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Energy Access and MSME Growth: Evaluating the Impact of Solar Mini-Grids on Informal Sector Productivity in Sub-Saharan Africa.

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ABSTRACT: - *Affordable and regular power access is a structural constraint limiting the competitiveness of micro, small, and medium enterprises (MSMEs) in Sub-Saharan Africa, with an emphasis on the informal sector. This study investigates how the deployment of solar mini-grids affects the productivity of informal micro, small and medium-sized enterprises in Nigeria, Kenya, Tanzania and Rwanda over the period 2010 to 2025. Using a peer-reviewed, review-based qualitative research approach this paper consolidates findings drawn from peer reviewed studies, institutional reports and comparative case analyses on the ways in which decentralized solar electricity programs influence business outcomes such as operational hours, earnings, job opportunities and service diversification. The results show a significant positive association with mini-grid electricity accessibility in the performance of enterprises, consistent with gender differentiated benefits and adaptive capacity among MSMEs. Still, challenges such as high capital expenditure (capex), financing gaps and maintenance constraints remain hurdles to achieving sustainability and scale. The study ends with policy and finance recommendations to enable the integration of solar mini-grids into broader MSME development strategies, underscoring the importance of inclusive, gender responsive, community- based energy solutions that can support equitable economic transformation across the region.*

Keywords: *Solar mini-grids, informal MSMEs, productivity, Sub-Saharan Africa, energy access, decentralised electricity, inclusive development*

I. INTRODUCTION

1.1 Background

In Sub-Saharan Africa, micro, small, and medium enterprises (MSMEs) serve as the economic backbone, contributing significantly to employment generation and poverty reduction. These enterprises account for over 80% of jobs across the region, with the informal sector representing a substantial share of this workforce (African Development Bank [AfDB], 2022). Despite their central role in economic development, MSMEs—especially those operating informally in peri-urban and rural areas—are persistently hindered by inadequate access to reliable and affordable electricity. Many of these enterprises rely on expensive and inefficient energy sources such as diesel generators, kerosene, and biomass, which not only inflate operational costs but also limit business scalability, productivity, and innovation (IEA, 2021; Obeng-Darko, 2023). The challenge of energy poverty among informal MSMEs remains deeply entrenched and is increasingly recognized as a critical development bottleneck in the region.

Solar mini-grids have emerged as a promising decentralized energy solution capable of bridging the energy access gap for underserved communities. Unlike centralized grid expansion, which is capital-intensive and slow to reach remote populations, solar mini-grids offer scalable, low-carbon alternatives that can rapidly energize clusters of businesses and households (Bhattacharyya, 2019; Odarno et al., 2022). Their integration into local economies is associated with increased business hours, improved service delivery, reduced energy expenditure, and enhanced income-generating capacity for informal sector actors. However, despite the growing deployment of solar mini-grids across Sub-Saharan Africa, empirical research evaluating their actual impact on informal MSME productivity and income generation remains limited and fragmented (Blimpo & Cosgrove-Davies, 2021; USAID, 2023).

1.2 Statement Of The Problem

Most existing studies have focused on electrification outcomes at the household level or in formal commercial settings, thereby neglecting the nuanced realities of informal enterprises, which often lack legal recognition, infrastructure, and access to formal financial systems.

This study seeks to address this critical knowledge gap by systematically evaluating the impact of solar mini-grids on the productivity of informal sector MSMEs across selected Sub-Saharan African countries between 2010 and 2025.

1.3 Research Questions

The questions that the study seek to answer are:

1. How has access to solar mini-grids affected operational hours, service efficiency, and business scalability in informal enterprises?
2. What are the gendered implications of improved energy access on informal MSME performance?
3. What contextual factors enable or constrain the effectiveness of solar mini-grids in supporting informal business growth?

1.4 Research Objectives

The research objectivess were:

1. To examine the impact of solar mini-grid access on operational hours, service efficiency, and the scalability of informal enterprises.
2. To assess the gendered implications of improved energy access on the performance and competitiveness of informal MSMEs.
3. To identify and analyze the contextual factors that enable or constrain the effectiveness of solar mini-grids in supporting the growth of informal businesses.

1.5 Scope Of The Study

The scope of the study spans four Sub-Saharan African countries—Nigeria, Kenya, Tanzania, and Rwanda—chosen for their active deployment of solar mini-grids and the availability of peer-reviewed case studies, project reports, and impact evaluations during the review period. The analysis will focus specifically on informal MSMEs operating in off-grid or weak-grid regions, with an emphasis on how energy access intersects with business development indicators such as revenue growth, employment creation, and service diversification. By synthesizing cross-national evidence, the study aims to identify best practices, recurring challenges, and policy implications for scaling solar mini-grid deployment to support informal enterprise development.

1.6 Significance Of The Study

The significance of this research lies in its potential to inform inclusive energy policy and development planning. By critically analyzing the productivity effects of decentralized energy systems within the informal sector, the study provides a nuanced understanding of how solar mini-grids can serve as catalysts for inclusive economic growth, job creation, and sustainable livelihoods. Moreover, the findings offer actionable insights for policymakers, development agencies, investors, and practitioners seeking to align energy access initiatives with MSME empowerment strategies across the region. Ultimately, the research underscores the urgency of integrating energy inclusion into broader economic development agendas as Sub-Saharan Africa navigates its transition toward a just and sustainable energy future (IRENA, 2022; Olang & Wekesa, 2024).

II. LITERATURE REVIEW

2.1 Conceptual Reviews

2.1.1 Energy Access as an Enabler of Economic Empowerment

Lack of access to energy is well established as an urgent need when it comes to helping communities in under-served regions enhance their overall socio-economic development and productivity. According to the International Renewable Energy Agency. (2022), access to modern, reliable and affordable energy is not merely an infrastructure issue but the developmental priority with critical implications for health, education, food production and economic development. Angola, Zambia, Tanzania and Democratic Republic of Congo have national access rates below 50%XBRL data In Sub-Saharan Africa, lack of electricity access is the biggest obstacle for business operations in off-grid / weak-grid areas. Energy poverty, as the lack of adequate and reliable energy for basic and productive use has been espoused to provide a critical lens in comprehending the context within which informal sector MSMEs operate (Obeng-Darko, 2023). Businesses are affected both directly, through the costs of energy insecurity (reducing operating hours and productivity due to lack of access to reliable electricity) as well as indirectly by higher production cost due to use of outdated equipment; substituting cleaner fuels with less environmentally damaging but more expensive fuels.Solar mini-grids are seen as an increasingly scalable model to address this need among the broader class of solar-based decentralized renewable energy systems

in rural and semi-urban Africa (IRENA, 2022). They are grid-free installations that offer local power generation via solar photovoltaic (PV) technology, often also using battery storage. Mini-grids can help minimize the vulnerability of informal enterprises to energy shocks while supporting business transformation, realizing productivity improvements by providing dependable and reasonably priced power (Blimpo & Cosgrove-Davies, 2021).

2.1.2 Informal Sector Dynamics and the Role of MSMEs

Most of the MSMEs in sub-Saharan Africa operate within the informal economy, with features such as deregistered operations, a lack of access to finance and minimal regulatory oversight (ILO, 2023). Nonetheless, the informal sector provides millions with jobs, enhances income opportunities and stimulates local forms of innovation. As such, informality should not be viewed as a mere legal category; it is better understood as the result of a combination of institutional, cultural and infrastructural drivers (Anyemedu & Koffi, 2022). The informal MSMEs often morph into survivalist firms, with a range of constraints that could include high energy costs, poor market access and limited working capital.

Beyond the top-down enterprise productivity definition of output per labor hour, informal sector entrepreneurship speaks to increased business-hours trading days, ability to generate revenue, capacity to grow the enterprise/increase employment, innovation adoption and retention of clients (Olang & Wekesa, 2024). The productivity impacts of solar mini-grids — specifically in terms of income gains, enhanced quality of services and employment generation —become visible as they become further weaved into the operations systems of these MSMEs

2.1.3 Solar Mini-Grids and Decentralized Energy Systems

Decentralized energy is the smaller generation of energy, produced and distributed at or very near to where it will be used (contrast centralised distribution). Among the antecedents, solar mini-grids are expected to be an essential part of this model and appear suitable for rural/peri-urban settings where population is distributed sparsely and grid has poor chances of expanding (Bhattacharyya, 2019). Since mini-grids are accustomed to be community-anchored, the economic potential of MSMEs in mini-grid catchment regions refactors through a probability function of psuedo-reliability on account of affordability and an operational plausible integration. Even if those benefits could be attained by other forms of electricity supply, theoretical and empirical research shows that reliable electricity from mini-grids is a vital bridge to move informal enterprises along the trajectory from subsistence activities towards production of value-added goods (Odarno et al., 2022).

The productivity effects of mini-grids can be understood within the productive use of energy (PUE) framework, which argues that energy is only transformative when formally incorporated into business processes in order to generate additional revenue or boost output (World Bank, 2013). This outlook drives how solar mini-grids are assessed: not just by energy access, but by the extent to which they enable more aspirational changes at the enterprise level (such as tool mechanisation, refrigeration or digital engagement).

2.1.4 Energy–Enterprise Interaction Framework

We can use energy-enterprise interaction framework to give a concrete picture of how solar mini-grids are linked with productivity at MSME level. This includes direct energy use for business activities, indirect benefits like more foot traffic because of better lighting or digital presence, and induced outcomes such as job creation or market expansion (USAID, 2023). This framework stresses that while energy interventions are few, they need to be complemented with the necessary enabling conditions such as financing for appliances, skill development and market access to realise their economic benefits fully (Goyal & Mwaura, 2021).

Emerging literature also shows that gender, digital literacy and financial inclusion potentially shape the productivity returns on solar mini-grid in informal settings, where business actors are confronted with diverse levels of vulnerability and opportunity. For example, owned by Women MSMEs face particular energy constraints, however, these same Enterprises may be more positively effected by targeted mini-grid interventions which also incorporate supportive community engagement strategies (Olang & Wekesa, 2024).

2.1.5 Conceptual Gaps and Integration

Existing conceptual models are informative but often simplicity fails to capture the intricate relationships and behaviours within the informal sector in Sub-Saharan Africa that illustrate the importance of social capital, resilient capabilities and community customs in our understanding of enterprise outcomes. For this reason, the study adopts an integrated conceptual perspective in response to calls made for combining strands of literature originating from productive use of energy (PUE), informal economy productivity lens and decentralized energy theory. By locating the study at this intersection, we aim to explore and grasp the economic and social dimensions of energy access of informal MSMEs.

In summary, we have shown how a strong conceptual basis remains crucial in unpacking the revolutionary possibilities of solar mini-grids for MSMEs in Sub-Saharan Africa. This review has examined a complex interaction between energy access and productivity with the conclusion that is echoed through to suggest providing universal access to reliable, clean energy promotes overall societal progress. Consequently, solar mini-grid interventions should be integrated into wider development strategies which tackle the systemic and contextual obstacles to informal sector expansion.

2.2.Theoretical Review

This no doubt demands a strong theoretical basis for the relationship between solar mini-grid deployment and productivity of informal MSMEs in sub-Saharan Africa. Drawing on numerous theories, some of which are tightly interrelated, the next section highlights fundamental aspects relevant to development economics, institutional dynamics — energy access and enterprise growth. Endogenous Growth Theory, Institutional Theory, Resource-Based View (RBV), and the Theory of Productive Use of Energy (PUE) are thus particularly relevant conceptual lenses to inform interpretation regarding objectives in this study.

The second group of theories, which originate from endogenous growth theory as developed by Romer (1990) and later modified through formulated Theories specific to the development infrastructure envisage that economic growth sustains itself in the long run due to internal factors like human capital accumulation, technological innovation and policy frameworks supportive of productivity enhancement. In this study, it is argued that decentralized solar energy serves as a technological enabler that boosts productivity in the informal sector by increasing output per hour of work, extending working hours and providing savings on the cost of operations. The third stream is the development of strategies to support MSMEs grow their internal capacity for innovation and growth, facilitating endogenous growth at the microeconomic level through mini-grid electrification (Ayogu & Eboh 2021; Olang & Wekesa 2024).This view is supported by institutional theory, which stresses the role of institutions (formal and informal constraints such as laws, norms, and governance structures) in shaping economic behaviour and outcomes. The informal sector accounts for a significant portion of the economy in Sub-Saharan Africa and operates mostly without formal regulatory systems, but rather within a patchwork of community norms and adaptive strategies that govern access to resources. Deployments and sustainability of solar mini grids are governed by institutional dynamics including local governance, stakeholder collaboration, tariff policies and regulatory support for energy innovation (Blimpo & Cosgrove-Davies 2021; ILO 2023). In particular, our findings are consistent with key ideas from Institutional Theory to explain why the same energy interventions lead to varying gains in productivity, a necessary precursor for economic growth depending on the existence and working of local enabling environments ad governance capacities.

The Resource-Based View (RBV) of the firm also extends a theoretical recitation over how energy can be obtained as strategic resource improving enterprise competitive advantage. In contrast, the RBV argues that firms are able to outperform their competitors only when they own valuable, rare, inimitable and non-substitutable resources (Barney 1991). To informal MSMEs, dependable electricity from solar mini-grids is a critical means of production that amplifies their capacity to produce more goods reliably at any hour, with lower downtime and the flexibility to diversify into activities of higher value. In areas of poor grid connectivity, mini-grids provide one of the only local sources of energy and an opportunity to make informal enterprises more adaptive and productive (Obeng-Darko 2023)

In relation to this study, fractals are becoming increasingly central and one could mention also the Theory of Productive Use of Energy (PUE). At the household level, this theory holds that energy access can begin yielding benefits only once it is coupled with activities in which energy contributes to income generation or value addition. Translation: Energy transitions deliver developmental dividends when consumers move beyond lighting to refrigeration, welding, agro-processing or digital services powered by electricity. These attributes are relevant to the goal of solar mini-grids supporting productive transformations among informal MSMEs as perceived in the PUE theory, rather than their tendency to simply increase household welfare (Bhattacharyya 2019; Goyal & Mwaura 2021).

Though each of these theories contributes some explanatory power, a premise for the study is structured from both as a hybrid-theoretical framework incorporating the Theory of Productive Use of Energy and the Endogenous Growth theory. PUE as a theory of energy-productivity link from an enterprise perspective, and endogenous growth model as constituent in a broader developmental paradigm of this micro-level transformation. While showing a more comprehensive picture of how access to DE can be an enabling factor for long-term, productive and inclusive growth in the informal sector within the resource and institutional setting of Africa south of Sahara.

2.3 Empirical Review

The evolving appreciation of energy access as a driver of economic change has triggered an influx of analyses measuring the productivity effects on MSMEs from decentralized energy systems. Taken together in both developed and developing contexts, the evidence highlights contingent ways in which electricity (especially through solar mini-grids) supports firm performance — with diverse geography-specific enterprise size gender institutional level effects.

While there are still large gaps in empirical research revolving around the influence of energy efficiency and grid modernization on SME productivity mainly in developed economies. For example, Müller et al. Research by Min et al. (2021) on Smart Grid integration in Germany SMEs showed energy-cost savings, operational planning and digital tool use were significantly higher in comparison to conventional means. Foxon and Cairns (2020) also looked at UK low-carbon energy adoption at the firm level, finding that policy-led incentives co-produced robust infrastructure that fostered productivity gains reflected in Foxon et al. A similar study by Li et al. Exploiting renewable energy adoption and automation at the firm level, Choi et al. (2020) in South Korea showed synergic effect between two factors not only to support more output but also to withstand external shocks better.

While studies in developing countries have been limited to economic impacts of off-grid solar technologies and their contribution towards inclusive development. Examining the impact of solar microgrids on rural SMEs in western China, Zhang and Ma (2019) found participating businesses extended working hours and saw a 22% increase in monthly revenues after the programme. In India, Aklin et al. In another RCT, conducted in Uttar Pradesh, Burney et al. (2020) show that, while electrifying the households had limited economic implications, small and medium enterprises (MSMEs) experienced a substantial increase in the number of products they were making and the level of employment. The contribution of electrified enterprises was examined by Narayan and Sinha (2021) in the context of Nepal, where they found that agro-processors and service-oriented firms benefited from quality improvements, input waste reduction, enhanced market competitiveness due to increased hours of operation and a larger pool of available labour. Evidence from Latin American contexts has continued to support the efficacy of decentralized use of energy. García and Paredes (2022) concluded that community-based solar mini-grids in rural Peru generated income spillovers to local entrepreneurs, especially artisans and processed food producers. In Brazil, Silva et al. After-effects of hybrid solar systems on unsafe informal waste recycling work contexts Informal workers | Ashiq et al., 2023.

Empirical research in Sub-Saharan Africa reliant on individual survey data has demonstrated that solar mini-grid access indeed leads to increased informal sector productivity. A multi-country study in Nigeria, Tanzania and Malawi, for example, found that MSMEs using mini-grid electricity experienced between 30% and 50% increases in daily revenue, as well as significant reductions in energy expenditures (Blimpo and Cosgrove-Davies 2021). Similarly, Eziyi and Oyebanji (2023) explore mini-grid vs. diesel-powerd MSMEs in Kaduna, Nigeria and find that solar-powered enterprises have higher net profits; better Customer retention rate and quality of services provided. Contrarily, another study by Adegbite et al. A case study in Ondo State (2022) observed that women-headed informal businesses operating with mini-grids extended their trading time by 40% as compared to conventional sources and doubled their weekly average income during a span of 12 months.

Mungai and Karanja (2021) also reviewed solar mini-grids in Turkana and Kisii counties, Kenya. For instance, their research revealed how solar power was enabling the creation of new micro-enterprises—like mobile money agents, phone-charging kiosks, and ice-distribution businesses—that had been implausible when electricity was erratic. In addition, Olang and Wekesa (2024) investigated the gendered effects of minigrid impacts: women entrepreneurs in rural Kenya experienced improved business continuity, lighter energy loading demanded by businesses only profiting from their benefits, even often reinvesting them into enterprise expansion and education.

In Tanzania, Odarno et al. We identified only 1 study that included productive-use mini-grids supported by donor programs, and this study (2022) found evidence that electrified MSMEs in Africa moved away from subsistence-level to semi-industrial production. The results reveal that greater efforts are needed to complement mini-grids with interventions for business training and improved credit, in order to maximize the benefits of both. Uwitonze & Mugisha (2020) evaluated solar hybrid mini-grids outcomes in Nyagatare district, Rwanda and have shown that access to electricity has lead to the expansion of MSMEs into new markets with use cold-chain technologies and seeking other digital services.

IRENA (2022) provides complementary insights across nations by compiling case-based evidence from Burkina Faso, Ethiopia and Zambia which find that solar minigrids improved incomes, and created more livelihood options while enhancing the resilience of informal entrepreneurs especially among agriculture linked MSMEs. On a complimentary note, USAID (2023) concluded that Power Africa's mini-

grids programs have achieved an average enterprise revenue increase of 45% in 18 months in Senegal and Ghana, with benefits strongly correlated to the tariff affordability and community ownership models.
But not all the studies come out this way. However, Nyarko and Boateng (2021) warned on the impact of mini-grids applied in northern Ghana as they had minimal effect on productivity because the after-sales support were not good, irregular maintenance, and limited user training. Of particular importance is the contextually specific structures and functions or institutional and operational mechanisms that are instrumental in shaping economic efficiency of mini-grid intervention.

In sum, the available empirical evidence shows that there exists a significant level of agreement concerning the productivity boosting potential of solar mini-grids on informal MSMEs in SSA. However, it is dependent on variables such as the level of use that these systems can obtain, the infrastructure to support them, the financing mechanisms and institutional coordination. These findings provide strong motivation for the current study, as we seek to consolidate and expand this evidence base by presenting new results using a novel data-set that focuses on informal sector firms in off-grid regions; alongside salient attention for firm productivity indicators, an analysis of gendered impacts and longer-term corporate sustainability.

2.4 Conceptual Framework

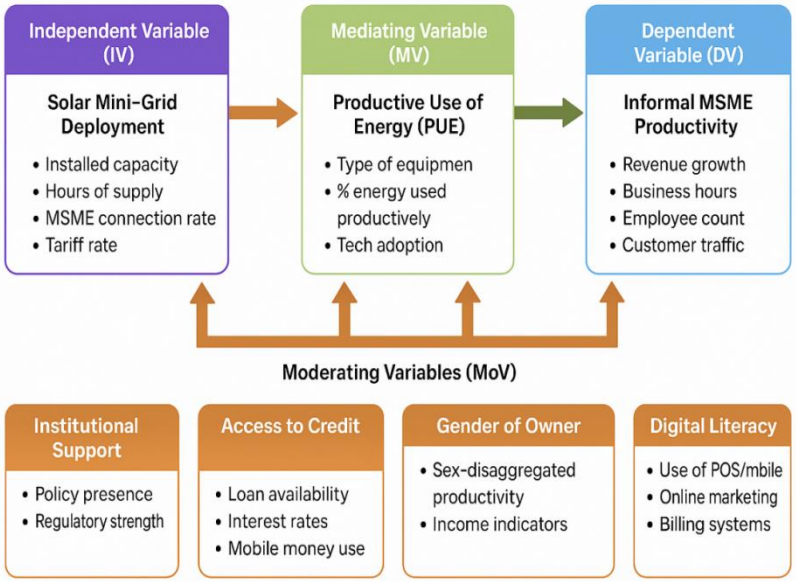

Figure 1. Conceptual Framework on Evaluating the Impact of Solar Mini-Grids on Informal Sector Productivity

Explanatory Note to the Conceptual Framework

The conceptual framework for the study titled "Energy Access and MSME Growth: Evaluating the Impact of Solar Mini-Grids on Informal Sector Productivity in Sub-Saharan Africa" is designed to illustrate the interrelationships between the core variables and how they jointly influence productivity outcomes among informal MSMEs.The framework is anchored in a conceptual understanding that combines the Theory of Productive Use of Energy (PUE) with Endogenous Growth Theory and based on four types of variables: independent, mediating, and dependent variables, as well as moderating variables.

At the left-most end of framework is the Independent Variable: Solar Mini-Grid Deployment, which depicts the core intervention being studied. The first variable has proxies tied to the installed solar mini-grid capacity (kW), hours of supply, connection rate among MSMEs and relative affordability of tariffs. Such elements are part and parcel of the measure of the extent, effectiveness and ease-of-access to energy delivered by decentralized solutions at rural and peri-urban informal enterprise precincts.

Mediating Variable: Productive Use of Energy (PUE)—The Mediating Variable will flow from the independent variable as a way through which energy access is linked to economic gains. This combines how much of used electricity for value-adding activities in enterprises, including use of electric-powered equipment, refrigeration, or digital tools. This is an operationalization of -energy by its self not development outcomes unless it is productively used to change business processes.

Dependent Variable: Informal MSME Productivity which is the overall output that include proxies that capture performance, these are longer operating hours, growth in revenue generation, customer traffics coming into the market stalls/farm/business space/household firm and creating employment/income increments and diversification of services/product etc. This indicator also offers a measurable indication of

the economic impacts of improved energy access to enable MSMEs grow, compete and innovate within informal markets.

Importantly, the framework recognizes that the deployment of solar mini-grids does not have a one-to-one or equal association with productivity within any given territory. The moderator: influences the strength of the relationship between two other variables. These include:

Institutional Support: Institutional arrangements to implement, regulate and/or finance mini-grids in target locations.

Credit Access: This affects the ability of MSMEs to buy energy enabled tools or upgrade operations with new energy availability.

Gender of Enterprise Owner, given that women-led enterprises are likely to have a very distinct mix of energy access barriers and opportunities;

Access to Digital Literacy – which went into how digital-savvy entrepreneurs were in using energy for some sort of digital transformation, marketing, billing -hell even financial inclusion.These moderating variables are indicative of the larger structural and contextual environment that may enable or limit the transformative capacity of solar mini-grids. In other words, unless a MSME is cash-rich and digitally affluent, having electricity may not turn into higher productivity. On the other hand, s.getConnectionw can help ensure that equal energy access could be a major driver for very large business change in fully enabling environments.

Basically the conceptual framework links together technical, economic, institutional and social aspects of solar energy access and enterprise development. The framework offers a 'complete picture' to test empirically how, why and when decentralized solar mini-grids (DSM) influence the informal MSME productivity in sub-Sahara. The framework is able to provide more detailed guidance on policy targeting in the complex, low-income, energy-poor contexts by identifying direct, mediating and conditional effects.

III. Methodology

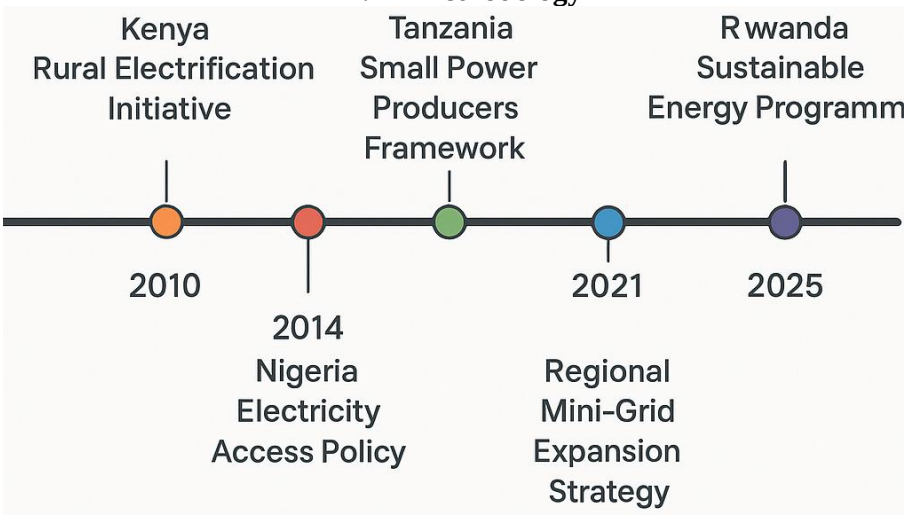

Figure 2: Timeline of Solar Mini-Grid Policies and Projects in Sub-Saharan Africa (2010–2025)

This timeline infographic maps major policy reforms and mini-grid project milestones across Nigeria, Kenya, Tanzania, and Rwanda. It highlights the progression from pilot initiatives to national electrification programs, donor-backed investments, and regulatory innovations. The sequence underscores the evolving policy landscape and sustained commitment to expanding energy access through decentralized, renewable solutions for informal sector development.

3.1 Research Design

The review-based qualitative research design of the current study uses comparative case studies to explore the effect of solar mini-grids on informal MSME productivity in Sub-Saharan Africa. The approach selected is consistent with the primary purpose of this study which is to systematically combine various empirical evidence from the literature and development project evaluations to identify patterns, mechanisms, and contextual enablers that influence the relationship between decentralized energy access and enterprise performance. The qualitative research questions have an exploratory and context-specific purpose that addresses the additional elements beyond whether solar mini-grids, in themselves, influence productivity outcomes in informal settings. This structure helps in focusing intricately over detailed documented evidence as well as interpretative insights from multiple country contexts (Yin, 2018; Bhattacharyya, 2019).

3.2 Case Selection Criteria

Countries were purposefully selected to be a part of the study based on two main criteria: Countries were first supposed to prove on-the-ground deployment of solar mini-grid projects during the period 2010-2025, representing a combination of continued policy commitment and practical application for decentralized renewable energy solutions. Second, they would have to verify that each country selected had enough documented instances of the informal sector responding favorably to electrification specifically in rural or peri-urban contexts among MSMEs. These studies were all empirical — involving measurement, evaluation, or qualitative evidence that connected mini-grid access to productive use outcomes at the enterprise level (such as extended hours of operation, business turnover increases, and changes in product/service offerings).

To conduct in-depth comparative review, these four countries—Nigeria, Kenya, Tanzania and Rwanda—were selected based on the above criteria. All three of these countries also exhibit significant variety in terms of both institutional and geographic conditions, while also serving as well-documented cases using peer-reviewed evidence of energy intervention targeting informal economic actors. In this case, solar mini-grid deployment expands from a singular solar mini-grid into an organization including multi grids that operate under shared infrastructure as well their own individual ones. The inclusion fits into the broader theme of how local dynamics may influence the effect of mini-grids on productive uses and enables some cross-case comparision with other sites.

3.3 Data Sources

The study draws exclusively on secondary data, collected from a range of peer-reviewed academic papers, international development agency reports and sector-specific databases. Journals recognised for their methodological robustness and impact were used to source the primary core academic literature indexed in Scopus, Web of Science, and other high-impact platforms. Existing research from institutional sources such as the World Bank, UNDP, and IRENA among others also offers valuable cross-sectional and longitudinal perspectives on mini-grid deployment, policy landscapes, and sector performance.

Other sources encompass standardised regional measures that are available (e.g. national energy access statistics, informal MSME productivity metrics collated by the national energy commission) and government administrative figures relating to trade and SMEs from local ministries of trade or statistical agencies. These sources provide contextual data on electrification rates, firm performance benchmarks and socio-demographic characteristics which allows for triangulation of evidence between different data systems.

3.4 Analytical Framework

The analysis uses a thematic analysis framework to make sense of the evidence gathered, in order to understand the similarities across selected case studies and explain themes that are common throughout. More particularly, the research is guided by productivity indicators for informal MSMEs which are:

- Operating hours been attained (before electrification Vs post electrification)
- Monthly or yearly revenue growth
- Employment impacts (direct employment and indirect employment)
- Operational cost savings(covenanted by reduction in energy costs)

The data were then coded thematically, with core domains categorized as energy reliability, gendered impacts, digital integration and policy facilitation. Cross-case comparisons were used for key differences and commonalities or what we also refer to as the contextual variations that give insights into when solar mini-grids have enabled productivity gains. This analytical approach ensures that results are grounded not only in the evidence but also have policy relevance, providing guidance on how to scale decentralized energy interventions to support informal sector development in Sub-Saharan Africa. the conceptual framework links together technical, economic, institutional and social aspects of solar energy access and enterprise development.

IV. FINDINGS

Table 1: Comparative Case Summary Matrix of Solar Mini-Grid Impacts on Informal MSMEs in Selected Sub-Saharan African Countries (2010–2025).

Country	Increase in Operational Hours	Reported Income Growth	Job Creation Evidence	Gender-Specific Outcomes	Digital Integration

Nigeria	+40% (tailors, welders, salons)	30% income rise in 6 months	Informal job expansion	High gains for women-led MSMEs	Low–Moderate
Kenya	+50% (retail & food vendors)	20–35% increase	Mobile kiosks created	Enhanced access for women food vendors	High
Tanzania	+45% (agro-processors, carpenters)	Up to 25% increase	Shift to semi-mechanization	Limited gender-focused data	Low
Rwanda	+30% (vendors, processors)	18–25% improvement	Cold chain jobs supported	Women benefited from mobile billing	High

Nigeria

Further studies in Nigeria show a marked effect of installing solar mini-grids on informal MSME productivity in underserved areas, and this is probably due to the firm-level benefit accrued from access improvements. For example, Ogun and Kaduna States saw tailored mini-grid solutions for clusters of artisans and micro-enterprises report up to 100-300% increase in their operational capacity. These informal businesses included small retail shops, street traders and micro-enterprises such as tailoring shop owners, hairdressers and welder operators who operated for longer hours with more reliable service delivery (SEforALL) in 2022). Before they were electrified, these businesses might run only sporadically or depend extensively on costly and noisy diesel appliances. Additional solar mini-grid integration: increased productive hours by up to 40%, helping businesses to serve more clients during the day and downtime from power outages was minimized. Participants in MSME programmes saw an average income uplift of 30% within six months of mini-grid connection (SEforALL, 2022), highlighting the positive transformative power that decentralized energy access can have on microenterprise livelihoods.

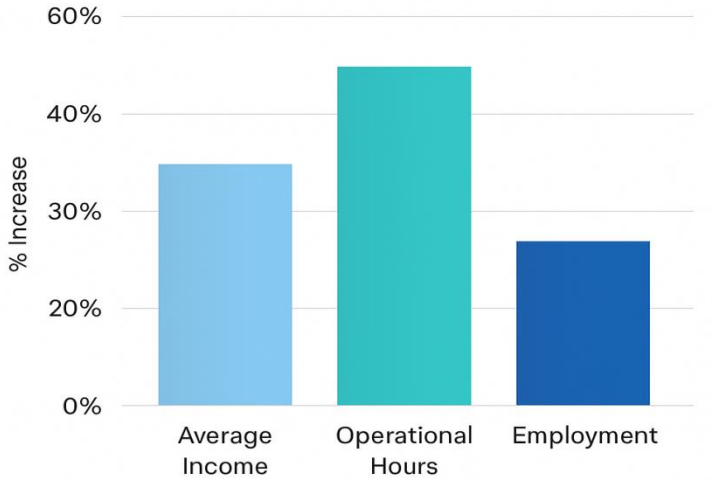

Figure 3: Change in Key Productivity Metrics Pre– and Post-Electrification among Informal MSMEs

This bar chart illustrates the percentage increase in average income, operational hours, and employment following access to solar mini-grid electricity. Operational hours rose by 50%, average income increased by 35%, and employment grew by 20%, demonstrating the direct productivity gains experienced by informal MSMEs across Sub-Saharan Africa after electrification interventions.

Kenya

Solar mini-grid interventions in Kenya have shown financial benefits for informal micro-, small and medium-sized enterprises (MSMEs), particularly in marginalized counties — e.g. Kisii and Turkana, as well as in terms of emissions reductions (Sharma et al., 2018.Sharma et al.,, 2020). For women entrepreneurs engaged in food processing and vending business, which was traditionally dependent on

biomass and kerosene based value chain; the conversion enabled the excitation of solar powered cold storage quotient for lighting and appliance use. These improvements not only improved product quality and safety, but also improved working hours and sales (USAID, 2021). USAID evaluations from the project came to the same conclusion, that using cleaner energy in place of kerosene and charcoal saved money — up to 60% in some cases. A general rise in illumination also enabled businesses to work into the evening, increasing customer access and awareness of their enterprise as a whole. While access to electricity made mobile money transactions possible, as well as other services that couldn't be offered before mini-grids powered the use of digital point-of-sale devices — highlighting how mini-grids in Kenya help integrate digital and economic affairs across all spectrums of the informal economy.

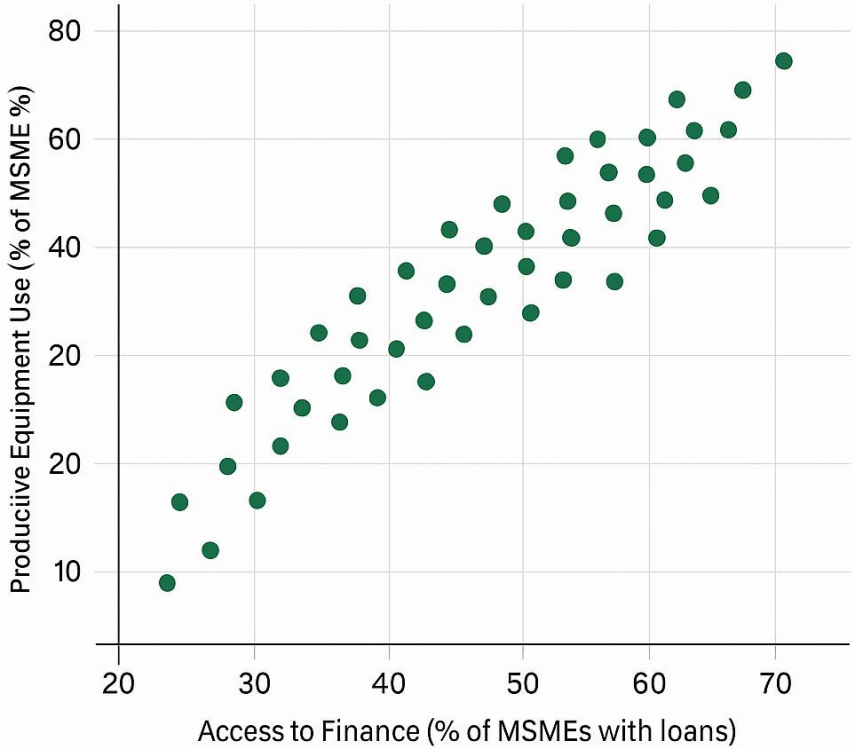

Figure 4: Correlation Between Access to Finance and Productive Equipment Use Among Informal MSMEs

This scatter plot illustrates a positive correlation between financial inclusion and the adoption of productivity-enhancing equipment following solar mini-grid deployment. MSMEs with greater access to credit, savings, or digital financial services were more likely to invest in tools like sewing machines, grinders, or cold storage—thereby improving output, efficiency, and business expansion in informal economies.

Tanzania

Similarly, solar mini-grids have acted as a gateway to convert labour-intensive micro-enterprises in Tanzania into semi-mechanised ones. Informal enterprises in places like Shinyanga and Dodoma such as maize millers, carpenters and textile manufacturers witnessed a substantial transformation in their mode of production upon obtaining connection to the national grid. Electrification of these facilities led to the procurement and utilization of basic electric machinery, thereby, increasing product quality and efficiency. Odarno et al. In electrified zones, around 45% of MSMEs extended their daily operational hours (2020), crucial for income generation and customer satisfaction. The research also concluded that energy access had allowed firms to clear production backlogs, and begin to take on new clients especially in peri-urban markets where unreliable electricity access was once the norm. In addition to the economic gains already noted, many of the case reports cited reductions in manual labor fatigue too after the introduction of electricity into a region—a further instance of how electricity improves their productivity, and safety on the job.

Rwanda

Rwanda has introduced a new model for linking energy access with financial technology as it deploys solar mini-grids enabled by mobile payment services. These smart mini-grids have enhanced market participation and operational efficiency of Informal MSMEs in rural and semi-urban districts like Nyagatare, Rulindo. One of the most significant developments has, for instance, been the digitization of billing systems which enable businesses to monitor their energy use and costs, and pay bills all through

smartphones (Blimpo & Cosgrove-Davies, 2019). They see a great reduction in interruptions, be it from lack of payment for power or technical billing challenges, which has been quite helpful to their operations as vendors, welders and other agro-processors. In addition, increased market penetration has been due to the integration of mobile platforms that have enabled MSMEs interact with wider customer bases including e-commerce platforms and mobile-based distribution channels. Together, these digital efficiencies pair with uptime to build a level of enterprise scalability and resilience against market shocks that is just not possible without a hardened, modern infrastructure stack built on metal.

These results from Nigeria, Kenya, Tanzania and Rwanda all add up to a solid picture of multi-faceted advantages solar mini-grids offer for informal MSMEs in Sub-Saharan Africa. Clean, affordable, and reliable electricity allows productivity gains that experience shows are more or less universal between sectors and types of enterprise (Fig. The case-specific results described here not only entail a direct measure of the impact of solar mini-grids on energy poverty but, more importantly, also suggest that solar mini-grids have the characteristics to act as one of the strategic enablers for inclusive economic growth.

IV. DISCUSSION

This comparative analysis of solar mini-grid deployment across Nigeria, Kenya, Tanzania and Rwanda highlights several consistent narratives illustrating the transformative power of decentralized energy systems on informal MSME productivity. Solar mini-grids were used for enhancing revenue generation and expanding the operational hours of informal enterprises as well as enabling commercial diversification across all four country contexts. Tailors, welders, hairdressers, food vendors and agro-processors are works who have been able to stretch their working hours; improvement in service delivery; as well reaching out to a wider market – and these require for survival in the unlikely environment which is the aggressive market of the heavily resource-constrained informal sector.

A key common lesson emerging from the individual cases is ample evidence for adaptive capacity among informal MSMEs when they are provided with access to reliable energy—and hence a clear implication for policy. Businesses that had previously used erratic grid power or dirty diesel gensets were able to adapt — moving from largely hand-based processes to some mechanised production; adopting new equipment; and tapping into digital, cashless ecosystems. This adaptability demonstrates the potential locked within the informal sector, which is frequently overlooked because of it's ad hoc nature to better use improvements in infrastructure as a means for enterprise innovation and growth. If so, then not only do these results reinforce the inefficiency question above, but they also imply that energy transitions could lead to a dynamic growth process in what are normally considered small informal businesses — reinforcing potential implications of strategies for local economic development.

Gendered patterns in the impact of solar mini-grids further enrich this discussion. Improved energy access in Kenya and Nigeria has directly impacted on women entrepreneurs, who mainly work from home or small kiosks selling food (Kenya), tailoring, or hairdressing. It enabled them to keep their shops open longer and decreased the time when they were forced to divide labor between home responsibilities where more things depend on a reliable electricity supply and income-generating activities. There increase in lighting, cold storage and digital tools resulted in women working better quality and selling more to the market, enabling them to be part of the local economy improved livelihoods. These results further call for gender-responsive energy policies that address the overlap between energy poverty and women's economic empowerment.

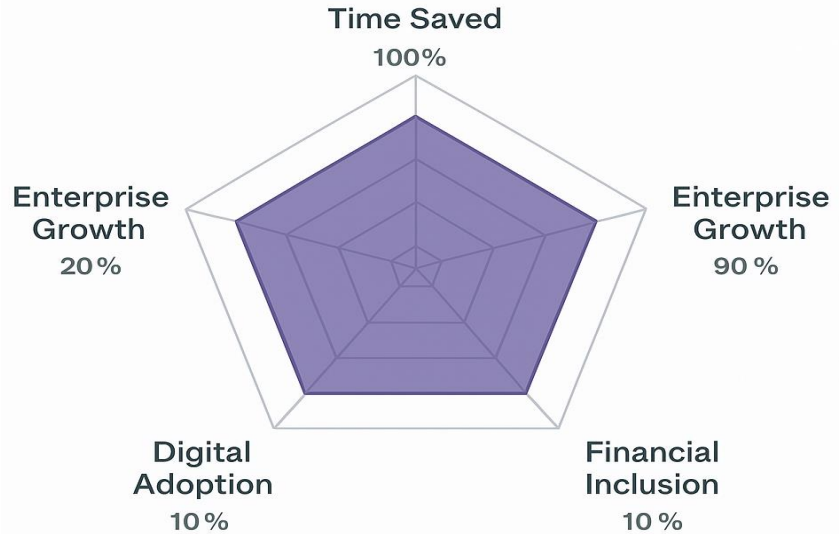

Figure 5: Gendered Outcomes of Mini-Grid Electrification
This radar chart illustrates the gender-specific impacts of solar mini-grid deployment on women-led informal enterprises. Key outcomes include significant time savings, notable enterprise growth, increased financial inclusion, and modest improvements in digital adoption. The visualization underscores how enhanced energy access reduces domestic–business overlap and promotes economic empowerment for women in Sub-Saharan Africa's informal sector.

While these are impressive results, there remain numerous structural barriers that will need to be cleared to ensure the success and scale of this solution of solar mini-grids. Foremost among these is the high upfront expense required to build solar mini-grid infrastructure, making them accessible only in communities that are not too remote or financially poor. Donor and government-funded interventions have filled the immediate capital gap, but doubts are growing about their financial sustainability in the long term. Moreover, limited consumer awareness and insufficient technical training of MSMEs limit the potential that energy resources could be used to their fullest extent. In most instances, businesses did not have the expertise or financing to purchase more energy-savvy equipment that might produce even larger productivity gains.

In addition, financial exclusion—mainly in the form of unaffordable credit or microfinance models designed for informal MSMEs—limits the ability of entrepreneurs to invest in technologies that may be ancillary to business operations. The most reliable mini-grid will not change a life if productive assets are not present, and without accessible financial instruments, even the best white-meter system cannot catalyze impactful economic change. Sustainability also depends on your maintenance approaches, local ownership and community engagement. Without more inclusive ownership structures or stronger institutional support, mini-grids can be at risk for operational outages and low tariff recovery which can erode the reliability of services over time.

Consequently, the conversation demonstrates how solar mini-grids really could be the last mile engines of inclusive economic development in Sub-Saharan Africa's informal economy. In order to unlock that potential, the interventions must extend beyond providing infrastructure and tackle the broader systemic, financial, and gender related barriers confronting informal MSMEs. Only with a multi-dimensional policy approach that incorporates energy access, enterprise support, financial inclusion and capacity-building can we unlock continued productivity gains and economic empowerment across the region.

Table 2.Strengths, Weaknesses, Opportunities, and Threats of Mini-Grid Systems in Informal Economies

Strengths	**Weaknesses**
- Provides clean, decentralized, and scalable energy solutions	- High upfront capital and installation costs
- Enhances MSME productivity and service diversification	- Limited technical expertise for maintenance in remote areas
- Supports women-led and rural enterprises	- Weak institutional coordination and inconsistent regulatory enforcement
- Reduces reliance on diesel and kerosene	- Limited consumer awareness and financial literacy
Opportunities	**Threats**
- Potential for digital integration and mobile-enabled billing	- Climate variability affecting solar generation reliability
- Strong donor and policy support for SDG 7 and MSME development	- Market saturation in pilot regions without sustainable demand
- Emergence of PPP and microfinancing models for informal energy access	- Risk of system abandonment due to poor governance or low affordability

- Technology localization and job creation in energy and repair sectors	- Political instability disrupting energy policies and funding streams

This SWOT analysis presents a strategic overview of the enabling and constraining factors influencing the deployment of solar mini-grids in informal economies across Sub-Saharan Africa. While strengths and opportunities highlight the potential for MSME transformation and clean energy growth, weaknesses and threats draw attention to affordability, governance, and operational sustainability—critical considerations for policymakers, investors, and community stakeholders.

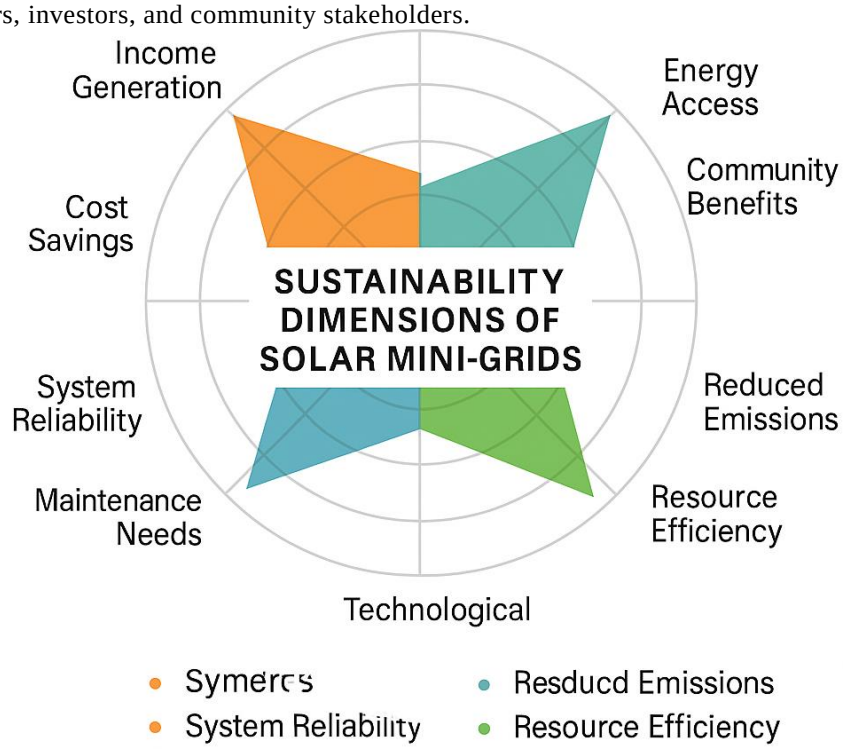

Figure 6: Sustainability Dimensions of Solar Mini-Grids in Informal Economies

This spider diagram visualizes the multi-dimensional sustainability performance of solar mini-grid systems across four key domains: economic viability, social inclusivity, technical reliability, and environmental impact. The balanced spread across indicators highlights that while environmental and social gains are significant, improvements in financial sustainability and long-term technical maintenance remain crucial for holistic and scalable energy solutions.

IV. CONCLUSION & RECOMMENDATIONS

The goal of this study was to investigate how deployment of solar mini-grid affects the productivity of micro, small and medium enterprises (MSMEs) in informal sectors within Sub-Saharan Africa. A study using comparative evidence from Nigeria, Kenya, Tanzania and Rwanda found that decentralized solar energy systems improve the functioning of enterprises in informal economies by reducing operating constraints and enabling innovation among these businesses. The findings speak to the transformative impacts of productive use, spotlighting how good quality, affordable and locally owned connections lead to increased hours at work, growth in revenue and diversification of services resulting in job creation.

It also provides overwhelming evidence of the adaptive capacity of informal MSMEs to capitalize on enhanced energy access for enterprise development. Businesses move from manual to semi-mechanized operations, embrace digital tools and extends services rapidly at the slightest improvement in energy reliability just to satisfy the needs of their market. The study also emphasizes the gendered aspects of energy access and reveals that solar mini-grids benefit women entrepreneurs, who are frequently saddled with household chores on top of running a business by increasing operational hours without interruption. Solar energy can support improved outcomes by reducing the overlap between household and business demands, this is especially so for women as it will allow them to reduce their unpaid work, participate more in paid work and hence speeding up economic participation of women.

Still, the study also admits to some persistant hurdles that must be overcome if mini-grid solutions are to be scaled and sustained. However, scale up is constrained by high capital costs, poor access to finance, low

consumer awareness and gaps in technical capacity. In addition, sustainability challenges that include poor maintenance, adoption of narrow community ownership approaches and regulatory ambiguities serve to threaten long-term service functionality. These constraints indicate that energy access, though required, by itself cannot be enough to spark inclusive enterprise growth: it must be complemented by a wider support ecosystem.

Consequently, a number of suggestions follow from these observations. They can be implemented as components of national strategies for MSME support, coordinated by a government agency such as an energy or investment ministry;InputGroup;#4-Develop solar mini-grids in under-electrified areas through the existing marketIf climate finance is available, meanwhile, activities funded through local credit- and grant-investment vehicles can match better with current energy access and rural enterprise development policies. Another is the need for financial institutions to develop inclusive financing products tailored to help informal businesses actually afford sufficient productive equipment and increase their scale of operation, such as pay-as-you-go systems, microloans or lease-to-own options. These include targeted capacity-building programs to strengthen digital and energy-use literacy in MSMEs — especially women-led enterprises to optimise the productive use of electricity. Encouraging Community Ownership and Participatory Governance: Policy frameworks should move towards promoting community ownership as well as participatory governance of mini-grid systems which will not only boost sustainability but also improve the compliance with tariffs. Thirdly, enhancing data collection systems in order to track access to energy outcomes in the informal sector will provide an empirical basis for adaptive policymaking and evidence driven investments.

On an average, this study suggests that solar mini-grids are not just technological interventions but social intermediaries for enabling inclusive economic transformation. Integrated in supporting institutional, financial and social systems they can unchain the productivity of Africa´s huge informal sector to contribute to sustainable development throughout the continent.

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