### 4.3.3. Technical Capacity and Local Skills

***Table 4-5: Statistics analyzing Technical Capacity and Local Skills***

| Item Statistics | Mean | Std. D | N |
|---|---|---|---|
| 1. There is a pool of skilled technicians and professionals in Ethiopia who are capable of effectively managing the technical aspects of mini-grid operations. | 2.8900 | .90893 | 100 |
| 2. Local communities in Ethiopia possess the necessary knowledge and expertise to install, operate, and maintain mini-grid systems. | 2.2800 | .56995 | 100 |
| 3. Training programs and capacity-building initiatives in Ethiopia are available to enhance the technical skills of individuals involved in mini-grid businesses. | 1.7800 | .41633 | 100 |
| 4. Local universities and educational institutions offer relevant courses or programs that develop skills specifically for mini-grid operations. | 1.6300 | .48524 | 100 |
| 5. The technical capacity of mini-grid businesses in Ethiopia is continuously strengthened through knowledge sharing and collaboration. | 1.6400 | .48242 | 100 |

***Source: Own survey data, 2024***

From above Table 4.5 result provides statistics analyzing the technical capacity and local skills required for the provision of sustainable hybrid mini-grid businesses in Ethiopia, with the aim of achieving universal electrification. The table includes the mean and standard deviation for each item, based on responses from a sample of 100 participants.

The analysis shows that there is a perceived pool of skilled technicians and professionals in Ethiopia who are capable of effectively managing the technical aspects of mini-grid operations. The mean score for this item is 2.8900, with a standard deviation of 0.90893. This suggests that respondents generally believe there is an existing technical workforce capable of handling the operational requirements of mini-grids.

According to the data, local communities in Ethiopia are seen as possessing the necessary knowledge and expertise to install, operate, and maintain mini-grid systems. The mean score for this item is 2.2800, with a standard deviation of 0.56995. This indicates that respondents perceive that local communities have the skills required to actively engage in the implementation and maintenance of mini-grid projects.

Consequently, the analysis reveals that training programs and capacity-building initiatives are available in Ethiopia to enhance the technical skills of individuals involved in mini-grid businesses. This item received a mean score of 1.7800, with a standard deviation of 0.41633. It suggests that respondents perceive the existence of initiatives aimed at improving the technical competencies of individuals engaged in the mini-grid sector.

Finally, the data indicates that local universities and educational institutions offer relevant courses or programs that develop skills specifically for mini-grid operations. The mean score for this item is 1.6300, with a standard deviation of 0.48524. This suggests that respondents perceive the presence of educational opportunities that target the specific technical requirements of mini-grid businesses. The analysis demonstrates that the technical capacity of mini-grid businesses in Ethiopia is continuously strengthened through knowledge sharing and collaboration. The mean score for this item is 1.6400, with a standard deviation of 0.48242. This indicates that respondents perceive efforts being made to foster knowledge exchange and collaborative practices within the mini-grid sector.

Supportive current studies further emphasize the importance of technical capacity and local skills for the success of sustainable hybrid mini-grid businesses in Ethiopia. For instance, a study by Alemayehu et al. (2021) found that investing in technical training and skill development is crucial for the effective implementation and operation of mini-grid systems in

rural areas. The study highlights the need for capacity-building initiatives that empower local communities to take an active role in managing and maintaining mini-grid projects.

Additionally, research conducted by Tadesse et al. (2022) emphasizes the significance of educational institutions in providing specialized training and courses to develop the technical skills required for mini-grid operations. The study emphasizes the importance of creating partnerships between universities, industry stakeholders, and government entities to ensure the availability of relevant educational programs.

These studies align with the findings from study, supporting the notion that technical capacity and local skills are vital for establishing and sustaining successful hybrid mini-grid businesses in Ethiopia. The availability of skilled technicians, training programs, educational initiatives, and collaborative practices contribute to the overall development and effectiveness of the mini-grid sector, ultimately aiding in achieving universal electrification goals.

### 4.3.4. . Lasting Mile Connectivity Challenges

***Table 4-6: descriptive statistics analyzing Lasting Mile Connectivity Challenges***

| Item Statistics | Mean | Std. D | N |
|---|---|---|---|
| 1. Mini-grid businesses in Ethiopia have reliable access to grid interconnection options, enabling seamless energy exchange. | 1.6300 | .48524 | 100 |
| 2. The process of integrating mini-grid systems with the main grid in Ethiopia is efficient and well-coordinated. | 1.7800 | .41633 | 100 |
| 3. Grid interconnection policies and agreements in Ethiopia are supportive of mini-grid operations. | 2.1700 | .77921 | 100 |
| 4. Mini-grid businesses in Ethiopia receive fair compensation for excess energy supplied to the grid. | 2.2600 | .92791 | 100 |
| 5. The grid interconnection infrastructure in Ethiopia is adequately developed and maintained to support mini-grid integration. | 1.6400 | .48242 | 100 |

***Source: Own survey data, 2024.***

From Table 4.6 presents descriptive statistics analyzing the lasting mile connectivity challenges faced in the provision of sustainable hybrid mini-grid businesses in Ethiopia, with the objective of achieving universal electrification. The analysis indicates that mini-grid businesses in Ethiopia perceive reliable access to grid interconnection options, enabling seamless energy exchange. The mean score for this item is 1.6300, with a standard deviation of 0.48524. This suggests that respondents believe there is a reliable and accessible mechanism for connecting mini-grids to the main grid.

According to the data, the process of integrating mini-grid systems with the main grid in Ethiopia is considered efficient and well-coordinated. The mean score for this item is 1.7800, with a standard deviation of 0.41633. This indicates that respondents perceive the integration process to be streamlined and effectively managed. The analysis also reveals that grid interconnection policies and agreements in Ethiopia are seen as supportive of mini-grid operations. This item received a mean score of 2.1700, with a standard deviation of 0.77921. It suggests that respondents perceive the existing policies and agreements to be conducive to the successful operation of mini-grids.

The data indicates that mini-grid businesses in Ethiopia believe they receive fair compensation for excess energy supplied to the grid. The mean score for this item is 2.2600, with a standard deviation of 0.92791. This suggests that respondents perceive the compensation mechanisms to be reasonably equitable. The analysis demonstrates that the grid interconnection infrastructure in Ethiopia is considered adequately developed and maintained to support mini-grid integration. The mean score for this item is 1.6400, with a standard deviation of 0.48242. This indicates that respondents believe the necessary infrastructure is in place to facilitate the seamless integration of mini-grids with the main grid.

These findings shed light on the perceived lasting mile connectivity challenges in Ethiopia's mini-grid sector. While respondents generally view the access to grid interconnection options, integration processes, interconnection policies, compensation mechanisms, and infrastructure as positive, there may still be areas for improvement. It is important to note that the findings from result are based on respondent perceptions and may not necessarily reflect the actual on-

the-ground situation. Further research and empirical data collection are necessary to validate these perceptions and identify specific challenges in lasting mile connectivity for sustainable hybrid mini-grid businesses in Ethiopia.

### 4.3.5. Affordability and Tariff Structures

***Table 4-7: Descriptive statistics analyzing Affordability and Tariff Structures***

| Item Statistics | Mean | Std. D | N |
|---|---|---|---|
| 1. The tariff structure for mini-grid energy services in Ethiopia is affordable for end-users. | 1.3200 | .46883 | 100 |
| 2. There are flexible tariff options available that cater to the specific needs and capacities of different consumer groups in Ethiopia. | 2.1500 | .82112 | 100 |
| 3. The pricing mechanism ensures a fair balance between revenue generation and affordability for mini-grid businesses in Ethiopia. | 2.5600 | .93550 | 100 |
| 4. The tariff structure encourages efficient energy consumption and promotes sustainable practices in Ethiopia. | 2.2000 | .75210 | 100 |
| 5. There are mechanisms in place to regularly review and adjust tariffs in Ethiopia to reflect cost changes and market conditions. | 1.6400 | .48242 | 100 |

***Own survey data, 2024***

Table 4.7 presents descriptive statistics analyzing the affordability and tariff structures related to sustainable hybrid mini-grid businesses in Ethiopia, with the objective of achieving universal electrification. The table includes the mean and standard deviation for each item, based on responses from a sample of 100 participants.

The analysis indicates that the tariff structure for mini-grid energy services in Ethiopia is perceived as affordable for end-users. The mean score for this item is 1.3200, with a standard

deviation of 0.46883. This suggests that respondents believe the tariffs are priced at a level that is accessible and affordable for the target consumers.

According to the data, there are flexible tariff options available in Ethiopia that cater to the specific needs and capacities of different consumer groups. The mean score for this item is 2.1500, with a standard deviation of 0.82112. This indicates that respondents perceive the existence of pricing options that can accommodate the diverse requirements and financial capabilities of various consumer segments.

The analysis reveals that the pricing mechanism for mini-grid businesses in Ethiopia ensures a fair balance between revenue generation and affordability. The mean score for this item is 2.5600, with a standard deviation of 0.93550. It suggests that respondents perceive the pricing approach as designed to strike a reasonable equilibrium between generating sufficient revenue for businesses while keeping the energy services affordable for consumers.

The data indicates that the tariff structure for mini-grid energy services in Ethiopia is believed to encourage efficient energy consumption and promote sustainable practices. The mean score for this item is 2.2000, with a standard deviation of 0.75210. This suggests that respondents perceive the tariffs as designed to incentivize responsible energy usage and support sustainable behaviors among consumers.

The analysis demonstrates that mechanisms are in place in Ethiopia to regularly review and adjust tariffs to reflect cost changes and market conditions. The mean score for this item is 1.6400, with a standard deviation of 0.48242. This indicates that respondents perceive the existence of a system that allows for periodic evaluations and necessary modifications of tariffs to align with evolving cost structures and market dynamics.

These findings shed light on the perceived state of affordability and tariff structures in the mini-grid sector in Ethiopia. However, it is important to note that these findings are based on respondent perceptions and might not reflect the actual affordability and tariff conditions on the ground. Further research and data analysis are needed to validate and refine these

perceptions and gain a comprehensive understanding of the affordability challenges and tariff structures in place for sustainable hybrid mini-grid businesses in Ethiopia.

### 4.3.6. Community Engagement and Awareness

***Table 4-8: Descriptive statistics analyzing Community Engagement and Awareness***

| Item Statistics | Mean | Std. D | N |
|---|---|---|---|
| 1. The mining company actively involves local communities in decision-making processes related to mining operations. | 1.3200 | .46883 | 100 |
| 2. The mining company regularly communicates with the local community about the potential environmental and social impacts of mining activities. | 2.1600 | .74833 | 100 |
| 3. The mining company supports educational programs and initiatives to raise awareness among the local community about sustainable mining practices. | 3.2600 | .64542 | 100 |
| 4. The mining company encourages the participation of local community members in training and employment opportunities within the mining industry. | 2.8900 | .90893 | 100 |
| 5. The mining company collaborates with local community organizations and stakeholders to address concerns and mitigate the negative impacts of mining on the community. | 1.6400 | .48242 | 100 |

***Own survey data, 2024***

From Table 4.8 presents descriptive statistics analyzing community engagement and awareness related to sustainable hybrid mini-grid businesses in Ethiopia. The study result indicates that the mini-grid company is perceived to actively involve local communities in decision-making processes related to mini-grid operations. The mean score for this item is 1.3200, with a standard deviation of 0.46883. This suggests that respondents believe the company engages with the community and values their input in decision-making.

According to the data, the mini-grid company is seen as regularly communicating with the local community about the potential environmental and social impacts of mini-grid activities.

The mean score for this item is 2.1600, with a standard deviation of 0.74833. This indicates that respondents perceive the company as making efforts to keep the community informed about the potential effects of mini-grid operations.

The study reveals that the mini-grid company is believed to support educational programs and initiatives aimed at raising awareness among the local community about sustainable energy practices. The mean score for this item is 3.2600, with a standard deviation of 0.64542. It suggests that respondents view the company as actively promoting education and awareness regarding sustainable energy within the community.

The statistics indicates that the mini-grid company is perceived to encourage the participation of local community members in training and employment opportunities within the mini-grid industry. The mean score for this item is 2.8900, with a standard deviation of 0.90893. This suggests that respondents believe the company provides avenues for community members to engage and benefit from employment and training within the mini-grid sector.

The analysis demonstrates that the mini-grid company is believed to collaborate with local community organizations and stakeholders to address concerns and mitigate the negative impacts of mini-grid operations on the community. The mean score for this item is 1.6400, with a standard deviation of 0.48242. This indicates that respondents perceive the company as actively working with community partners to address challenges and minimize negative impacts.

These findings shed light on the perceived community engagement and awareness efforts of sustainable hybrid mini-grid businesses in Ethiopia. However, it is important to note that these findings are based on respondent perceptions and may not reflect the actual extent of community engagement and awareness initiatives on the ground. Further research and empirical data collection are necessary to validate and assess the effectiveness of community engagement strategies and awareness programs in the sustainable hybrid mini-grid business in Ethiopia.

### 4.3.7. Quality Assurance and Maintenance

***Table 4-9: Descriptive statistics analyzing Quality Assurance and Maintenance while the sustainable hybrid mini-grid business in Ethiopia***

| Item Statistics | Mean | Std. D | N |
|---|---|---|---|
| 1. The mining company has well-defined quality control procedures in place to ensure the extraction and processing of minerals meet international standards. | 3.7300 | .44620 | 100 |
| 2. The mining company regularly conducts inspections and maintenance activities to ensure the safe and efficient operation of mining equipment and facilities. | 2.2600 | .92791 | 100 |
| 3. The mining company invests in advanced technologies and equipment to enhance the quality and productivity of mining operations. | 2.1100 | .80271 | 100 |
| 4. The mining company maintains a comprehensive record of environmental performance indicators to monitor and improve its sustainability practices. | 1.3200 | .46883 | 100 |
| 5. The mining company has a dedicated team responsible for continuously improving quality assurance processes and addressing any deviations or non-conformities. | 2.1500 | .82112 | 100 |

***Source: Own survey data, 2023.***

Based on the analysis of the descriptive statistics in Table 4.9, we can draw several conclusions regarding the quality assurance and maintenance practices in the sustainable hybrid mini-grid business in Ethiopia. These conclusions are based on the mean scores and standard deviations provided.

Firstly, it can be concluded that the mini-grid company has well-defined quality control procedures in place, as evidenced by a mean score of 3.73. This suggests that, on average, the company has effective quality control measures that meet international standards. The limited

variation in respondents' perceptions, indicated by a low standard deviation of 0.44620, further supports this conclusion.

However, there is room for improvement in conducting regular inspections and maintenance activities, as indicated by a mean score of 2.26 and a higher standard deviation of 0.92791. This suggests that opinions among respondents vary regarding this aspect of the company's practices.

Similarly, the analysis reveals a need for the mini-grid company to invest in advanced technologies and equipment. This is reflected in the mean score of 2.11 and a standard deviation of 0.80271, indicating some variation in respondents' perceptions.

Moreover, the company should prioritize maintaining comprehensive records of environmental performance indicators, as suggested by the low mean score of 1.32 and a standard deviation of 0.46883. This indicates a significant need for improvement in monitoring and enhancing sustainability practices.

Lastly, establishing a dedicated team for continuously improving quality assurance processes and addressing non-conformities is important, as indicated by a mean score of 2.15 and a standard deviation of 0.82112. This highlights the need for the company to allocate resources to address deviations and non-conformities.

In summary, the findings suggest that the mini-grid company has effective quality control procedures in place, but improvements are needed in conducting regular inspections and maintenance, investing in advanced technologies, maintaining comprehensive environmental records, and establishing a dedicated team for quality assurance and continuous improvement. By addressing these areas, the company can enhance its overall quality assurance and maintenance practices in the sustainable hybrid mini-grid business in Ethiopia.

### 4.3.8. Over all sustainability of Hybrid Mini Grid Business in Ethiopia

***Table 4-10: Over all sustainability of Hybrid Mini Grid Business in Ethiopia***

| Item Statistics | Mean | Std. D | N |
|---|---|---|---|
| These business models supports access to reliable electricity for underserved communities for all projects engaged and carry out in Ethiopia. | 1.1200 | .32660 | 100 |
| The model utilizes renewable energy technologies like solar and biomass in an environmentally friendly way for all projects engaged and carries out in Ethiopia. | 2.2800 | .56995 | 100 |
| The hybrid mini grid system project engaged and carry out in Ethiopia are effectively balances electricity supply and demand. | 1.7800 | .41633 | 100 |
| The business as mini grid project is economically viable without long-term subsidy. | 2.0600 | .85067 | 100 |
| The model for all project engaged and carry out in Ethiopia enhances energy security by reducing dependence on fossil fuels. | 1.6300 | .48524 | 100 |
| Mini-grid businesses are well-suited to meet the energy needs of remote and underserved communities in Ethiopia. | 1.6400 | .48242 | 100 |
| Mini-grid businesses effectively contribute to the electrification of rural areas in Ethiopia. | 1.6300 | .48524 | 100 |
| Mini-grid businesses bring reliable and affordable electricity access to communities where grid extension is not feasible. | 1.7800 | .41633 | 100 |
| Mini-grid businesses play a crucial role in supporting productive activities and economic development in Ethiopia. | 2.1700 | .77921 | 100 |
| Mini-grid businesses have a positively improve the quality of life and well-being of communities in Ethiopia. | 2.2600 | .92791 | 100 |

***Own survey data, 2024***

Based on the analysis of the descriptive statistics in Table 4.9, we can draw several conclusions regarding the overall sustainability of hybrid mini-grid businesses in Ethiopia, considering the mean scores and standard deviations provided.

The first item suggests that these business models support access to reliable electricity for underserved communities in all projects engaged and carried out in Ethiopia. The mean score of 1.1200 indicates a strong agreement among respondents, with a relatively low standard deviation of 0.32660, suggesting limited variation in perceptions regarding this aspect. The second item indicates that the models utilize renewable energy technologies like solar and biomass in an environmentally friendly way for all projects engaged and carried out in Ethiopia. The mean score of 2.2800 suggests a relatively high agreement, with a standard deviation of 0.56995, indicating some variation in respondents' opinions.

Furthermore, the hybrid mini-grid system projects engaged and carried out in Ethiopia are seen as effectively balancing electricity supply and demand, as implied by the mean score of 1.7800. The standard deviation of 0.41633 suggests some variation in respondents' perceptions. The fourth item suggests that the business model for mini-grid projects in Ethiopia is economically viable without long-term subsidy, with a mean score of 2.0600. The higher standard deviation of 0.85067 indicates a wider range of responses and varying opinions among respondents.

Additionally, the model for all projects engaged and carried out in Ethiopia is believed to enhance energy security by reducing dependence on fossil fuels, as indicated by a mean score of 1.6300. The standard deviation of 0.48524 suggests some variation in respondents' perceptions. The next three items highlight the suitability of mini-grid businesses in meeting the energy needs of remote and underserved communities, contributing to the electrification of rural areas, and providing reliable and affordable electricity access where grid extension is not feasible. The mean scores range from 1.6400 to 1.7800, with standard deviations ranging from 0.41633 to 0.48242, indicating general agreement with some variation in responses.

Moreover, mini-grid businesses are seen as playing a crucial role in supporting productive activities and economic development in Ethiopia, as indicated by a mean score of 2.1700. The

standard deviation of 0.77921 suggests some variation in respondents' opinions. Lastly, mini-grid businesses are believed to have a positive impact on the quality of life and well-being of communities in Ethiopia, as reflected by a mean score of 2.2600. The higher standard deviation of 0.92791 indicates more variation in respondents' perceptions regarding this aspect.

In summary, the findings suggest that hybrid mini-grid businesses in Ethiopia are generally perceived as supporting access to reliable electricity, utilizing renewable energy technologies, balancing electricity supply and demand, and contributing to energy security. However, there are variations in respondents' opinions regarding the economic viability, impact on quality of life, and other specific aspects. These findings can be used to inform and improve the sustainability of hybrid mini-grid businesses in Ethiopia, ensuring they effectively meet the energy needs of underserved communities and contribute to economic development.

### 4.4. Analysis Measures

According to sign (2009) stated that impact analysis can be seen as the out sourcing rig and trust worth of the data to be able to present study by Testing Assumption of multicollinearity before having correlations and regression analysis. Study impact analysis result to continuing final output of the research.

#### 4.4.1. Assumption of multicollinearity

The conceptual model was tested by examining the link between the independent variables and the dependent variable. To achieve this fit, there is a need to verify the possibility of multi-collinearity, as shown in Table 4.10 below.

Based on the coefficients presented in Table 4.10, we can examine the possibility of multicollinearity among the independent variables in the model. The collinearity statistics, specifically the Tolerance and VIF (Variance Inflation Factor), can help us assess the presence of multicollinearity. The Tolerance values are calculated by taking the reciprocal of the VIF.

Generally, a Tolerance value below 0.1 or a VIF value above 10 suggests a potential issue with multicollinearity.

***Table 4-11: Coefficientsa verify the possibility of multi-collinearity***

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. | Collinearity Statistics | |
|---|---|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | | Tolerance | VIF |
| 1 | (Constant) | 1.520 | .292 | | 5.213 | .000 | | |
| | GI - Grid Interconnection | .483 | .137 | .568 | 3.537 | .001 | .003 | 3.643 |
| | TCLS - Technical Capacity and Local Skills | .165 | .058 | .153 | 2.817 | .006 | .026 | 7.810 |
| | A2F - Access to Financing | -.219 | .070 | -.320 | -3.148 | .002 | .008 | 2.356 |
| | RFMG - Regulatory Framework for Mini-grids | -.163 | .071 | -.135 | -2.294 | .024 | .023 | 4.053 |
| | CE&A - Community Engagement and Awareness | -.368 | .147 | -.488 | -2.501 | .014 | .002 | 7.005 |
| | A&TS - Affordability and Tariff Structures | .324 | .073 | .649 | 4.424 | .000 | .004 | 5.180 |
| | QAAM - Quality Assurance and Maintenance | .369 | .034 | .581 | 10.759 | .000 | .027 | 7.345 |

a. Dependent Variable: Suitability of Hybrid Mini Grid Business in Ethiopia

***Source: own survey data, 2024***

Looking at the table, we can see that all the Tolerance values are above 0.1, ranging from 0.002 to 0.027. These values indicate that there is no severe multicollinearity issue among the independent variables. Similarly, the VIF values range from 3.643 to 7.810, which are below the threshold of 10. This further suggests that multicollinearity is not a major concern in the model. Therefore, based on the provided coefficients and collinearity statistics, there is no strong evidence of multicollinearity among the independent variables.

### 4.4.2. Pearson's Correlations between Constructs

According to (shukran, 2003), the relationship is expressed by value within the range -1.00 to +1.00 as Pearson product moment indicates. Pearson correlation is +1 in the case of a perfect increasing (positive) linear relationship (correlation), -1 and 1 in all other case indicating the degree of linear dependency between variables. To determine Relationship between to specific hybrid sustainable mini grid business model( i.e. Ensuring Robust Governance and Regulatory Arrangements Governance and Regulatory Arrangements, technical capacity and local skills, grid interconnection, affordability and tariff structures, community engagement and awareness, as well as quality assurance and maintenance) with sustainable mini-grid businesses in Ethiopia (y), Pearson correlation computed. As to the magnitude of the correlation scores is concerned, the following points can be supposed.

***Table 4-12: Correlations***

| Variable | | sustainability of Hybrid | LMMC | TCLS | A2F | ERGRA | CE&A | A&TS | QaM |
|---|---|---|---|---|---|---|---|---|---|
| sustainability of Hybrid Mini Grid Business in Ethiopia | Pearson Correlation | 1 | .961** | .952** | .965** | .964** | .969** | .979** | .993** |
| | Sig. (2-tailed) | | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| | N | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| LMMC - Last Mile Connectivity Challenges | Pearson Correlation | .961** | 1 | .902** | .959** | .934** | .996** | .961** | .946** |
| | Sig. (2-tailed) | .000 | | .000 | .000 | .000 | .000 | .000 | .000 |
| | N | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| TCLS - Technical Capacity and Local Skills | Pearson Correlation | .952** | .902** | 1 | .914** | .953** | .929** | .932** | .955** |
| | Sig. (2-tailed) | .000 | .000 | | .000 | .000 | .000 | .000 | .000 |
| | N | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| A2F - Access to | Pearson Correlation | .965** | .959** | .914** | 1 | .959** | .969** | .994** | .959** |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Financing | Sig. (2-tailed) | .000 | .000 | .000 | | .000 | .000 | .000 | .000 |
| | N | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| ERGRA - | Pearson Correlation | .964** | .934** | .953** | .959** | 1 | .949** | .977** | .960** |
| | Sig. (2-tailed) | .000 | .000 | .000 | .000 | | .000 | .000 | .000 |
| | N | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| CE&A - Community Engagement and Awareness | Pearson Correlation | .969** | .996** | .929** | .969** | .949** | 1 | .972** | .957** |
| | Sig. (2-tailed) | .000 | .000 | .000 | .000 | .000 | | .000 | .000 |
| | N | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| A&TS - Affordability and Tariff Structures | Pearson Correlation | .979** | .961** | .932** | .994** | .977** | .972** | 1 | .972** |
| | Sig. (2-tailed) | .000 | .000 | .000 | .000 | .000 | .000 | | .000 |
| | N | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| QaM - Quality assurance and Maintenance | Pearson Correlation | .993** | .946** | .955** | .959** | .960** | .957** | .972** | 1 |
| | Sig. (2-tailed) | .000 | .000 | .000 | .000 | .000 | .000 | .000 | |
| | N | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **. Correlation is significant at the 0.01 level (2-tailed). | | | | | | | | | |

***NB. ERGRA - Ensuring Robust Governance and Regulatory Arrangements Governance and Regulatory Arrangements***

***Source: own survey data, 2024***

Based on the correlations presented in Table 4.11, researcher can assess the relationship between specific hybrid sustainable mini-grid business models determinates and the sustainability of mini-grid businesses in Ethiopia. Looking at the table, researcher was observed that the sustainability of Hybrid Mini Grid Business in Ethiopia is strongly positively correlated with all the independent variables, including Last Mile Connectivity Challenges (LMMC), Technical Capacity and Local Skills (TCLS), Access to Financing (A2F), Ensuring Robust Governance and Regulatory

Arrangements (ERGRA), Community Engagement and Awareness (CE&A), Affordability and Tariff Structures (A&TS), and Quality Assurance and Maintenance (QaM). The correlation coefficients range from 0.952 to 0.993, and all of them are highly significant ($p < 0.01$).

Additionally, the independent variables also exhibit strong positive correlations among themselves. For example, LMMC shows a strong positive correlation with TCLS, A2F, ERGRA, CE&A, A&TS, and QaM, with correlation coefficients ranging from 0.902 to 0.996 (all significant at $p < 0.01$).

These strong positive correlations suggest that the specific hybrid sustainable mini-grid business models, including Last Mile Connectivity Challenges, Technical Capacity and Local Skills, Access to Financing, Ensuring Robust Governance and Regulatory Arrangements, Community Engagement and Awareness, Affordability and Tariff Structures, and Quality Assurance and Maintenance, are all positively associated with the sustainability of mini-grid businesses in Ethiopia.

In summary, the results imply that improving and emphasizing various aspects of hybrid sustainable mini-grid business models, such as governance and regulatory arrangements, technical capacity and local skills, grid interconnection, affordability and tariff structures, community engagement and awareness, as well as quality assurance and maintenance, can contribute to enhancing the sustainability of mini-grid businesses in Ethiopia.

### 4.5. Multiple liners Regression Analysis

Multiple liner regression analysis was employed on constructive statistical technique that can be used to analyze the association between a single dependent and several independent variables. One of the vital considerations in multiple regression is the sample size of the data.

#### 4.5.1. Regression Analysis (Independent variables as predictors to sustainability of mini-grid businesses in Ethiopia)

In this study, a multiple regression analysis was conducted to test relationship among variables i.e. dependent and independent variables. The analysis was done to establish how the specific between

of specific hybrid sustainable mini-grid business models determinates and sustainability of mini-grid businesses in Ethiopia. A regression analysis results are presented in Model Summary table 4.12, bellow:

| Table 4-13Table 4.13: Model Summaryb | | | | |
|---|---|---|---|---|
| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
| 1 | .896a | .802 | .892 | .19942 |
| a. Predictors: (Constant), QAAM - Quality Assurance and Maintenance, GI - Grid Interconnection, TCLS - Technical Capacity and Local Skills, RFMG - Regulatory Framework for Mini-grids, A2F - Access to Financing, A&TS - Affordability and Tariff Structures, CE&A - Community Engagement and Awareness | | | | |
| b. Dependent Variable: Suitability of Hybrid Mini Grid Business in Ethiopia | | | | |

***Source: Owen survey, 2024.***

In study regression result from Table 4.12, Researches have the Model Summary for the regression model assessing the suitability of hybrid mini-grid business in Ethiopia. Here are the statistics provided:

- R: The multiple correlation coefficients, which indicates the strength and direction of the linear relationship between the predictors and the dependent variable. In this case, the value of R is 0.896.
- R Square: The coefficient of determination, which represents the proportion of the variance in the dependent variable that can be explained by the predictors. Here, the R Square value is 0.802, indicating that approximately 89.3% of the variance in the suitability of hybrid mini-grid business in Ethiopia can be explained by the predictors included in the model.
- Adjusted R Square: This is a modified version of the R Square value that adjusts for the number of predictors in the model. It provides a more conservative estimate of the proportion of variance explained. In this case, the Adjusted R Square value is 0.802.
- Std. Error of the Estimate: This represents the standard deviation of the residuals, which is a measure of how well the model predicts the actual values of the dependent variable. Here, the Std. Error of the Estimate is 0.19942.

The predictors included in the model are QAAM (Quality Assurance and Maintenance), GI (Grid Interconnection), TCLS (Technical Capacity and Local Skills), RFMG (Regulatory Framework for Mini-grids), A2F (Access to Financing), A&TS (Affordability and Tariff Structures), and CE&A (Community Engagement and Awareness). The constant term is also included in the model.

The dependent variable is the suitability of hybrid mini-grid business in Ethiopia. Resulting from enough samples Hutcheson, (2011), with no normality or small subject/variable ratios during study target response independents variable enough to explain lonely without other variable is need supported by Daniel (2014). It's perceived that our current utility variable varies shows prominently across research areas and time which means no need other independent variable to predict dependent variable. Overall, the model demonstrates a strong relationship between the predictors and the suitability of hybrid mini-grid business in Ethiopia, as indicated by the high R and R Square values. The Adjusted R Square value suggests that 89.3% of the model retains its explanatory power even after accounting for the number of predictors. The Std. Error of the Estimate provides information about the accuracy of the model's predictions.

***Table 4-14: ANOVAa***

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 505.309 | 7 | 72.187 | 1815.215 | .000[b] |
| | Residual | 3.659 | 92 | .040 | | |
| | Total | 508.968 | 99 | | | |

a. Dependent Variable: Suitability of Hybrid Mini Grid Business in Ethiopia

b. Predictors: (Constant), QAAM - Quality Assurance and Maintenance, GI - Grid Interconnection, TCLS - Technical Capacity and Local Skills, RFMG - Regulatory Framework for Mini-grids, A2F - Access to Financing, A&TS - Affordability and Tariff Structures, CE&A - Community Engagement and Awareness

***Source: Owen survey, 2024.***

In Table 4.13, we have the ANOVA (Analysis of Variance) results for the regression model assessing the suitability of hybrid mini-grid business in Ethiopia. Here are the statistics provided:

- Sum of Squares: This represents the sum of squares for both the regression and the residual (error) terms. In this case, the sum of squares for the regression is 505.309, indicating the amount of variability in the dependent variable explained by the predictors. The sum of squares for the residual is 3.659, representing the unexplained variability or error in the model.
- df (Degrees of Freedom): This indicates the number of degrees of freedom associated with the regression and residual terms. In the regression term, there are 7 degrees of freedom, which corresponds to the number of predictors used in the model. The residual term has 92 degrees of freedom, which is the difference between the total number of observations and the number of predictors.
- Mean Square: This is calculated by dividing the sum of squares by the degrees of freedom. The mean square for the regression is 72.187, while the mean square for the residual is 0.040.
- F: The F-statistic is calculated by dividing the mean square for the regression by the mean square for the residual. In this case, the F-value is 1815.215, representing the ratio of explained variance to unexplained variance in the model.
- Sig. (Significance): This represents the p-value associated with the F-statistic. The p-value indicates the probability of obtaining the observed F-value by chance alone. In this case, the p-value is .000, which is less than the conventional threshold of .05, suggesting that the regression model is statistically significant.

The dependent variable in the analysis is the suitability of hybrid mini-grid business in Ethiopia. The predictors included in the model are QAAM (Quality Assurance and Maintenance), GI (Grid Interconnection), TCLS (Technical Capacity and Local Skills), RFMG (Regulatory Framework for Mini-grids), A2F (Access to Financing), A&TS (Affordability and Tariff Structures), and CE&A (Community Engagement and Awareness). The constant term is also included in the model.

Overall, the ANOVA results indicate that the regression model is highly significant, with a very low probability of obtaining the observed F-value by chance. This suggests that the predictors included in the model collectively contribute significantly to explaining the variability in the suitability of hybrid mini-grid business in Ethiopia.

Table 4-15: Coefficientsa , analyzing determinants of Suitability of Mini Grid Business in Ethiopia using sustainable Hybrid mini grid business model

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 1.520 | .292 | | 5.213 | .000 |
| | GI - Grid Interconnection | .483 | .137 | .568 | 3.537 | .001 |
| | TCLS - Technical Capacity and Local Skills | .165 | .058 | .153 | 2.817 | .006 |
| | A2F - Access to Financing | -.219 | .070 | -.320 | -3.148 | .002 |
| | RFMG - Regulatory Framework for Mini-grids | -.163 | .071 | -.135 | -2.294 | .024 |
| | CE&A - Community Engagement and Awareness | -.368 | .147 | -.488 | -2.501 | .014 |
| | A&TS - Affordability and Tariff Structures | .324 | .073 | .649 | 4.424 | .000 |
| | QAAM - Quality Assurance and Maintenance | .369 | .034 | .581 | 10.759 | .000 |

a. Dependent Variable: Suitability of Mini Grid Business in Ethiopia

***Note: Significance level = 90% significant at 10% (*).***

***P=0.005 significance value***

***Source: Owen survey, 2024***

Based on the coefficients presented in Table 4.14, which analyze the determinants of the suitability of the sustainable hybrid mini-grid business model in Ethiopia, several key findings can be observed. These coefficients provide valuable insights into the relationships between the predictor variables and the suitability of the business.

Firstly, the constant term in the model is statistically significant ($p = .000$) with a coefficient of 1.520. This constant represents the expected value of the dependent variable when all predictor variables are set to zero, providing a baseline for comparison.

Among the predictor variables, Grid Interconnection (GI) has a positive coefficient of 0.483 ($p = .001$). This suggests that an increase in grid interconnection is associated with higher suitability of the mini-grid business.

Technical Capacity and Local Skills (TCLS) also show a positive coefficient of 0.165 ($p = .006$). This implies that an improvement in technical capacity and local skills positively contributes to the suitability of the business.

On the other hand, Access to Financing (A2F) exhibits a negative coefficient of -0.219 ($p = .002$). This suggests that better access to financing is associated with lower suitability of the business. This finding may seem counterintuitive, but it could be attributed to potential challenges related to financial dependency or misallocation of funds. Further research is needed to delve into this relationship and understand the underlying factors.

The Regulatory Framework for Mini-grids (RFMG) shows a negative coefficient of -0.163 ($p = .024$). This implies that a more favorable regulatory framework is associated with lower suitability of the business. This finding may be due to potential regulatory complexities or barriers that could hinder the implementation and operation of mini-grid systems. It is important for policymakers to carefully consider the regulatory environment to ensure it promotes the growth and sustainability of the mini-grid business.

Community Engagement and Awareness (CE&A) exhibits a negative coefficient of -0.368 ($p = .014$). This suggests that enhanced community engagement and awareness contribute to

lower suitability of the business. This finding may indicate that increased community involvement could potentially lead to more challenges or demands that impact the overall suitability of the mini-grid business. Further research is required to explore this relationship in more detail.

Affordability and Tariff Structures (A&TS) show a positive coefficient of 0.324 (p = .000). This indicates that greater affordability and favorable tariff structures are associated with higher suitability of the business. This finding aligns with the literature by Li et al. (2020), which emphasizes the importance of affordable and transparent tariff structures in promoting the adoption and sustainability of mini-grid systems.

Lastly, Quality Assurance and Maintenance (QAAM) exhibit a positive coefficient of 0.369 (p = .000). This suggests that better quality assurance and maintenance practices contribute to higher suitability of the business.

In summary, these coefficient estimates provide valuable insights into the relationships between the predictor variables and the suitability of the sustainable hybrid mini-grid business model in Ethiopia. Further research and analysis are necessary to fully understand the underlying dynamics and implications of these relationships.

### 4.6. Discussion

Despite the growing body of regression result have investigated the specific hybrid sustainable mini grid business model. This includes addressing factors such as the regulatory framework, access to financing, technical capacity and local skills, grid interconnection, affordability and tariff structures, community engagement and awareness, as well as quality assurance and maintenance (IRENA, 2017, World Bank, 2021). Based on the coefficients presented in Table 4.14, which analyze the determinants of the suitability of the sustainable hybrid mini-grid business model in Ethiopia, several key findings can be observed. These coefficients provide valuable insights into the relationships between the predictor variables and the suitability of the business.

**1. Grid Interconnection (GI):**

The positive coefficient of 0.483 (p = .001) suggests that an increase in grid interconnection is associated with higher suitability of the mini-grid business. This finding aligns with recent literature that emphasizes the positive impact of grid interconnection on mini-grid businesses. For example, studies conducted in Nigeria (Adefulu and Ogunmade, 2020), Kenya (Nyakundi et al., 2019), and Ethiopia (Gebreeyesus and Melesse, 2021) have all highlighted the importance of grid interconnection for enhancing the scalability, reliability, and performance of mini-grid systems.

**2. Technical Capacity and Local Skills (TCLS):**

The positive coefficient of 0.165 (p = .006) suggests that an improvement in technical capacity and local skills contributes to the suitability of the business. Recent literature supports this finding, as studies conducted in Kenya (Nyakundi et al., 2019), Tanzania (Kibira et al., 2021), and other regions have emphasized the significance of developing and leveraging local expertise and skills to ensure the efficient operation, maintenance, and long-term sustainability of mini-grid systems.

**3. Access to Financing (A2F):**

The negative coefficient of -0.219 (p = .002) indicates that better access to financing is associated with lower suitability of the business. This finding is supported by recent literature that highlights the challenges and implications related to access to financing in the mini-grid sector. Studies conducted in Ethiopia (Gebreeyesus and Melesse, 2021), East Africa (Oduor et al., 2020), and Nigeria (Adefulu and Ogunmade, 2020) have discussed the need for improved access to financing to ensure the growth, sustainability, and appropriate allocation of funds in the mini-grid business context.

**4. Regulatory Framework for Mini-grids (RFMG):**

The negative coefficient of -0.163 (p = .024) suggests that a more favorable regulatory framework is associated with lower suitability of the business. Recent literature supports this

finding by highlighting the complexities and barriers within the regulatory environment that can impact the suitability of mini-grid businesses. Studies conducted in East Africa (Oduor et al., 2020), Ethiopia (Gebreeyesus and Melesse, 2021), and Nigeria (Adefulu and Ogunmade, 2020) have discussed the challenges posed by regulatory frameworks and the need for more favorable and supportive policies to promote the growth, sustainability, and operational efficiency of mini-grid systems.

**5. Community Engagement and Awareness (CE&A):**

The negative coefficient of -0.368 (p = .014) indicates that enhanced community engagement and awareness contribute to lower suitability of the business. Recent literature has highlighted the challenges and implications associated with community engagement in the context of mini-grid businesses. Studies conducted in Kenya (Njenga et al., 2021), Nigeria (Adefulu and Ogunmade, 2020), and other regions have discussed the potential demands, complexities, and community concerns that can arise with increased community involvement, potentially impacting the suitability and operational efficiency of mini-grid systems.

**6. Affordability and Tariff Structures (A&TS):**

The positive coefficient of 0.324 (p = .000) suggests that favorable affordability and tariff structures are associated with higher suitability of the business. This finding is supported by recent literature that emphasizes the importance of transparent, affordable tariff structures in promoting the adoption, financial viability, and long-term sustainability of mini-grid businesses. Studies conducted in East Africa (Kithinji et al., 2020), Kenya (Nyakundi et al., 2019), and Ethiopia (Gebreeyesus and Melesse, 2021) have all discussed the positive impact of affordable tariffs on the suitability and acceptance of mini-grid systems.

**7. Quality Assurance and Maintenance (QAAM):**

The positive coefficient of 0.369 (p = .000) indicates that better quality assurance and maintenance practices contribute to higher suitability of the business. Recent literature supports this finding, emphasizing the significance of robust quality assurance and

maintenance processes in ensuring the reliability, efficiency, and longevity of mini-grid systems. Studies conducted in various regions, such as Kenya (Nyakundi et al., 2019), Tanzania (Kibira et al., 2021), and Nigeria (Adefulu and Ogunmade, 2020), have discussed the importance of regular maintenance, monitoring, and quality control measures to optimize the performance and customer satisfaction of mini-grid businesses. These practices help address technical issues promptly, minimize downtime, and ensure the continuous availability of electricity to end-users. In finally, the positive coefficient associated with Quality Assurance and Maintenance (QAAM) aligns with the recent literature, emphasizing the critical role of effective maintenance practices and quality assurance measures in enhancing the suitability and overall performance of mini-grid businesses.

In summary, the analysis of the coefficients aligns with recent literature, highlighting the importance of grid interconnection, technical capacity, access to financing, regulatory frameworks, community engagement, and affordability in shaping the suitability, Quality Assurance and Maintenance (QAAM), and long-term viability of mini-grid businesses.

# 5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

## 5.1. Summary of Major Findings

Ethiopia's regulatory framework for mini-grid businesses is robust, addressing legal barriers effectively (mean score 1.1200, SD 0.32660) and fostering a favorable business environment (mean score 1.7800, SD 0.41633) that encourages innovation and investment (mean score 2.0600, SD 0.85067). However, improvements are needed in transparent licensing processes (mean score 1.6300, SD 0.48524) and access to finance remains challenging, despite perceived accessibility and affordability (mean score 1.32, SD 0.46883). Adequate local technical capacity (mean score 2.8900, SD 0.90893) supported by community training initiatives ensures proficient installation and maintenance (mean score 1.7800, SD 0.41633). Mini-grid businesses benefit from reliable grid interconnection options (mean score 1.6300, SD 0.48524) and positive integration policies (mean score 2.1700, SD 0.77921), alongside fair compensation for excess energy supplied (mean score 2.2600, SD 0.92791). Affordable tariff structures (mean score 1.3200, SD 0.46883) with flexible options (mean score 2.1500, SD 0.82112) support diverse consumer needs, balancing revenue and affordability (mean score 2.5600, SD 0.93550). Community involvement in decision-making (mean score 1.3200, SD 0.46883), environmental awareness (mean score 2.1600, SD 0.74833), and sustainable energy education (mean score 3.2600, SD 0.64542) are key initiatives. While quality assurance meets international standards (mean score 3.73, SD 0.44620), improvements in inspections (mean score 2.26, SD 0.92791) and technological investments (mean score 2.11, SD 0.80271) are essential for ongoing enhancement.

Similarly, regression analysis reveals a strong linear relationship between predictors and the suitability of hybrid mini-grid businesses in Ethiopia ($R = 0.896$, $R^2 = 0.893$). Key predictors include quality assurance, grid interconnection, technical capacity, regulatory framework, access to financing, affordability, and community engagement. These findings emphasize transparent tariffs, robust maintenance, and effective grid interconnection as crucial for business suitability. Project participation data shows varied involvement, indicating significant

experience in the sector. The model summary and ANOVA results further underscore the robustness of these findings.

### 5.2. Conclusion

In conclusion, this study's analysis of descriptive statistics and regression coefficients provides crucial insights into the factors shaping the suitability of hybrid mini-grid business models in Ethiopia. Descriptive statistics reveal widespread agreement on the positive role of mini-grids in providing reliable electricity and using renewable energy technologies to address energy access challenges. Regression analysis highlights key factors: Grid Interconnection (GI) enhances scalability and reliability, while Technical Capacity and Local Skills (TCLS) are critical for system efficiency and sustainability. Challenges include Access to Financing (A2F) and Regulatory Framework for Mini-grids (RFMG), which need improvement to support business viability. Community Engagement and Awareness (CE&A) and Affordability and Tariff Structures (A&TS) also influence sustainability positively, alongside Quality Assurance and Maintenance (QAAM) practices. Addressing these factors through targeted interventions and further research can enhance mini-grid sustainability, supporting Ethiopia's energy goals and economic growth.

### 5.3. Recommendations

Based on the study's findings, several key recommendations are proposed:

- Enhance Access to Financing: Despite challenges highlighted by the negative coefficient for Access to Financing (A2F), efforts should focus on mitigating financial constraints through targeted funding schemes, partnerships with financial institutions, and innovative financing models like crowdfunding and impact investment. This approach aims to ensure adequate resources for developing and operating mini-grid systems.
- Review and Revise Regulatory Frameworks: The negative coefficient for Regulatory Framework for Mini-grids (RFMG) underscores the need to overhaul regulations to foster a supportive environment. Streamlining licensing procedures, clarifying

guidelines for operators and incentivizing sector investments will promote private sector involvement and bolster mini-grid business growth.

- Strengthen Community Engagement and Awareness Strategies: Despite challenges noted in the negative coefficient for Community Engagement and Awareness (CE&A), proactive measures should be taken to improve community involvement. Effective strategies include targeted awareness campaigns, participatory decision-making processes, and regular communication channels between operators and communities. Building trust and involving communities in project development will enhance long-term success.
- Enhance Technical Capacity and Local Skills: While Technical Capacity and Local Skills (TCLS) received a positive coefficient; ongoing efforts are needed to bolster technical expertise within the mini-grid sector. Investing in training programs, fostering knowledge exchange, and collaborating with educational institutions will enhance system efficiency, sustainability, and operational longevity.

### 5.4. Limitations and suggestions for future studies

The study encountered several limitations that merit attention for future research. Firstly, it featured a modest sample size of 101 participants, potentially limiting the generalizability of its findings. To broaden applicability, future studies should strive for greater participant diversity by involving multiple organizations. The depth of analysis relied significantly on the availability and reliability of data pertaining to mini-grid business operations in Ethiopia.

Secondly, the generalizability of findings may be constrained by Ethiopia's distinct socio-economic, political, and regulatory milieu. To extend the relevance of findings beyond this context, future studies could incorporate comparative analyses across diverse regions. Such approaches can help discern both universal and context-specific factors influencing mini-grid sustainability.

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## APPENDIX

***Subject: <u>Invitation to Participate in Research on Sustainable Mini-Grid Business in Ethiopia</u>***

I hope this research questionnaires via (xxx) finds you well. I am a graduate MBA student at Addis Ababa University conducting research on "exploring the determinants of sustainable mini-grid business in Ethiopia". As an employee of a mini-grid provider company or supporters, your insights are crucial to the success of this study. I kindly request your participation in a questionnaire that will help us gather your opinions and perceptions on sustainable mini-grid businesses. The questionnaire consists of two parts: demographic information and Likert scale questions. Thank you for considering this invitation. Your contribution will greatly enhance our understanding of sustainable mini-grid business in Ethiopia.

Best regards,

[*Selamawit Beneberu*]

MBA Graduate Student

[Addis Ababa University]

**Part one: Demographic characteristics of respondents (employees of a mini-grid provider company):**

These categories can be used to collect demographic information from the employees of the mini-grid provider company. It is important to note that the categories can be adjusted or expanded based on the specific requirements of the survey or study being conducted.

1. Gender:

   a. Male
   b. Female

2. Educational Qualifications:

   a. Bachelor's Degree

b. Master's Degree

c. Doctorate Degree above

d. Other (Specify: _____)

3. Participation in the Number of Projects:

a. Less than 5 projects

b. 5-10 projects

c. 11-15 projects

d. 16-20 projects

e. More than 20 projects

**Part two: determinants of "Applicability of Mini-Grid Business" and "Suitability of Hybrid Model" in Ethiopia**

Here are five Likert scale items for each independent variable and five items for each aspect of the dependent variable "Applicability of Mini-Grid Business" and "Suitability of Hybrid Model" in Ethiopia based on it, Likert scale categories ranging from 1 to 5 that can be used for various Likert scale questions: ***1. Very Poor; 2. Poor; 3. Fair; 4. Good; 5. Excellent***

These Likert scale categories are often used to assess the quality, satisfaction, or performance of a particular item or concept. They provide a clear progression from very low to very high, allowing respondents to indicate their perception or evaluation on a continuum. These categories can be applied to measure subjective opinions, preferences, or experiences in a wide range of research or survey contexts.

| **Category A**<br>**Variable Determinants of sustainability Mini-Grid Business in Ethiopia** | | | | | |
|---|---|---|---|---|---|
| **Independent Variable: The Regulatory Framework** | 1 | 2 | 3 | 4 | 5 |
| 1. The regulatory framework in Ethiopia provides clear guidelines that facilitate the establishment and operation of mini-grid businesses. | 1 | 2 | 3 | 4 | 5 |
| 2. The regulatory framework in Ethiopia effectively addresses legal and regulatory barriers, enabling mini-grid businesses to | 1 | 2 | 3 | 4 | 5 |

| | | | | | |
|---|---|---|---|---|---|
| thrive. | | | | | |
| 3. The regulatory framework in Ethiopia promotes a favorable business environment for mini-grid enterprises. | 1 | 2 | 3 | 4 | 5 |
| 4. The regulatory framework in Ethiopia encourages innovation and investment in the mini-grid sector. | 1 | 2 | 3 | 4 | 5 |
| 5. The regulatory framework in Ethiopia ensures fair and transparent processes for licensing and approvals related to mini-grid operations. | 1 | 2 | 3 | 4 | 5 |
| **Independent Variable: Access to Financing** | 1 | 2 | 3 | 4 | 5 |
| 1. There are accessible and affordable financing options available specifically for mini-grid businesses in Ethiopia. | 1 | 2 | 3 | 4 | 5 |
| 2. Financial institutions in Ethiopia are supportive and willing to provide loans or investments for mini-grid projects. | 1 | 2 | 3 | 4 | 5 |
| 3. Mini-grid businesses in Ethiopia have access to grants or subsidies that enhance their financial viability. | 1 | 2 | 3 | 4 | 5 |
| 4. Financing mechanisms in Ethiopia encourage private sector participation in the mini-grid sector. | 1 | 2 | 3 | 4 | 5 |
| 5. There is a well-established financial ecosystem in Ethiopia that facilitates the mobilization of capital for mini-grid ventures. | 1 | 2 | 3 | 4 | 5 |
| **Independent Variable: Technical Capacity and Local Skills** | 1 | 2 | 3 | 4 | 5 |
| 1. There is a pool of skilled technicians and professionals in Ethiopia who are capable of effectively managing the technical aspects of mini-grid operations. | 1 | 2 | 3 | 4 | 5 |
| 2. Local communities in Ethiopia possess the necessary knowledge and expertise to install, operate, and maintain mini-grid systems. | 1 | 2 | 3 | 4 | 5 |
| 3. Training programs and capacity-building initiatives in Ethiopia are available to enhance the technical skills of individuals involved in mini-grid businesses. | 1 | 2 | 3 | 4 | 5 |
| 4. Local universities and educational institutions offer relevant | 1 | 2 | 3 | 4 | 5 |

| | | | | | |
|---|---|---|---|---|---|
| courses or programs that develop skills specifically for mini-grid operations. | | | | | |
| 5. The technical capacity of mini-grid businesses in Ethiopia is continuously strengthened through knowledge sharing and collaboration. | 1 | 2 | 3 | 4 | 5 |
| **Independent Variable: Grid Interconnection** | 1 | 2 | 3 | 4 | 5 |
| 1. Mini-grid businesses in Ethiopia have reliable access to grid interconnection options, enabling seamless energy exchange. | 1 | 2 | 3 | 4 | 5 |
| 2. The process of integrating mini-grid systems with the main grid in Ethiopia is efficient and well-coordinated. | 1 | 2 | 3 | 4 | 5 |
| 3. Grid interconnection policies and agreements in Ethiopia are supportive of mini-grid operations. | 1 | 2 | 3 | 4 | 5 |
| 4. Mini-grid businesses in Ethiopia receive fair compensation for excess energy supplied to the grid. | 1 | 2 | 3 | 4 | 5 |
| 5. The grid interconnection infrastructure in Ethiopia is adequately developed and maintained to support mini-grid integration. | 1 | 2 | 3 | 4 | 5 |
| **Independent Variable: Affordability and Tariff Structures** | 1 | 2 | 3 | 4 | 5 |
| 1. The tariff structure for mini-grid energy services in Ethiopia is affordable for end-users. | 1 | 2 | 3 | 4 | 5 |
| 2. There are flexible tariff options available that cater to the specific needs and capacities of different consumer groups in Ethiopia. | 1 | 2 | 3 | 4 | 5 |
| 3. The pricing mechanism ensures a fair balance between revenue generation and affordability for mini-grid businesses in Ethiopia. | 1 | 2 | 3 | 4 | 5 |
| 4. The tariff structure encourages efficient energy consumption and promotes sustainable practices in Ethiopia. | 1 | 2 | 3 | 4 | 5 |
| 5. There are mechanisms in place to regularly review and adjust tariffs in Ethiopia to reflect cost changes and market conditions. | 1 | 2 | 3 | 4 | 5 |
| **Independent Variable: Community Engagement and Awareness** | 1 | 2 | 3 | 4 | 5 |

| | | | | | |
|---|---|---|---|---|---|
| 1. The mining company actively involves local communities in decision-making processes related to mining operations. | 1 | 2 | 3 | 4 | 5 |
| 2. The mining company regularly communicates with the local community about the potential environmental and social impacts of mining activities. | 1 | 2 | 3 | 4 | 5 |
| 3. The mining company supports educational programs and initiatives to raise awareness among the local community about sustainable mining practices. | 1 | 2 | 3 | 4 | 5 |
| 4. The mining company encourages the participation of local community members in training and employment opportunities within the mining industry. | 1 | 2 | 3 | 4 | 5 |
| 5. The mining company collaborates with local community organizations and stakeholders to address concerns and mitigate the negative impacts of mining on the community. | 1 | 2 | 3 | 4 | 5 |
| **Independent Variable: Quality Assurance and Maintenance** | 1 | 2 | 3 | 4 | 5 |
| 1. The mining company has well-defined quality control procedures in place to ensure the extraction and processing of minerals meet international standards. | 1 | 2 | 3 | 4 | 5 |
| 2. The mining company regularly conducts inspections and maintenance activities to ensure the safe and efficient operation of mining equipment and facilities. | 1 | 2 | 3 | 4 | 5 |
| 3. The mining company invests in advanced technologies and equipment to enhance the quality and productivity of mining operations. | 1 | 2 | 3 | 4 | 5 |
| 4. The mining company maintains a comprehensive record of environmental performance indicators to monitor and improve its sustainability practices. | 1 | 2 | 3 | 4 | 5 |
| 5. The mining company has a dedicated team responsible for continuously improving quality assurance processes and addressing any deviations or non-conformities. | 1 | 2 | 3 | 4 | 5 |

| **Dependent Variable : *suitability of Hybrid mini-grid business Model in Ethiopia*** | | | | | |
|---|---|---|---|---|---|
| 1. These business models supports access to reliable electricity for underserved communities for all projects engaged and carry out in Ethiopia. | 1 | 2 | 3 | 4 | 5 |
| 2. The model utilizes renewable energy technologies like solar and biomass in an environmentally friendly way for all projects engaged and carries out in Ethiopia. | 1 | 2 | 3 | 4 | 5 |
| 3. The hybrid mini-grid system project engaged and carry out in Ethiopia are effectively balances electricity supply and demand. | 1 | 2 | 3 | 4 | 5 |
| 4. The business as mini-grid project is economically viable without long-term subsidy. | 1 | 2 | 3 | 4 | 5 |
| 5. The model for all project engaged and carry out in Ethiopia enhances energy security by reducing dependence on fossil fuels. | 1 | 2 | 3 | 4 | 5 |
| 6. Mini-grid businesses are well-suited to meet the energy needs of remote and underserved communities in Ethiopia. | 1 | 2 | 3 | 4 | 5 |
| 7. Mini-grid businesses effectively contribute to the electrification of rural areas in Ethiopia. | 1 | 2 | 3 | 4 | 5 |
| 8. Mini-grid businesses bring reliable and affordable electricity access to communities where grid extension is not feasible. | 1 | 2 | 3 | 4 | 5 |
| 9. Mini-grid businesses play a crucial role in supporting productive activities and economic development in Ethiopia. | 1 | 2 | 3 | 4 | 5 |
| 10. Mini-grid businesses have a positively improve the quality of life and well-being of communities in Ethiopia. | 1 | 2 | 3 | 4 | 5 |

**NB:** If you are looking for unclear questions say further in supporting of above statement regarding to the determinants of sustainable mini-grid business in Ethiopia, here are two sample questions:

(1) In your opinion, what role does access to financing play in the success and sustainability of mini-grid businesses in Ethiopia?

.....

.....

(2) How important is community engagement and social acceptance in ensuring the long-term viability of mini-grid businesses in Ethiopia?

.....

.....

(3) In your experience, what role does the regulatory environment play in attracting investments and promoting innovation within the mini-grid sector in Ethiopia?

.....

.....

(4) Can you share your experiences and perceptions regarding the key factors that contribute to the sustainability of mini-grid businesses in Ethiopia?

.....

.....

Thank you1