Building Partnerships to Accelerate Energy Access through Mini-Grids in Zambia

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University of Strathclyde

Equal Access Energy

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This paper is part of the *Accelerating Energy Access in Rural Zambia through Scalable Mini-Grid Deployment in Zambia* project, funded through the Scottish International Science Partnership Fund, and supported by the Scottish Global Renewables Centre.

Lloyds Financials Limited, located in the capital city of Zambia is a financial and technical services advisory company, that offers unparalleled expertise to a growing demand for financial solutions. Its core business is to improve access to project and development finance for both public and private institutions and companies. With services tailored to address climate change, energy, strategic partnerships, and building capacities, Lloyds aims to deliver sustainable, equitable, and impactful development.

The University of Strathclyde (Glasgow, UK), is a place of useful learning and one the UK's leading universities for engineering. It has been working on off-grid community energy access in Sub-Saharan Africa for over a decade. Energy for Development research carried out at Strathclyde has an emphasis on improving sustainability of rural energy systems, techno-economic and business modelling of minigrids, and using data to understand the impact and performance of off-grid renewable energy systems.

= Access Energy is a social enterprise providing technical support, capacity building and investment to accelerate off-grid energy access in Africa. We contribute to our vision of low carbon, affordable and sustainable energy access for all by building partnerships with local organisations in Sub-Saharan Africa and supporting them to deploy and operate off-grid renewable energy systems serving rural communities.

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EXECUTIVE SUMMARY

The potential for mini-grids to address Zambia's energy challenges, particularly in rural areas, is significant. However, the deployment of these systems is hindered by several factors, including unsustainable business models, inadequate planning, and insufficient data on energy demand and operational costs. Without addressing these critical gaps, there is a risk of resource misallocation and project failure, further delaying the country's progress toward universal energy access.

This report presents findings of a collaborative project between Lloyds Financials Limited, the University of Strathclyde and Equal Access Energy. The project aims to accelerate rural electrification in Zambia through the development of sustainable, scalable mini-grid systems through developing robust financial models and strategic partnerships that can foster long-term sustainability for mini-grid projects in underserved areas.

Objectives

1. Accelerate energy access in rural Zambia with minigrids: This project seeks to bridge the energy gap in rural areas, where only a small percentage of the population has access to reliable electricity. By supporting the sustainable deployment of solar-powered mini-grids, the project aims to provide affordable and sustainable energy solutions to remote communities.

2. Develop sustainable and investable mini-grid business models: By addressing current weaknesses in business models, the project aims to create financially viable systems that can attract investment and scale deployment across Zambia.

3. Foster collaboration between academic researchers and the private sector: The project seeks to leverage the expertise of local and international academic institutions, in partnership with Zambian businesses and government bodies to develop innovative, data-driven solutions.

Key Activities

Mapping the current mini-grid sector: Comprehensive mapping of Zambia's existing mini-grids, their capacities, and operational statuses identifies key trends and challenges. Outlining the geographic distribution of projects and the policy landscape governing mini-grid development helps inform the sector with valuable insights.

Stakeholder engagement and needs assessments: Ongoing interviews with key stakeholders, including developers, government bodies, and community members, to provide valuable insights into the challenges and opportunities for scaling mini-grids. This engagement helps identify critical gaps in technical capacity, regulatory oversight, and funding availability.

Data collection and financial modelling: In-depth analysis of capital and operational costs, as well as data on revenue streams, informs the development of new business models that can support sustainable mini-grid systems in rural Zambia.

Initial Findings

The mini-grid sector is underdeveloped and lacks cohesive business models: Despite some success stories, many existing projects face technical and financial sustainability challenges, with limited capacity to scale. Additionally, the absence of accurate and comprehensive data on energy demand and operational costs hinders effective planning.

Key stakeholders and their roles have been identified: Stakeholder mapping revealed a need for greater collaboration between government agencies, private developers, and financial institutions to ensure the success of mini-grid deployments.

Opportunities exist for investment and partnerships: The report highlights several funding opportunities from international donors, development banks, and public-private partnerships, which could provide the necessary financial backing for mini-grid projects.

Recommendations

Improve business models and financial strategies: A key recommendation is to develop adaptable business models that can cater to the specific needs of rural Zambian communities while ensuring long-term financial sustainability. This includes creating more flexible tariff structures and exploring productive use of energy initiatives to increase the viability of mini-grids.

Enhance stakeholder collaboration: Fostering stronger partnerships between academia, the private sector, and the government is crucial for ensuring the continued development of mini-grid projects. The creation of a national mini-grid working group could facilitate knowledge sharing and policy coordination.

Leverage international funding and donor support: Strategic engagement with international donors and climate finance initiatives can unlock significant funding for mini-grid projects. Developing partnerships with institutions such as the Green Climate Fund and the African Development Bank will be essential for scaling the deployment of mini-grids in Zambia.

Next Steps

Continue key activities: The minigrid sector in Zambia is dynamic, and continuing to map updates, carry out stakeholder engagement and refine financial models will be essential

Collect and Collate Existing data on minigrids: this report is a call to action to share minigrid data and outlines best practice recommendation on the same.

Build Partnerships to accelerate minigrids in Zambia: stakeholder workshops are proposed where partnerships in academia, private sector and government can be formed to take forward the activities proposed in this report.

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List of Acronyms

8NDP – Eighth National Development Plan
AFDB – African Development Bank
BGFA – Beyond the Grid Fund for Africa
CDF – Constituency Development Fund
CEEC – Citizen Economic Empowerment Commission
COSMO – Cooking Support on Mini-Grids
CPs – Cooperating Partners
DBZ – Development Bank of Zambia
DFI – Development Finance Institution
DRE – Decentralized Renewable Energy
ERB – Energy Regulation Board
ESG – Environmental, Social, and Governance
GEF – Global Environment Facility
GIS – Geographic Information System
GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit
IAEREP – Increased Access to Electricity and Renewable Energy Production
IPP – Independent Power Producer
IRENA – International Renewable Energy Agency
MECS – Modern Energy Cooking Services
MoE – Ministry of Energy
MoF – Ministry of Finance
NEAS – National Energy Access Survey
NGO – Non-Governmental Organization
OGRESS – Off-Grid Rural Electrification Smart Solutions Programme
OPPPI – Office for Promoting Private Power Investment
PAYG – Pay-As-You-Go
PUE – Productive Use of Energy
REA – Rural Electrification Authority
RECP – Renewable Energy Cooperation Programme
REMP – Rural Electrification Master Plan
RBF – Results-Based Financing
SEforALL – Sustainable Energy for All
SHS – Solar Home System
UNEP – United Nations Environment Programme
UNIDO – United Nations Industrial Development Organization
USAID – United States Agency for International Development
USADF – United States African Development Foundation
ZAMSTAT – Zambia Statistics Agency
ZEDSI – Zambia Energy Demand Stimulation Incentive
ZESCO – Zambia Electricity Supply Corporation
ZRA – Zambia Revenue Authority
ZECDP – Zambia Electric Cooperative Development Programme

1. INTRODUCTION

1.1 Overview of the project

Energy access in Zambia remains a major barrier to economic growth and improved living standards, especially in rural areas where the national grid has limited reach. The *Building Partnerships to Accelerate Energy Access through Mini-Grids in Zambia project* seeks to address this issue fostering deployment of solar-powered mini-grids to underserved communities.

This project is designed to enhance local economic development by supporting expansion of energy access through decentralised energy infrastructure. By partnering with key stakeholders, the project aims to provide a scalable and sustainable solution to rural electrification.

The project is designed to:

- Accelerate energy access in rural Zambia.
- Develop sustainable and investable mini-grid business models for Zambia.
- Foster collaboration between academic researchers and the Zambian private sector

The research conducted through this project aims to delve into the current landscape of mini-grid systems in Zambia, exploring their capacities, operational statuses, and the factors that influence their performance in order to understand and inform more sustainable business models. The project's ultimate goal is to bridge the energy gap, empower local economies, and improve the quality of life for millions of Zambians who currently lack access to consistent, affordable electricity.

1.2 The role of minigrids in providing energy access in Zambia

Energy access remains a significant challenge in Zambia, particularly in rural areas where only about 5% of the population has reliable electricity [1]. This lack of access to energy affects critical sectors such as education, healthcare, and local businesses, stalling overall economic development and limiting the quality of life in underserved communities. Without reliable electricity, opportunities for growth, innovation, and prosperity remain out of reach for many Zambians.

Zambia's energy sector, particularly in rural areas, faces significant challenges in terms of infrastructure, affordability, and sustainability. Electrification is a crucial component of economic development, and the deployment of mini-grids has emerged as a promising solution to address the energy access gap in many developing countries [2]. Solar minigrids, which leverage Zambia's abundant solar resources, offer a reliable and low carbon alternative to traditional energy sources and the gaps in energy provision present an opportunity for solar mini-grids to fill a critical need.

Several studies have highlighted the potential for solar mini-grids to revolutionise energy access in Zambia [3]. However, despite abundant solar resources and the opportunity for rural electrification that mini-grids has the potential to fulfil, there are only approximately 60 operational mini-grids currently serving the country. Successful models in neighbouring countries show that, with the right financing mechanisms and stakeholder engagement, these systems can provide a sustainable and scalable solution to rural electrification.

1.3 Methodology

The methodology for this project employed a comprehensive approach that integrated several key components in the Zambian context, comprising:

- Thorough review of relevant literature to inform ecosystem mapping, site identification and highlighted best practices.
- Stakeholder engagement to understand specific experiences, challenges, and potential development.
    - A stakeholder workshop was held in Lusaka in 2024 to gauge opinions and experiences on minigrid deployment (See Annex 1).
    - Interviews with local authorities, energy experts, and mini-grid operators provided qualitative insights into the specific challenges and opportunities for energy access in the target areas.

- Assessment of existing models to evaluate their effectiveness and applicability in the Zambian context.

Combining these methods, the project ensured that the model developed for the mini-grids in rural Zambia are sustainable, ultimately contributing to long-term energy solutions for rural communities. Additionally, gaps were identified that could hinder the successful implementation and operation of mini-grids. This informed the strategies for capacity building and financial support in the project areas.

2. MAPPING THE CURRENT ZAMBIAN MINI GRID SECTOR

2.1 Country Overview

Zambia has a population of approximately 20 million people, the majority of whom (54%) live in rural areas, with a population density of about 26.1 people per square kilometre [4]. As of the 2022 census, the population stands at approximately 20 million people, growing at an annual rate of about 2.8% [5]. By 2030, the population is projected to exceed 24 million people. In terms of socio-economic conditions, an estimated 60% of the population lived below the poverty line in 2022, a rise from 54.4% in 2015 [Ibid]. The Human Development Index (HDI) ranks Zambia at 153rd out of 191 countries as of 2022, reflecting ongoing challenges in education, health, and income levels.

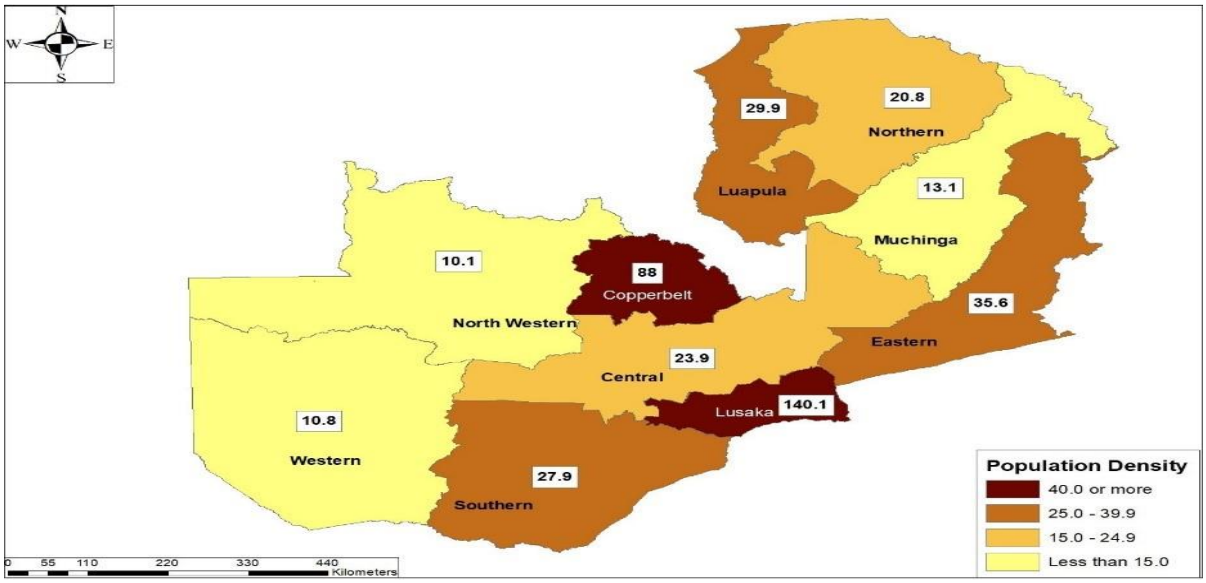

FIGURE 1: POPULATION DENSITY PER PROVINCE, ZAMBIA (CENSUS, 2022)

The 2024 drought further complicated Zambia's economic landscape. The country is increasingly vulnerable to climate change, with approximately 90% of agricultural production relying on rain-fed systems. The drought devastated about one million hectares of maize, affecting food security for over 20% of the population [6].

Zambia's economic future hinges on effectively managing its natural resources while addressing climate vulnerabilities. Integrating mini-grids into the energy landscape offers a promising pathway for sustainable development, ensuring that both urban and rural populations can thrive despite ongoing challenges.

2.2 Zambia's Energy Demand in Rural Areas: Focus on Mini-Grids

Zambia's energy sector has faced significant challenges in recent years, with the country's annual increase in GDP leading to a corresponding rise in electricity demand [7]. The country's reliance on hydropower as the primary source of grid electricity generation has made it vulnerable to the impacts of El Niño droughts, leading to severe power outages that have had a profound effect on Zambian. Zambia faces significant energy

challenges, particularly in rural areas where access to electricity is critically low. Currently, only about 14.5% of rural residents have access to the national power grid, compared to 67% of urban residents [8]. This disparity highlights the urgent need for alternative energy solutions to meet the growing demand in these underserved communities.

To address this energy gap, mini-grids are emerging as viable solutions. These localised energy systems can provide reliable electricity to rural households, facilitating economic development by powering agricultural activities and small businesses and improving living standards[9]. By integrating solar energy into mini-grid systems, Zambia can reduce its reliance on traditional energy sources while promoting sustainable development. The Lunga mini-grid in Luapula Province and the Chunga mini-grid are examples of initiatives aimed at increasing electrification rates through off-grid solutions. These projects are part of the government's broader goal to achieve a rural electrification target of 51% by 2030 [10].

The government recognises the potential of mini-grids to support economic growth and improve living standards and The National Energy Policy (2019) policy emphasises the importance of renewable energy technologies, including solar mini-grids, in enhancing energy access, particularly in rural area [11]. Initiatives aimed at expanding mini-grid infrastructure can help mitigate the impacts of drought on agriculture by ensuring that farmers have access to irrigation and other essential services. Additionally, enhancing energy access through mini-grids can stimulate local economies by creating jobs and improving educational opportunities.

However, according to the *National Energy Access Survey (NEAS) Report* conducted by the Ministry of Energy in collaboration with the Zambia Statistics Agency (ZamStats) in 2023, mini-grids remain a limited source of electricity for Zambian households [12]. Only 0.2 percent of households reported using local mini-grids as their primary energy source. Among those who accessed power from mini-grids, reliability concerns were evident, with 36.4 percent perceiving the power supply as irregular. Additionally, 11.4 percent of mini-grid users cited inadequate hours of electricity, while 5.9 percent experienced high voltage issues, and 0.9 percent reported frequent unscheduled electricity supply interruptions.

Despite these challenges, mini-grid service providers showed relatively quick response times to faults, with 56.7 percent of affected households reporting that issues were resolved in less than a day, while 26.4 percent had their faults rectified within one day. The survey further highlights the broader energy access landscape in Zambia, where only 34.0 percent of rural households had electricity, compared to 80.3 percent in urban areas.

Although national grid electricity was the most commonly used energy source (34.4 percent of households), off-grid solutions, including solar home systems (18.6 percent), played a significant role in rural electrification. The findings suggest that while mini-grids have the potential to contribute to expanding energy access, their adoption remains low due to reliability concerns and limited coverage. Strengthening mini-grid infrastructure and service quality could enhance their role in addressing rural electrification gaps and improving energy security for off-grid communities (*National Energy Access Survey (NEAS) Report, 2023*) [12].

2.3 Zambian Minigrid Ecosystem

2.3.1 Key Policy drivers and regulatory

Zambia has recognised the importance of diversifying its energy mix and expanding electricity access, particularly in rural areas. This has led to the emergence of key policy drivers promoting solar and mini-grid development:

Eighth National Development Plan (8NDP): This outlines Zambia's strategic objectives to achieve Vision 2030 and advance towards becoming a prosperous middle-income nation. It addresses persistent socio-economic challenges such as low economic diversification, high youth unemployment, poverty, inequality, and insufficient access to social services.

National Energy Policy 2019: This overarching policy aims to increase the share of renewable energy sources, including solar, in the national grid and promote off-grid solutions like mini-grids for rural electrification (Government of Zambia, 2019).

Rural Electrification Master Plan: This plan outlines strategies for achieving universal electricity access by 2030, with a strong emphasis on off-grid solutions like mini-grids for remote communities (Rural Electrification Fund Act – Policies - IEA, 2012).

Energy Regulation Act No. 12 of 2019: This Act provides a legal framework for the regulation of the electricity sector, including provisions for licensing and regulating mini-grid operators (Zambia Law Development Commission, 2019).

Mini-Grid Regulatory Framework: Developed by the Energy Regulation Board, this framework provides specific guidelines and regulations for the development and operation of mini-grids in Zambia (Energy Regulation Board, 2020).

Open Access Policy in Electricity Sector: This policy promotes competition and private sector participation in the electricity sector, including provisions for third-party access to the grid, which can benefit mini-grid developers (Ministry of Energy, 2020).

Zambia Rural Electrification Master Plan: This plan focuses specifically on strategies and targets for expanding electricity access in rural areas, emphasising off-grid solutions like mini-grids (Ministry of Energy, 2020).

Energy Access Policy and Planning: This policy framework guides the government's efforts to ensure equitable and sustainable energy access for all Zambians, focusing on promoting clean energy solutions like solar and mini-grids (Government of Zambia, 2021).

These policies, along with specific initiatives like the Feed-in Tariff for Renewable Energy and the mandate of the Rural Electrification Authority, create a supportive environment for solar and mini-grid development in Zambia.

2.3.2 Government Structure and Agencies

The Ministry of Energy serves as the principal regulatory authority overseeing the energy sector in Zambia. Its portfolio functions encompass energy policy, electricity, as well as biofuels, renewable and alternative sources of energy. As the principal regulating authority, it is responsible for carrying out energy planning, formulation and implementation of national energy policies, strategies and plans, and the development of new energy programmes.

- **The Office for Promoting Private Power Investment (OPPPI),** established in 1999 and responsible for promoting private investments in the electricity generation and transmission sector by reducing the complexity of procedures, rules and regulations, and red tape usually associated with obtaining the required approvals, permits or licences. OPPPI deals primarily with projects that are 10MW and above.

- **Ministry of Finance (MoF),** Manages financial resources and budgets related to energy projects. It plays a crucial role in funding energy initiatives and investments, ensuring economic viability and sustainability in energy development.

Other important organisations that make up the institutional structure of the energy sector in Zambia include:

- **The Energy Regulation Board (ERB),** which was established under the Energy Regulation Act in 1996 and is responsible for the licensing of Independent Power Producers (IPPs), setting electricity tariffs and the development of technical standards. In January 2017, the ERB began regulating the import of solar components.

- **Rural Electrification Authority (REA**), which was established by the Rural Electrification Act of 2003. REA's mandate is to increase rural electrification rates through the development of electricity infrastructure, and manages the Rural Electrification Fund. The REA is responsible for the development, implementation and revision of the Rural Electrification Master Plan (REMP).

- **Zambia Electricity Supply Corporation (ZESCO),** is the state-owned vertically integrated utility company, established in 1970. It is responsible for generation, transmission and distribution of electricity.

- **Zambia Environmental Management Agency,** Responsible for environmental protection and management related to energy projects. ZEMA ensures that energy developments comply with environmental regulations and standards to minimize negative impacts on ecosystems.

- **Zambia Revenue Authority (ZRA),** Manages tax collection and revenue generation from the energy sector, including taxes on energy production and consumption. ZRA plays a role in ensuring that the government receives appropriate revenues from energy-related activities.

- **Solar Industrial Association of Zambia,** Supports the growth of the solar energy sector by promoting solar technologies and advocating for off-grid solar solutions.

- **Zambia Renewable Energy Association,** Advocates for the development of renewable energy sources in Zambia, promoting policies that support sustainable energy practices.

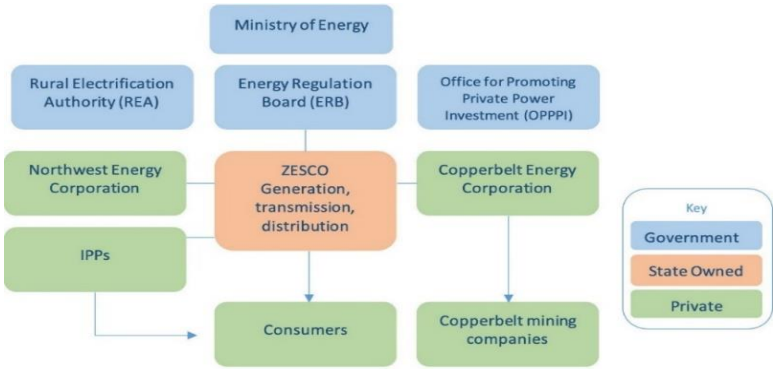

FIGURE 2: INSTITUTIONAL STRUCTURE OF ZAMBIA'S POWER SECTOR (ADAPTED FROM (IRENA, 2013)

2.3.3 Donor Initiatives

Donor initiatives play a crucial role in enhancing rural electrification in Zambia's mini-grid ecosystem by facilitating the deployment of renewable energy technologies and supporting regulatory frameworks. These initiatives help bridge the gap between centralised and decentralised electrification approaches, fostering sustainable energy solutions.

TABLE 1: THE COOPERATING PARTNERS(CPS)

Project	Role	Project Timeline
USAID- Zambia Electric Cooperative development Programme (ZECDP)	The Initiative aims to work with local stakeholders and partners, to develop viable electric cooperatives in rural communities. These cooperatives will play a crucial role in expanding electrification efforts in Zambia	2023 - 2025
Beyond the Grid Fund for Africa	Result-based financing supporting 11 Private sector companies in Zambia in development of minigrids and deployment of SHS, The program aims to support development of 22 minigrids and upscaling of 1 Minigrid in Zambia. Total value of the Project in Zambia is EUR 23 Million.	2023 - 2027
Sustainable Energy for All	The programme supports the Zambian government's initiative to power 1,000 rural communities through SEforALL's Integrated Electrification Framework, which addresses the challenges of decentralized renewable energy (DRE) and rural electrification. It aims to improve mini-grid viability by stimulating sustained electricity consumption and catalyzing a financial	2022-2030

	strategy to scale DRE investments by 2030. Through the Zambia Energy Demand Stimulation Incentive (ZEDSI), the programme drives energy consumption growth in agri-value chains, businesses, public institutions, and households, fostering rural development and ensuring the viability of over 100 mini-grids. It also supports scaling financing inflows to expand from 100 to 1,000 communities by enabling developers to leverage diverse DRE technologies inclusively.	
Off-Grid Rural Electrification Smart Solutions Programme (OGRESS)	The OGRESS Programme, led by Zambia's Rural Electrification Authority (REA), aims to bring electricity to rural areas using renewable energy like solar power and mini-grids. Though its parent programme, ESAP, has ended, the successful model applied in OGRESS.	2020 -

2.4 Overview of Existing Minigrid Projects

2.4.1 Analysis of mini grid capacities and operational statuses

In Zambia, the analysis of mini-grid capacities and operational statuses is of particular importance, as the country grapples with the challenge of providing reliable and affordable electricity to its population, particularly in rural areas.

The current status of mini grid electrification in Zambia is not well-documented, but some insights can be gleaned from the existing literature. Zambia has a significant potential for renewable energy development, including solar and hydropower, which could be harnessed through the deployment of mini grids [3]. However, the country has faced challenges in securing financing for power projects, which could also impact the development of mini grids [2].

Zambia has several operational solar mini-grids with varying capacities, ranging from 24 kW to 100 kW. These mini-grids are primarily located in the Eastern Province, with one in the North Western Province. Interestingly, despite their potential to provide sustainable electricity to rural areas, none of these mini-grids are fully sustainable financially or technically [3].

The challenges include incorrect sizing during planning, use of substandard components, lack of technical support, inefficient operation, and inappropriately structured tariff plans. Additionally, economic tariffs that can sustain both capital and operational expenses are often unaffordable for rural residents due to their low-income levels [3].

While Zambia has made progress in implementing solar mini-grids, there are significant sustainability challenges. To improve their effectiveness, a well-thought-out public-private partnership model for construction, operation, and maintenance is needed. Furthermore, smart subsidies aligning the interests of the government, private sector, and clients should be developed to replace up-front subsidies[3]. Addressing these issues could help Zambia achieve its Vision 2030 goal of universal access to electricity.

2.4.2 Geographic distribution and key features of current projects

The geographic distribution of solar mini-grid projects in Zambia highlights the country’s commitment to enhancing access to reliable and sustainable energy in rural areas. These decentralized renewable energy systems have been strategically implemented across various regions, addressing the unique needs and challenges faced by rural communities [13].

Solar mini-grids are particularly prevalent in regions with limited or no access to the national grid, especially in remote and sparsely populated areas. This strategy recognises that extending the national grid to meet the electricity demands of small populations may not be economically feasible. Consequently, localised electricity generation through stand-alone or mini-grid applications has emerged as a more viable solution. Alternative business models such as corporative models are currently being tested on the Zambian market, for example the Zambian Electric Cooperative Development Programme [14].

Research indicates that these solar mini-grid projects are concentrated in areas characterised by favourable climatic conditions and abundant solar resources. They have proven especially effective in regions with high

solar radiation and low population density, where the cost-effectiveness of decentralized renewable energy systems becomes more evident.

2.4.3 Key Features of Solar Mini-Grid Projects

Zambia's solar mini-grid projects are designed to tackle specific challenges encountered by rural communities. These include:

- **Capacity:** Ranging from 24 kW to 100 kW.
- **Focus:** Primarily aimed at rural electrification.
- **Operation:** Often run on an ad-hoc or pilot basis without well-defined business models.
- **Sustainability Challenges:** Both financial and technical hurdles persist.

In the Eastern Province, notable projects include:

- Magodi Mini-Grid: 48 kW in Lundazi
- Katamanda Mini-Grid: 52 kW in Chipangali
- Chitandika Mini-Grid: 28 kW in Chipangali
- Muhanya Mini-Grid: 24 kW in Sinda

Additionally, the North Western Province features a 32 kW Chibwika mini-grid in Mwinilunga.

Despite Zambia's significant solar energy potential—approximately 20,442 TWh/year technical potential, with an annual solar energy availability of 2109.97 kWh/m² and about 4403.12 hours of sunshine—the country has yet to fully harness this resource for electricity generation[15]. This discrepancy underscores the necessity for improved planning and implementation of solar mini-grid projects

TABLE 2: INSTALLED GENERATION CAPACITY (KWP) SOURCE (REA, 2024)

Project Name	Province	District	Year of Implementation	Initial Connections
100kWp Chilubi Hospital Solar Mini Grid Phase I	Northern	Chilubi	2023	74
90kWp Chief Lundu Solar Mini Grid	Eastern	Chama	2023	300
30kWp Chief Lundu Solar Mini Grid	Eastern	Chama	2023	50
60kWp Chief Mpidi Solar Mini Grid	North Western	Zambezi	2023	100
100kWp Natukoma Solar Mini Grid	Western	Shangombo	2023	250
70kWp Chieftainess Mwanya Solar Mini Grid	Eastern	Lumezi	2023	220
50kWp Chief Chama I Solar Mini Grid	Luapula	Kawambwa	2023	50
30kWp Chief Chama II Solar Mini Grid	Luapula	Kawambwa	2023	50
40kWp Chief Chama III Solar Mini Grid	Luapula	Kawambwa	2023	50
30kWp Chibwika Solar Mini Grid (Technical Assistance)	North Western	Mwinilunga	2023	100
Ngabwe Council Solar Mini Grid	Central	Ngabwe	2021	60
28 kWp Ngabwe Mukatamwene and Mumeno Solar Mini Grid	Central	Ngabwe	2021	512
90kWp Chunga SMG	Central	Mumbwa	2023	87
20kWp Chief Moyo Solar Mini Grid	Southern	Pemba	2023	35
30kWp Nkandanzovu Solar Mini Grid	Southern	Kalomo	2023	80
Chilubi Mainland Mini Grid	Northern	Chilubi	2021	220
Moyo Mini Hospital Mini Grid	Southern	Pemba	2021	56
Mpanta Solar Mini-Grid	Luapula	Samfya	2012	468
Lunga Solar Mini-Grid	Luapula	Lunga	2018	250
TOTAL				

TABLE 3: INSTALLED MINI-GRID PROJECTS (KWP)

Project Developers	Existing	2024	2025	Pipeline Total	Support Program
ENGIE Power Corner	1	30	44	75	IAEREP
Arc Power	0	13	-	13	OGRESS
Virunga Power	1		-	1	BGFA
Solar 23	0	7	-	11	IAEREP / OGRESS
Standard Micro-grid	4	-	-	-	BGFA
Kawaida	0	13	-	13	OGRESS
Rising Sun Zambia	-	-	11	11	BGFA
Smart Energy	1	6	-	7	USADF
Other (Companies or Organisations Without 2024/2025 Construction pipeline)	34	-	-	-	Various
Total Market Activity	41	69	55	165	

2.4.4 Challenges facing Minigrid deployment in Zambia

While Zambia has initiated several solar mini-grid projects across rural areas, particularly in the Eastern and North Western Provinces, these initiatives face considerable sustainability challenges. The country's vast solar potential remains largely untapped, indicating a pressing need for more strategic development of solar mini-grid projects to effectively meet rural electrification demands. A number of shortcomings of the mini-grid sector have been identified, including limited user feedback on their experiences with the mini-grid, insufficient strategies to address affordability issues related to high tariffs, and a lack of specific measures for managing peak energy demand. Additionally, while future expansion plans are mentioned, case study reports do not analyse potential logistical or technical challenges. There is also a lack of detailed environmental impact assessments and long-term sustainability strategies. Finally, limited discussion on community engagement initiatives may hinder user satisfaction and awareness of energy conservation practices. Key challenges affecting the deployment of mini-grids in Zambia include:

High Capital Costs and Limited Financing: Mini-grid projects, particularly solar-powered ones, require significant upfront investment. While there is interest from international donors and development banks, local financing options are limited. Zambian financial institutions often lack the experience and confidence to finance renewable energy projects, leading to a reliance on donor funding, which is not always sufficient or sustainable in the long term.

Regulatory and Policy Uncertainty: The regulatory framework for mini-grids in Zambia, while improving, still lacks clarity in areas such as licensing, tariffs, and grid integration. Uncertainty regarding tariffs—particularly the balance between cost-reflective and socially acceptable rates—makes it difficult for developers to plan for long-term financial sustainability. Additionally, the absence of clear policies for transitioning mini-grids to the national grid when grid extension occurs creates risk for developers.

Maintenance and Operational Challenges: Ensuring the long-term operation and maintenance of mini-grid systems is a significant challenge. In many rural areas, there is limited technical expertise and access to spare parts, which can lead to system breakdowns and long downtimes. Training local operators and ensuring a reliable supply chain for maintenance is crucial but currently underdeveloped.

Affordability and Low Ability to Pay: Many rural Zambian households have low income levels, which limits their ability to pay for electricity. This reduces the revenue potential of mini-grid projects, making it difficult to recover costs and achieve financial sustainability. Subsidies and innovative financing mechanisms, such as pay-as-you-go (PAYG) models, are being explored but are not yet widely implemented.

Inadequate Data for Planning: As highlighted in Section 3, data on energy demand, operational costs, and socio-economic conditions in rural Zambia is limited. Without this data, mini-grid developers struggle to accurately

size their systems, plan for demand growth, or design effective business models. This lack of data also hampers efforts to attract investors, as financial viability remains uncertain.

Community Engagement and Acceptance: Effective community engagement is essential for the successful deployment and operation of mini-grids. In some cases, projects have faced resistance or low uptake due to a lack of understanding about the benefits of electrification, concerns about costs, or cultural barriers. Building trust within communities, ensuring participatory planning, and demonstrating the economic benefits of electricity access are critical for improving acceptance.

Climate and Environmental Risks: Zambia's reliance on hydropower makes its energy system vulnerable to climate change, particularly droughts. While solar mini-grids can help diversify the energy mix, their deployment must account for environmental risks such as extreme weather conditions, which can affect the performance of solar systems. Ensuring resilience in the face of climate change is a key consideration for future mini-grid projects.

Addressing these challenges requires a coordinated effort between the government, private sector, and international partners to develop a more supportive ecosystem for mini-grid development. By overcoming these obstacles, Zambia can better harness its solar potential and accelerate progress toward universal energy access in rural areas.

2.4.5 Mini-Grid Case Studies

Case study: Chitandika Solar Mini-Grid

Chitandika is a significant solar mini-grid project located in Chitandika village, Chipangali District, Eastern Province, Zambia. Commissioned in April 2019 by Power Corner, the project has been operated by Engie Power Corner and provides electricity to 156 households, two schools, and a rural health center. Additionally, it serves various commercial users, including two hammer mills (11 kW each), two dehala machines (7.5 kW each), a 4.4 kW welding machine, a 4 kW grinder, two hair salons, and 29 pressure cookers.

The mini-grid employs a prepaid metering system that allows customers to purchase electricity in different tiers known as bundles. These bundles are categorized as follows: Bundle A 40W, Bundle B 100W, Bundle C 1000W, Bundle D 3000W and Bundle E Above 3000W (commercial). Customers in lower bundles (e.g., Bundle A) are restricted from using appliances that exceed their bundle's capacity.

This project is notable as it is the first solar mini-grid developed by Engie Power Corner in Zambia and plays a crucial role in improving energy access in a region where only a small percentage of the population has electricity. It not only enhances the quality of life for residents but also supports local businesses and public services. The Chitandika mini-grid represents an innovative approach to rural electrification in Zambia, aligning with the country's goals to diversify its energy sources and improve electricity access for its rural population.

A comprehensive site visit on April 5, 2024, by renewable energy experts evaluated the mini-grid's performance, economic viability, social impact, and scalability. The system features a hybrid generation of solar PV, battery storage, and a diesel generator, with an installed capacity of 28.3 kWh and smart metering technology. Financial assessments show capital expenditures between $300,000 and $350,000, with low operational costs mainly for fuel and maintenance. While the mini-grid has positively impacted local economic activities and presents growth opportunities, challenges like high tariffs for some users remain. Additionally, it operates with zero carbon emissions and complies with stringent environmental regulations.

Case study 2 : Mpanta Solar Mini-Grid (Non-operational)

The Mpanta Solar Mini-Grid, commissioned in 2013 in Samfya district, Luapula Province, was the first solar PV mini-grid in Zambia, developed by the Rural Electrification Authority (REA) with a 60 kWp capacity. It aimed to demonstrate the technical and financial viability of isolated renewable mini-grids for rural electrification, targeting 480 households (approximately 6,000 people), public institutions like schools and health centers, and businesses in the fishing community of Mpanta.

The project was a collaboration involving the United Nations Industrial Development Organization (UNIDO), the United Nations Environment Programme (UNEP), the Global Environment Facility (GEF), and the Development Bank of Zambia (DBZ). REA partnered with the local Kafita Cooperative Society to manage operations and ensure community participation. The total project cost was USD 1.3 million.

Mpanta served households, small businesses, a school, a health center, and a harbor, providing lighting, phone charging, and power for small appliances. It also enhanced community life by improving security, health services, and school attendance, and reducing reliance on paraffin for lighting.

The system initially included 300 solar panels, inverters, charge controllers, and batteries, with an annual energy output of approximately 76,500 kWh. However, after damage caused by lightning in 2015, the system's capacity was downsized to 224 panels, reducing output and operation to 14 hours daily.

The project faced challenges such as seasonal income fluctuations from fishing, affordability issues, and community dissatisfaction with tariff structures. Over time, many households were disconnected due to inability to pay. Additionally, technical issues like lightning damage and the absence of productive energy use to sustain income generation further undermined its viability. By 2016, nearly half of the initial connections were lost, rendering the project financially unsustainable.

The Mpanta Mini-Grid highlighted the importance of integrating community-specific socio-economic conditions into project design, ensuring affordability, and fostering productive energy use for long-term sustainability.

3 DATA NEEDS ASSESSMENT AND GAP ANALYSIS

The development of bankable and technically viable mini-grid systems requires comprehensive data collection. This data forms the foundation for both the financial and operational planning necessary for successful mini-grid projects.

3.1 State of minigrid data in Zambia

This section outlines the ideal data requirements necessary to build effective and sustainable mini-grid business models and technical designs. It contrasts these ideal conditions with the reality of data collection in Zambia, identifying gaps that need to be addressed to improve mini-grid deployment.

TABLE 4: IDEAL AND CURRENT DATA COLLECTION SITUATION

Type of Data	Ideal	Zambia
Energy Demand Data	Detailed and disaggregated data on energy demand from households, businesses, and community services. This includes both current usage and future demand projections. Accurate energy demand data is crucial for determining the size of the mini-grid and forecasting revenue. It must account for seasonal fluctuations in usage and variations between different consumer segments (residential, commercial, agricultural, etc.).	There is a significant lack of detailed, disaggregated data on energy demand in rural areas. While some household surveys have been conducted, they often provide only a snapshot of current energy consumption without forecasting future demand. This makes it difficult to accurately size mini-grid systems or predict revenue streams.

Costs Data	Comprehensive data on the costs of equipment, installation, and ongoing operations is vital. This includes not only the cost of technology components (solar panels, batteries, inverters) but also costs associated with transportation, local labour, maintenance, and fuel for hybrid systems. This data should be updated regularly to reflect market changes and cost reductions in renewable energy technologies.	Although data on capital costs (e.g., solar panel prices) is available, operational cost data is often incomplete. Maintenance and operational costs, particularly for hybrid systems, are rarely tracked in detail, making it difficult to assess the long-term sustainability of mini-grid projects.
Financial Performance Data:	Data on existing mini-grid projects' financial performance, including key metrics such as payback periods, return on investment (ROI), and internal rate of return (IRR). This data helps in refining business models to attract investment.	Few mini-grid projects in Zambia have been extensively monitored for financial performance. As a result, there is limited understanding of which business models work best in the Zambian context, particularly in terms of cost recovery and profitability.
Geospatial Data	This includes geographic information system (GIS) data on population density, proximity to existing grid infrastructure, and potential sites for renewable energy generation. Geospatial data helps in site selection for mini-grids, ensuring that they are placed in locations with the highest potential for impact and cost efficiency.	Some geospatial data is available through national surveys and international development programs. However, there is often a lack of integration between this data and mini-grid planning efforts. Additionally, more granular data at the community level is often missing, leading to suboptimal site selection.
Socio-Economic Data	Information on household income, expenditure patterns, and willingness to pay for electricity services. Socio-economic data allows for the design of tariff structures that are affordable for consumers while ensuring financial sustainability. It also helps in identifying opportunities for productive use of electricity, such as agricultural or industrial activities that could boost demand and revenue.	Socio-economic data collection in Zambia has been largely anecdotal or based on broad national statistics. In many cases, there is little information available about rural households' willingness or ability to pay for electricity. This limits the ability to design appropriate tariff structures and identify opportunities for productive use.
Resource Availability Data	Data on renewable resources, such as solar irradiance and temperature is critical for designing systems that are appropriately sized and capable of meeting local energy needs sustainably. This data must be collected over time to ensure accuracy and account for seasonal variations.	Solar resource data is relatively well-documented in Zambia, but data on other renewable resources, such as wind or hydro, is sparse. Solar irradiance data tends to be limited to certain regions, and seasonal variations are not always well accounted for.
Regulatory and Policy Data	Information on local regulations, energy tariffs, and incentives for renewable energy projects. This data is essential for understanding the policy landscape and ensuring compliance with national and local energy regulations.	Zambia's energy policy framework is evolving, but there is still a need for clearer guidelines on mini-grid deployment, particularly regarding licensing and tariff-setting mechanisms. Data on regulatory processes is not always easily accessible, leading to delays and uncertainty for project developers.

3.2 Importance of Data and Recommendations to Address Shortfalls

Accurate and comprehensive data is critical for the successful planning, implementation, and scaling of mini-grid projects in Zambia. Reliable data ensures that mini-grids are appropriately sized, financially sustainable, and responsive to the actual energy needs of rural communities. Without adequate data, developers risk over- or under-sizing systems, leading to inefficiencies, financial losses, and reduced long-term viability. Additionally, robust data collection supports evidence-based policymaking, enhances investment confidence, and enables better integration of mini-grids into Zambia's broader energy strategy.

To bridge the identified gaps in data collection and utilisation, the following actions are recommended:

Improve Demand Forecasting and Energy Consumption Data

- Conduct detailed household and business energy surveys to understand expected customer demand.
- Deploy smart metering and monitoring systems to track consumption patterns, seasonal variations, and load growth in mini-grid communities.

Strengthen Financial Data Collection

- Establish standardised financial reporting frameworks for mini-grid projects, ensuring transparency in cost structures, revenues, and return on investment (ROI).
- Encourage developers to share anonymised financial performance data to help refine viable business models.

Enhance Socio-Economic and Willingness-to-Pay Assessments

- Integrate socio-economic surveys into mini-grid planning to assess household income, affordability levels, and payment behaviours.
- Pilot tiered or flexible tariff structures based on community affordability and productive use opportunities.

Expand Geospatial and Resource Data for Better Site Selection

- Utilise Geographic Information System (GIS) mapping to identify high-priority areas for mini-grid deployment.
- Enhance collaboration with meteorological agencies to improve solar and renewable resource mapping.

Develop Centralized Mini-Grid Data Repositories

- Establish a national mini-grid data platform to collate and share operational, financial, and performance data among developers, policymakers, and investors.
- Encourage partnerships between government agencies, universities, and the private sector to improve data accessibility and coordination.

4. FUNDING OPPORTUNITIES AND PARTNERSHIP DEVELOPMENT

4.1 Overview of Potential Funding Sources

Zambia's solar mini-grid sector can tap into various funding sources, including:

Government Grants and Loans: The Zambian government, in collaboration with international partners such as Sustainable Energy for All, offers grants and loans specifically aimed at supporting the productive use of energy component to ensure that minigrids are sustainable. Initiatives like the Demand Stimulation Incentive provide financial support to developers have been designed with support from Rockefeller Foundation. Other initiatives include creating a productive use fund under the ZECDP to support cooperatives managing the minigrids under the ZECDP.

International Climate Funds: The Green Climate Fund and other climate-focused funds support projects that contribute to climate change mitigation and adaptation.

Bilateral Donors: Countries like Germany through GIZ and REEEP offer grants, capacity building programmes and technical assistance for mini-grid development and integration of PUE in the business models.

International Development Agencies: Organisations such as the African Development Bank (AFDB) and the United Nations Industrial Development Organization (UNIDO) provide funding and technical assistance for renewable energy projects, including solar mini-grids.

Public-Private Partnerships: Combining public sector support with the efficiency and innovation of the private sector can unlock substantial funding for minigrid projects. Initiatives under the Rural Electrification Authority (REA), in collaboration with cooperating partners (CPs), have already begun fostering such partnerships, laying the groundwork for scaling up minigrid development and accelerating rural electrification efforts.

Constituency Development Fund (CDF): The CDF supports local communities by facilitating a decentralised system aimed at empowering constituencies to implement projects that directly address local needs. Each of Zambia's 156 constituencies has been allocated ZMW 28.3 million annually (as of 2024) to finance various projects, including infrastructure, education, health, and entrepreneurship. Although the CDF has primarily been used for community infrastructure and social services, it is gradually becoming a crucial mechanism for promoting energy access initiatives, such as minigrid development, which is still in its early stages. By aligning CDF projects with national energy goals, the fund has the potential to significantly contribute to the expansion of clean energy solutions at the local level.

Citizen Economic Empowerment Commission (CEEC): The CEEC is a government initiative aimed at promoting economic empowerment and entrepreneurship among Zambians, particularly for marginalised groups such as women, youth, and people with disabilities. By providing access to financial resources, technical support, and market linkages, the CEEC plays a crucial role in driving inclusive economic growth at the grassroots level. With a focus on fostering small and medium-sized enterprises (SMEs), the CEEC has financed a wide range of projects across key sectors such as agriculture, manufacturing, and renewable energy. While the focus on minigrid development has not been explored, the CEEC presents an important vehicle for scaling up local clean energy projects by supporting entrepreneurs in the energy sector. The CEEC has potential to enhance the development of sustainable energy solutions, contributing to the national goal of achieving universal energy access. Proposals on how the commission can support developers has been made and being considered for financing.

Private Sector Investment: Expanding private sector participation in mini-grid development is essential for unlocking sustainable financing in Zambia. To attract investment, targeted incentives should be introduced to create a more favourable investment climate. Institutions like the Zambia Development Agency, which maintains a pipeline of private investors seeking opportunities in the energy sector, can play a key role in facilitating these investments and connecting developers with potential funding sources.

4.2 Strategies for Securing Funding

Securing funding for solar mini-grid projects in Zambia requires a strategic approach to demonstrate viability, attract investors, and align with funders' priorities. The following strategies can enhance funding success:

- **Develop a robust business plan:** Clearly outline the project's financial viability, social impact, and technical feasibility to appeal to investors and development partners.
- **Align with investor priorities:** Understand the investment criteria of different funders to tailor proposals that effectively meet their requirements.
- **Highlight positive impacts:** Emphasise and quantify how mini-grids contribute to rural electrification, economic growth through productive energy use, and improved social well-being.

- **Leverage strong partnerships:** Demonstrate collaboration with local stakeholders, including government agencies, communities, and technical partners, to enhance project credibility and sustainability.
- **Account for seasonal demand variations**: Integrate considerations for fluctuating energy demand into project design to ensure reliability and financial sustainability.

4.3 Development of Collaborative Networks

Establishing strong collaborative networks is critical to securing and maximizing funding opportunities. Partnerships can help streamline financing, policy advocacy, and technical support for mini-grid development. Key actions include:

- **Engage with key stakeholders:** Build strong relationships with government agencies, regulatory bodies, community leaders, and technology providers to create a supportive environment for mini-grid deployment.
- **Partner with NGOs and development agencies:** Collaborate with organisations that can provide financial support, technical expertise, and capacity-building programs.
- **Strengthen industry advocacy:** Support existing industry associations in lobbying for favourable policies and regulatory frameworks that promote mini-grid sector growth.

To ensure clarity and long-term success, partnerships should be formalised through Memoranda of Understanding (MoUs) or other legally binding agreements. Well-defined partnerships help establish clear roles, responsibilities, and mutual benefits, fostering trust and transparency among stakeholders. This structured approach enhances collaboration and contributes to the sustainable expansion of Zambia's mini-grid sector.

5. KEY FINDINGS AND RECOMENDATIONS

5.1 Key Findings from Mapping and Analysis Activities

Rural electrification in Zambia faces significant challenges due to low population densities, which make it difficult to achieve financial viability for off-grid energy systems. The limited customer base in these areas constrains the ability to increase load factors and generate sufficient revenue, as economies of scale are harder to achieve. Additionally, high distribution costs further elevate the financial burden of developing off-grid systems in sparsely populated regions.

Affordability remains a major concern, with off-grid tariffs subject to social and political pressure, often making it difficult to implement cost-reflective pricing. The willingness and ability of rural households to pay for electricity are key determinants of viable tariff structures, yet poverty and low disposable incomes create a challenging environment for setting financially sustainable rates. As a result, many mini-grid projects rely heavily on grants and subsidies, raising concerns about long-term sustainability once external funding ends.

Policy and financing constraints further hinder the expansion of off-grid electrification. Zambia lacks a well-defined rural electrification strategy, and private sector investment remains insufficient, with financing tenures often limited to short-term commitments of five to seven years.. Additionally, local commercial banks and financial institutions have limited capacity and expertise in the renewable energy sector, leading to high risk perceptions that discourage investment.

Addressing these challenges requires a multi-faceted approach, including targeted policy reforms, innovative financing mechanisms, and strategic partnerships to ensure the long-term financial sustainability of off-grid energy solutions in Zambia, with suggestions outlined below:

5.1.1 Regulatory Environment and Policy Implications

A clear, supportive, and consistent regulatory framework is critical to the success of mini-grid projects in Zambia. The current regulatory environment, while improving, still lacks clarity on critical aspects such as licensing, tariffs, and integration with the national grid. In particular, the lack of well-defined policies for transitioning mini-grids to the main grid when it is extended creates uncertainty for developers. Addressing

these gaps will require coordinated efforts from the government, regulatory bodies, and international partners. Establishing transparent licensing processes and predictable tariff structures can boost investor confidence and encourage more private sector involvement.

5.1.2 Financial Sustainability and Investment Attractiveness

The financial viability of mini-grid projects remains a pressing concern. High upfront capital costs combined with the low-income levels of rural communities make it challenging to develop financially sustainable projects. Without adequate subsidies or innovative financing models, mini-grid developers face difficulty in recovering costs. The existing donor-funded models, while helpful, are not sufficient for long-term sustainability. Zambia needs to explore blended finance solutions that combine concessional financing with private capital to reduce risk and make projects more attractive to investors.

Furthermore, financial strategies such as pay-as-you-go (PAYG) systems, micro-financing options for consumers, and productive use of energy (PUE) initiatives can increase the affordability of electricity for rural households while improving revenue generation for developers. Promoting these solutions could help address the affordability gap while ensuring that mini-grids can recover their costs over time.

5.1.3 Technical Capacity and Maintenance

Ensuring the technical sustainability of mini-grid systems requires building local capacity for operation and maintenance. Many rural areas in Zambia face a shortage of skilled technicians and reliable access to spare parts, leading to long downtimes and operational inefficiencies. Addressing these challenges will require investments in local workforce development, including training programs for technicians and operators. Additionally, establishing reliable supply chains for essential components can reduce maintenance delays and improve system performance.

To support the long-term sustainability of mini-grids, it is also important to explore hybrid systems (e.g., solar combined with diesel generators) that provide reliable power during periods of low solar generation, particularly during the rainy season. Developing such resilient systems could further enhance energy security for rural communities.

5.1.4 Data and Planning Gaps

The lack of comprehensive data on energy demand, socio-economic conditions, and operational costs significantly hampers the planning and deployment of mini-grid systems. This makes it difficult to appropriately size systems, predict revenue streams, and assess long-term financial viability. More robust data collection processes are necessary, including detailed surveys of rural energy consumption and economic activities. Such data can inform better business models and system designs that are tailored to local contexts.

Moreover, as mini-grids are deployed, ongoing performance monitoring and data collection are essential to understanding how these systems are used and what improvements can be made. This will enable continuous refinement of mini-grid business models, ensuring that they remain adaptable to evolving local needs.

5.1.5 Community Engagement and Social Acceptance

Community involvement is vital for the success of mini-grid projects. A lack of awareness or engagement can lead to low uptake or resistance from rural communities, particularly if the benefits of electrification are not clearly communicated or if the cost of electricity is perceived as unaffordable. Effective community

engagement from the early stages of project development is essential. This involves participatory planning processes, transparent communication about the benefits and costs of electrification, and efforts to align mini-grid deployment with community priorities, such as improving access to education, healthcare, and economic opportunities.

Furthermore, demonstrating the productive uses of electricity—such as powering small businesses, agricultural processing, or other income-generating activities—can increase the perceived value of electrification and improve willingness to pay. This, in turn, supports the financial viability of mini-grid systems by boosting energy demand and revenue.

5.1.6 Climate Resilience and Environmental Sustainability

Finally, Zambia's reliance on hydropower makes its national grid vulnerable to climate change, particularly droughts. Solar mini-grids offer a critical opportunity to diversify the energy mix, reducing dependence on hydropower and increasing resilience to climate variability. However, solar mini-grids themselves must be designed to account for environmental risks, such as extreme weather conditions, that could affect system performance.

Incorporating climate resilience into the design and operation of mini-grids will be essential for ensuring their long-term sustainability. This could involve integrating battery storage systems, exploring hybrid energy models, and ensuring that mini-grid infrastructure is robust enough to withstand extreme weather events.

5.2 Recommendations for Future Research and Development

To accelerate the deployment of mini-grids in Zambia, future research and development efforts must focus on creating, refining, and scaling business models that ensure financial sustainability, adaptability to local contexts, and scalability. While considerable progress has been made in the technical aspects of mini-grid deployment, there is still a need for innovative business models that can address the economic realities of rural Zambia and attract investment from both the private and public sectors.

5.2.1 Exploring Diverse Business Models

Future research should focus on identifying and refining business models that align with the socio-economic realities of rural communities in Zambia. Mini-grid financial models must be designed to attract investment while mitigating risks for developers and financiers. Exploring a combination of donor-funded, private sector-driven, and public-private partnership approaches will be essential in determining the most effective strategies for scaling mini-grid deployment.

A key consideration is understanding how mini-grids can serve as catalysts for local economic growth by enabling productive use of energy, supporting small businesses, and strengthening agricultural value chains. This requires a clear framework that defines what constitutes economic growth in a mini-grid setting and how it can be systematically integrated into business models. Partnerships should play a central role in this process, bringing together key stakeholders from government, financial institutions, private sector developers, and local communities to create a collaborative ecosystem for sustainable mini-grid expansion.

Another critical area of exploration is how the Constituency Development Fund (CDF) can be effectively leveraged to support mini-grid projects. Given its role in financing local infrastructure and economic development, it is important to assess how CDF allocations can be strategically aligned with rural electrification initiatives to enhance impact and long-term viability.

Encouraging communities to pay for services and actively participate in the mini-grid economy is crucial for sustainability. This requires creating viable markets where consumers and businesses can engage with energy services in ways that generate economic value and increase demand. Developers must also play an active role in sharing data and collaborating with financial institutions to refine and optimize mini-grid financial models.

Transparent data sharing can help de-risk investments, improve financial planning, and enable more tailored funding solutions that align with the realities of rural electrification in Zambia. Specific business model innovations to be developed further in Zambia include:

Pay-as-You-Go (PAYG): This model has gained traction in other parts of Africa, especially for solar home systems. PAYG allows customers to pre-pay for electricity in small increments, making energy access more affordable and manageable for low-income households. Research is needed to assess how PAYG models could be adapted to mini-grid settings in Zambia, particularly in remote areas with limited financial infrastructure.

Community-Owned and Cooperative Models: Cooperative models, where local communities own and manage mini-grids, could empower rural populations and ensure local buy-in. This approach may increase social acceptance and engagement while providing a mechanism for long-term financial sustainability. Future research should focus on developing frameworks for community ownership, examining governance structures, and assessing the financial viability of cooperative models in Zambia.

Productive Use of Energy (PUE) Integration: PUE initiatives—where electricity is used to drive income-generating activities like small businesses, agricultural processing, or cold storage—are crucial for ensuring the financial sustainability of mini-grids. By fostering higher demand for energy, PUE can improve revenue streams for mini-grid operators. Research should focus on identifying sectors where productive use can be most effective and developing tailored business models that incorporate these activities into mini-grid operations, and ways to incentivise PUE through targeted programs, financing options for small businesses, and collaboration with local entrepreneurs.

Blended Finance Models: Future research should explore how blended finance—combining concessional funding with private capital—can reduce the risk associated with mini-grid projects. This model could involve leveraging donor or development bank funds to de-risk private sector investments, making mini-grid projects more attractive to commercial financiers. Research could examine case studies from other regions where blended finance has been successfully implemented to extract lessons applicable to Zambia.

Tariff Design and Affordability: A major challenge for mini-grid developers is balancing cost-reflective tariffs with the low ability to pay in rural areas. Research into innovative tariff structures, such as tiered pricing models based on consumption levels or differentiated tariffs for residential vs. commercial users, is needed. These models should focus on maximizing affordability for low-income households while ensuring that mini-grids remain financially viable in the long term.

Subsidies and Incentives: Government-backed subsidies and incentives will likely play a crucial role in scaling mini-grids. Future research should investigate different subsidy mechanisms, such as Results Based Funding (RBF), which links financial support to the number of connections achieved. Additionally, studying how subsidies can be combined with private investment to drive growth in the sector will be essential for building scalable models.

5.2.2 Adapting Business Models to Local Contexts

Zambia's rural areas exhibit diverse socio-economic and geographic conditions, requiring mini-grid business models to be flexible and responsive to these variations. Future research should focus on developing approaches that align with the specific needs and circumstances of different communities to ensure the long-term viability of mini-grid projects.

A crucial aspect of this adaptation is working closely with the Rural Electrification Authority to gain a deeper understanding of community needs before mini-grids are deployed. This involves assessing the types of economic activities that could be sustained within a mini-grid-powered environment, considering factors such as agricultural practices, small business potential, and local market structures. Given Zambia's varied landscapes, understanding these dynamics will help ensure that mini-grid projects are designed in a way that maximizes their economic and social benefits.

Another key research area involves addressing the persistent financing barriers that hinder mini-grid development. Financial institutions often cite specific risks and challenges that limit their willingness to invest in rural energy projects. Identifying these gaps and developing solutions to mitigate them will be essential for

unlocking greater private sector participation. Strengthening financial models, improving risk assessment methodologies, and creating tailored financing mechanisms could help make mini-grid investments more attractive and sustainable in Zambia's unique rural contexts.

Market Segmentation: Different regions of Zambia may have varying levels of energy demand, economic activity, and willingness to pay. Future research should explore market segmentation strategies that enable mini-grid developers to customise their offerings based on local conditions. For example, areas with higher economic activity may be able to support more robust and commercial mini-grids, while lower-income areas may require more heavily subsidised or basic systems.

Cultural and Behavioural Factors: Understanding the cultural and behavioural factors that influence energy consumption patterns in rural Zambia is crucial for designing business models that are socially acceptable and likely to succeed. Research into how these factors affect energy use, willingness to pay, and engagement with mini-grids will help developers refine their approaches.

5.2.3 Data-Driven Business Model Optimisation

Future business models should be grounded in robust data to ensure they are financially sustainable and scalable. This requires a strong emphasis on data collection and analysis. Areas for research include:

Real-Time Data Collection for Demand Forecasting: Mini-grid developers need accurate data on current and projected energy demand to size systems appropriately and predict revenue streams. Research should focus on developing cost-effective methods for real-time data collection and analysis. These methods could involve the use of smart meters, mobile-based data collection, and partnerships with local organisations for on-the-ground data gathering.

Monitoring and Evaluation: Research should also focus on developing frameworks for monitoring the financial and operational performance of mini-grids over time. Continuous evaluation can provide critical insights into how business models can be adjusted to improve performance, reduce costs, and better serve communities.

5.2.4 Partnerships and Stakeholder Engagement

Building successful business models for mini-grids will require strong partnerships between governments, private sector players, and local communities. Future research should explore:

Public-Private Partnerships (PPPs): PPPs are a proven model for infrastructure development, and their potential for mini-grids should be further explored. Research should investigate the best ways to structure these partnerships, ensuring that both public and private stakeholders benefit from risk-sharing and mutual incentives for success.

Engagement with Local Financial Institutions: Local financial institutions in Zambia often lack the capacity or appetite to finance mini-grid projects. Research should focus on how these institutions can be engaged through capacity-building initiatives, risk guarantees, or blended finance structures to unlock domestic financing for mini-grids.

5.2.5 Scaling Up and Replicating Successful Models

Once successful business models are developed, the challenge will be scaling them across Zambia's diverse rural landscape. Future research should focus on:

Replication of Successful Models: Studying regions where mini-grids have been successfully deployed and determining how these models can be replicated in other parts of Zambia will be crucial. Research should identify the key factors that contribute to the success of these models and how they can be adapted to different contexts.

Policy Recommendations for Scaling: Research should also generate policy recommendations that create an enabling environment for scaling mini-grid business models. This could include recommendations for regulatory reforms, incentives for private sector involvement, and strategies for integrating mini-grids with the national grid over time.

6. CONCLUSION

6.1 Summary of Project Outcomes

This report highlights the immense potential of solar-powered mini-grids to address Zambia's rural electrification challenges. Through detailed analysis and stakeholder engagement, we have identified key areas where mini-grid deployment can be improved, particularly in terms of financial sustainability, regulatory clarity, and technical capacity. The project has mapped current mini-grid efforts, assessed the gaps in data and business models, and proposed strategic recommendations for developing scalable and investable mini-grid solutions that cater to the needs of Zambia's underserved communities.

6.2 Impact on the Mini-grid Sector in Zambia

The findings from this project underscore the importance of building robust business models that can attract investment and ensure long-term sustainability. By addressing the financial, technical, and regulatory barriers outlined in this report, Zambia can unlock the full potential of its solar resources. The project's outcomes will contribute to shaping the future of mini-grid development in Zambia, supporting the country’s efforts to achieve universal energy access and promoting socio-economic development in rural areas.

6.3 Future Directions for Research and Collaboration

Future research must continue to focus on refining business models, optimising data collection for better planning, and fostering stronger partnerships between the public and private sectors. Collaboration with local communities and stakeholders will be crucial in ensuring the success and scalability of mini-grids. As the mini-grid sector evolves, continuous research into innovative financing models, regulatory frameworks, and technical advancements will be essential to overcoming remaining challenges and accelerating Zambia’s progress toward sustainable rural electrification.

7. REFERENCES

[1] "Zambia Electricity Service Access Project." Accessed: Mar. 11, 2025. [Online]. Available: https://www.worldbank.org/en/news/video/2025/02/13/zambia-afe-electricity-service-access-project?utm_source=chatgpt.com

[2] J. Peters, M. Sievert, and M. Toman, "Rural Electrification through Mini-Grids: Challenges Ahead," *SSRN Electronic Journal*, May 2019, doi: 10.2139/SSRN.3377033.

[3] F. Kapole, S. Mudenda, and P. Jain, "Study of major solar energy mini-grid initiatives in Zambia," *Results in Engineering*, vol. 18, Jun. 2023, doi: 10.1016/J.RINENG.2023.101095.

[4] "Rural population (% of total population) | Data." Accessed: Mar. 11, 2025. [Online]. Available: https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS

[5] "2022 census – Zambia Statistics Agency." Accessed: Mar. 11, 2025. [Online]. Available: https://www.zamstats.gov.zm/2022-census/?utm_source=chatgpt.com

[6] K. Gasior, P. Rattenhuber, A. A. Shahir, and A. Zasova, "Raindrop in the drought? Vulnerability to climate shocks and the role of social protection in Zambia," vol. 2024, Dec. 2024, doi: 10.35188/UNU-WIDER/2024/553-0.

[7] E. Gorkaltseva and U. Sinkala, "Power engineering challenges in Zambia," *MATEC Web of Conferences*, vol. 110, Jun. 2017, doi: 10.1051/MATECCONF/201711001034.

[8] "Zambia – Beyond Connections : Energy Access Diagnostic Report Based on the Multi-Tier Framework." Accessed: Mar. 11, 2025. [Online]. Available: https://documents.worldbank.org/pt/publication/documents-reports/documentdetail/477041572269756712/zambia-beyond-connections-energy-access-diagnostic-report-based-on-the-multi-tier-framework

[9] African Mini-grid Development Association, "The decade of the mini-grid: Accelerating innovation to address the energy trilemma in Sub-Saharan Africa | AMDA." Accessed: May 24, 2021. [Online]. Available: https://africamda.org/index.php/news-2/webinars-virtual-events-2/the-decade-of-the-mini-grid-accelerating-innovation-to-address-the-energy-trilemma-in-sub-saharan-africa/

[10] "Tackling Zambia's Rural Energy Hurdle with a Mini-Power Grid at Chipota Falls | United Nations Development Programme." Accessed: Mar. 11, 2025. [Online]. Available: https://www.undp.org/zambia/stories/tackling-zambias-rural-energy-hurdle-mini-power-grid-chipota-falls

[11] Government of Zambia, *National Energy Policy 2019*. Accessed: Jul. 17, 2023. [Online]. Available: https://www.moe.gov.zm/wp-content/uploads/2022/04/The-National-Energy-Policy-2019.pdf

[12] "MINISTRY OF ENERGY LAUNCHES 2023 NATIONAL ENERGY ACCESS SURVEY REPORT – Ministry of Energy." Accessed: Mar. 11, 2025. [Online]. Available: https://www.moe.gov.zm/?p=3813

[13] H. Chanda, E. Mohareb, M. Peters, and C. Harty, "Community-led solar energy technology adoption in rural Zambia: The role of observational learning and neighbor influence," *Energy Res Soc Sci*, vol. 122, p. 103972, Apr. 2025, doi: 10.1016/J.ERSS.2025.103972.

[14] "Zambia Electric Cooperative Development Program - NRECA International." Accessed: Mar. 11, 2025. [Online]. Available: https://www.nrecainternational.coop/zambia-zecdp/?utm_source=chatgpt.com

[15] M. Mwanza, J. Chachak, N. S. Çetin, and K. Ülgen, "Assessment of solar energy source distribution and potential in Zambia," *Periodicals of Engineering and Natural Sciences*, vol. 5, no. 2, pp. 103–116, 2017, doi: 10.21533/PEN.V5I2.71.

8. APPENDIX

8.1 Stakeholder Consultation Notes

WORKSHOP HELD ON 05 DECEMBER 2024.

PROJECT TITLE: BUILDING PARTNERSHIPS TO ACCERATE ENERGY ACCESS THROUGH MINIGRIDSIN ZAMBIA

STAKEHOLDER FEEDBACK

Key Challenges and Ideas

1. **Lack of Market Linkages**:
    - **Agnelli (Ministry of Energy)** said mini-grids often fail because they are not connected to markets that can use the electricity. For example, grain mills or other businesses that create value could be linked to mini-grids to boost local economies and ensure sustainability.
2. **High Electricity Costs**:
    - A representative from the **smart energy sector** explained that in the Eastern Province, households pay 10 to 40 kwacha per kilowatt for electricity. This is more than other areas. Small users are hit hardest, as they often pay more for energy, making it less affordable for rural families.
3. **Learning from Past Projects**:
    - **REA (Rural Electrification Authority)** shared lessons from a failed mini-grid in Mpanta, which produced 60 kilowatts but couldn't meet the community's needs. The failure showed the importance of proper planning and understanding what local people actually need.

Financial Barriers

1. **Hard to Get Funding**:
    - **Engie** explained that financing mini-grids is expensive. Loans from local banks come with high interest rates, while international funds are cheaper but take too long to process. Both options are challenging for developers.
2. **Using Constituency Development Funds (CDF)**:
    - **REX** highlighted that each community in Zambia contributes to the Constituency Development Fund (CDF). This money could buy tools and equipment for businesses that use electricity from mini-grids. **REA** already provides technical advice on how to use CDF for electrification projects.
3. **Balancing Grant, Equity, and Debt**:
    - **Professor Lloyd** suggested starting with grants or equity (where investors share the risk) before taking loans. This makes projects less risky for developers.

Technical and Operational Issues

1. **Maintaining Power Quality**:
    - **ERB (Energy Regulation Board)** shared that mini-grids must follow a national standard (Standard 25,387) to ensure the electricity supplied is reliable. Developers should meet these technical requirements to attract investors.
2. **Energy Use is Often Low**:
    - **Engie** noted that many mini-grids produce more electricity than the community uses. This unused energy is wasted and reduces revenue. Finding ways to increase energy use is essential for financial sustainability.

Community Involvement and Behavior

1. **Community Surveys Are Critical**:
    - **Strathclyde University** stressed the importance of talking to communities before building mini-grids. Developers need to learn about the local economy, people's electricity needs, and what businesses might grow if electricity is available.
2. **Mapping Economic Activities**:
    - **Dylan** explained that understanding what people in the community do for a living is key. For example, farmers may need milling machines, or shops might need refrigerators. Knowing this can help design mini-grids that meet their needs.
3. **Studying Behaviour Through Mobile Data**:
    - One stakeholder suggested studying how people buy TalkTime (mobile phone credit) to understand how much they are willing to spend on electricity. Many people prioritise spending on things they value, such as communication or TV, and this data could help plan affordable tariffs.

Suggestions for Better Mini-Grids

1. **Start with a Strong Plan**:
    - **Ministry of Energy** stressed that mini-grids must have well-structured plans from the start. Without clear goals and commercial models, projects are less likely to succeed.
2. **Encourage Local Financing**:
    - Some stakeholders suggested making loans easier to access through local banks and encouraging policies that reduce the cost of equipment and operations.
3. **Form Partnerships**:
    - Mini-grid developers should work with others to address market linkages, productive uses of energy (like running mills or irrigation), and local business needs. Partnerships with financial institutions, technical experts, and governments can make projects more effective.

Incorporating Social and Environmental Goals

1. **ESG (Environmental, Social, and Governance) Goals**:
    - **CBU (Copperbelt University)** mentioned that mini-grid projects should consider environmental impacts, social benefits, and governance (good management). Meeting ESG goals can attract funding from international investors who value these outcomes.
2. **Track Social Impact**:
    - It’s important to measure how mini-grids improve people's lives. For example, are families making more money because they have access to electricity? This data can help attract funding from organizations that care about community development.

Innovative Financing Ideas

1. **Carbon Credits and Renewable Energy Certificates (D-REC)**:

Developers can earn extra income by selling certificates that show they generate clean energy. These are bought by companies that want to reduce their environmental impact.

2. **Making Financing Easier**:

Alex noted that banks in Zambia are learning more about mini-grids and how to support them. Training for financial institutions is helping them understand that mini-grids are viable businesses.

Building Partnerships to Accelerate
Energy Access through Mini-Grids
in Zambia Green Mini-Grids

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