ENERGY ACCESS FOR SMALL ENTERPRISES SOURCING SOLAR MINI-GRID ELECTRICITY IN EASTERN DEMOCRATIC REPUBLIC OF CONGO

by

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Abstract

Access to electricity is widely considered essential to small enterprise performance and important to economic activity in low- and middle-income countries. However, the Democratic Republic of Congo (DRC) has disproportionately sparse electricity access, placing a significant burden on the country's small enterprises. Efforts are underway to expand electricity access in the DRC using decentralized solar mini-grids, but there is limited evidence of their effect on small enterprises. This study aims to address this gap in knowledge by examining electricity access from a recently developed solar mini-grid in a previously un-electrified neighborhood in the city of Goma in eastern DRC. We employ a case-control study design to assess electricity supply in a sample of 128 qualitatively similar small enterprises connected to a solar mini-grid by the private supplier, Nuru or the DRC's primary national grid supplier, the Société Nationale d'Électricité (SNEL). A set of five electricity access indicators are used to construct a detailed profile of small enterprise electricity access-based experiences. Using descriptive statistics and a series of logistic regressions in our analysis, we find that Nuru's solar mini-grid electricity provides significantly improved electricity in both quantity and quality relative to SNEL. Additionally, we find that even though Nuru-connected enterprises pay significantly more for their electricity, they report greater levels of perceived electricity affordability, value for money and overall satisfaction. Our results suggest that solar mini-grid electricity is a viable solution for improved enterprise electricity access in urban DRC.

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List of Abbreviations

CREDDA	Centre de Recherche sur la Démocratie et le Développement en Afrique
DRC	Democratic Republic of Congo
GDP	Gross Domestic Product
HDI	Human Development Index
MW	Megawatt
PV	Photovoltaic
SA	Société anonyme (limited company)
SARL	Société à responsabilité limitée (limited liability company)
SDG	Sustainable Development Goal
SNEL	Société Nationale d'Électricité
SSA	Sub-Saharan Africa
ULPGL	Université Libre des Pays des Grands Lacs
USD	United States Dollars

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Introduction

Access to electricity is widely considered essential to small enterprise performance and important to economic activity in low- and middle-income countries (Little, 1987; Tybout, 2000). However, access to electricity is exceptionally low in much of sub-Saharan Africa (SSA), placing significant constraints on human wellbeing and productive potential (Blimpo and Cosgrove-Davies, 2019). Recent efforts to address SSA's critical electricity needs have focused on using modern, sustainable technologies such as decentralized solar mini-grids. Yet there is limited evidence on their ability to meet the electricity needs of small enterprises in energy-poor areas of SSA. This study aims to address this gap in knowledge by understanding some of the effects of improved electricity access from a recently developed solar mini-grid in a previously un-electrified neighborhood of Goma in the Democratic Republic of Congo (DRC).

During the last decade, the global share of people without access to electricity has declined substantially. From 2010 to 2019, the total number of people without electricity decreased from 1.2 billion to 759 million (IEA, IRENA, UNSD, World Bank, WHO, 2021). However, access to electricity remains severely limited across much of SSA where an estimated 46.7% of the population has electricity, a level far below the average for low- and middle-income countries (88.2%) and well below the global average of 90.1% (World Bank, 2019). Accordingly, improving electricity access throughout SSA is a key development priority, with considerable attention to the potential for innovative energy solutions that meet electricity needs and prioritize sustainability. For example, the United Nations 2030 Agenda for Sustainable Development, and its resultant Sustainable Development Goals (SDGs) prioritize access to "affordable, reliable, sustainable, and modern energy" through SDG 7 (U.N. General Assembly resolution 70/1, 2015). Through its Sustainable Energy Fund for Africa, the African Development Bank has set ambitious goals to develop universal access to electricity while emphasizing the use of clean energy technologies (African Development Bank, 2020). Furthermore, the World Bank's Energy Sector Management Assistance Program

(ESMAP) is pushing for more comprehensive evaluations of electricity access to ensure that improved accessibility covers the principal requirements for enterprise productivity (Mikul and Nicolina, 2015).

The DRC is one of the least electrified countries in SSA. Approximately 19.1% of the country's population has access to electricity (World Bank, 2019). The DRC is a large and almost entirely landlocked country with a population exceeding 89 million people (World Bank, 2020c). By these estimates, more than 72 million people do not have access to electricity. Moreover, The DRC is a low-income country with a weak economy. Per capita Gross Domestic Product (GDP) in the DRC is $544 United States Dollars (USD), placing it near the bottom of countries by GDP rank (World Bank, 2020a). Additionally, an estimated 76.6% of the country's population lives below the international poverty line of $1.90 USD per day (United Nations Development Programme, 2020).

The DRC's low electrification rate is especially problematic for the country's small non-growth enterprises such as convenience stores, hairdressers, and electronics repair shops. This is evident in the results of the World Bank's 2013 Enterprise Survey, which cites electricity as the most common obstacle for small enterprises in the DRC, followed by access to finance and political instability. Further results from the survey indicate that 88.3% of small enterprises reported experiencing power outages numbering 12.2 outages on average in a typical month. Additionally, 56.6% of small enterprises report owning or sharing a generator and obtaining on average 39.1% of their total electricity from it (World Bank, 2013).

In eastern DRC, efforts are currently underway to expand electricity access through the installation of several decentralized solar mini-grids. As these efforts take shape, it is important to understand how solar mini-grids affect small enterprises and whether they have the capacity to meet enterprise electricity needs. Using a set of five electricity access indicators, this study builds a detailed profile on the energy experiences of small enterprises obtaining electricity from a newly implemented solar mini-grid in the city of Goma. These data give valuable insights into the existing energy context for small enterprises as well as further recommendations for improved electricity access in the DRC.

Literature Review

Electricity Access and Small Enterprise Performance in Low- and Middle-Income Countries

There is much discussion on electricity access for small enterprises in low- and middle-income countries in the academic literature. The effects of electricity access have generally been evaluated by exploring transitions from no prior electricity to new electricity sources or switching from less reliable to improved electricity. In addition, the outcome effects of electricity access have typically been analyzed using several financial and non-financial performance-based indicators, yielding a range of results.

Several studies have found limited effects of electricity access on small enterprise financial performance, while improvements in non-financial performance indicators were often observed. For example, research by Peters et al. (2011) found that electricity access in rural Benin resulted in the development of electricity-reliant enterprises but found no improvement in the profits of existing enterprises. In addition, a study by Pueyo and DeMartino (2018) used a difference-in-difference approach to assess the effect of solar mini-grids on micro-enterprise performance in rural Kenya and found that enterprises stayed open longer, but profits did not increase significantly. Similarly, Vernet et al. (2019) examined the effect of electrification in rural Kenya and found that electricity access had improved enterprise growth and development, but an increase in incomes was not observed.

Some studies have demonstrated that evaluating the impacts of electricity access among heterogeneous samples of different enterprise types and locations yields less substantial results than in more homogenous samples. For example, Grimm et al. (2013) performed a study of informal enterprises across several West African cities and found that electricity access had negligible impacts on enterprise financial performance; however, in a sector-specific subsample of tailoring enterprises, results showed that electricity access contributed to the uptake of new machinery. Obeng and Evers

(2010) found a similar result from rural micro-enterprises connected to solar photovoltaic (PV) systems in Ghana. Their work showed that extended lighting hours from solar PV electricity were significantly associated with increased incomes among merchandise stores but not among other types of enterprises.

Several studies have also shown a more favorable relationship between electricity access and enterprise financial performance. For example, Rao (2013) found that access to improved electricity supply was associated with higher incomes among non-farm enterprises in India. Likewise, Olanrewaju and Olanrewaju (2020) discovered that both access to electricity and the duration of electricity availability had a significant and positive effect on the profitability of women-owned micro-enterprises in rural Nigeria. Furthermore, Shibia and Barako (2017) determined that access to electricity was among several factors contributing to small enterprise growth in Kenya.

In addition to general accessibility, studies of existing supply quality and the transition to improved electricity reveal that many existing supplies' poor quality also affects small enterprise performance. For example, Arnold et al. (2008) found a significant relationship between enterprise performance and electricity reliability in a sample of manufacturing enterprises across SSA. Furthermore, in a study of small enterprises in Addis Ababa, Ethiopia, Ahadu (2019) showed that frequent power outages resulted in machinery failure and lagged enterprise performance. A similar result from Indonesia found that power outages had considerably decreased labor productivity (Falentina and Resosudarmo, 2019).

These results illustrate the complexity of assessing the effects of electricity access on small enterprise performance. The academic discussion may question the importance of electricity access if changes in enterprise profitability are nominal. Nevertheless, evidence from these studies points toward several key non-financial improvements, such as longer operational hours and the acquisition of new assets, which are important indicators to consider for enterprise performance. Moreover, evidence from the electricity reliability-performance nexus suggests that supply quality is an added critical factor to consider for small enterprise performance.

Altogether, the range in results illustrates that the effects of electricity are highly context-driven. Factors such as location, enterprise sector, and non-financial outcomes of interest influence variation across results, making any generalizable assertions on electricity access for small enterprises in low- and middle-income countries difficult to make.

Looking Beyond Financial Performance

Financial performance indicators remain common in the literature on electricity access for small enterprises in low- and middle-income countries. However, several studies have expanded on performance-based outcomes of interest, looking beyond enterprise-level performance to examine some of the broader effects of enterprise electricity access, such as impacts on local communities and overall human wellbeing. For example, research by Kooijman-van Dijk (2012) looked at electricity access among rural enterprises in the Himalayas and found that although incomes remained low, overall human wellbeing was improved through increased levels of comfort and better working conditions. Similarly, Neelsen and Peters (2011) examined electricity access and enterprise performance in rural Uganda and found that electrification positively affected community wellbeing through people moving in from outside areas, but enterprises had no increased profits or worker compensation. Additionally, a study examining the impacts of electricity on rural small enterprises in Bolivia, Tanzania, and Vietnam found that access to electricity had substantial impacts on community wellbeing as small enterprises could offer improved products and services; however, financial poverty reduction through higher enterprise incomes was not observed (Kooijman-van Dijk and Clancy, 2010). Lastly, a study by Nuru et al. (2021) found a series of co-benefits, including jobs and improved business opportunities, from the installation of a solar mini-grid system in rural Ghana. These studies illustrate that small enterprise electricity access has a wide range of impacts that may extend to the level of the individual and the wider community.

Electricity Uptake and Willingness to Pay

A considerable body of research has also assessed the uptake and willingness to pay for electricity among small enterprises in low- and middle-income countries. Willingness to pay is of particular concern as the high cost associated with electricity may pose a barrier for some small enterprises. In some cases, high electricity costs have been shown to reduce enterprise productivity (Eifert et al., 2008), and in a study on the uptake of grid-based electricity, Pelz et al. (2021) found that lower enterprise wealth was a reason for non-uptake among small enterprises in rural India.

However, many studies indicate that small enterprises take up improved electricity when given the option of more reliable electricity. For example, in a study examining the uptake of solar mini-grid electricity in grid-electrified villages in India, Sharma et al. (2020) found that enterprises sourced improved mini-grid electricity when grid-based electricity was deemed unreliable. Similarly, Ganguly et al. (2020) discovered that enterprises in rural India switched to mini-grid electricity as their primary electricity source due to the improved supply quality.

Many studies assessing the willingness to pay for improved electricity follow a similar pattern. Akpan et al. (2013) examined electricity access for micro-enterprises in rural Nigeria and showed that enterprise owners understand the positive impacts of electricity and are thus willing to pay for electricity when deemed affordable. Deutschmann et al. (2021) found that small enterprises in Senegal were willing to pay more for improved electricity quality without power outages. Likewise, Ghosh et al. (2017) found that small enterprises in India were willing to pay more to obtain improved electricity quality, and in Nepal, Niroomand and Jenkins (2020) showed that the willingness to pay for improved electricity is far greater among small enterprises than households.

Evidence suggests that the uptake of improved electricity and the willingness to pay are closely tied to supply quality and affordability. Although some studies have shown that high electricity costs may pose a constraint, considerable research suggests that small enterprises are generally willing to pay to take up electricity, especially in cases involving improved supply quality.

Complementary Factors for Small Enterprise Electricity Access

Much of the existing literature has focused directly on enterprise outcomes tied to electricity access. However, several studies point out that in addition to electricity access, small enterprises require complementary factors such as improved knowledge and markets to maximize their electricity usage and retain connectivity. For example, Terrapon-Pfaff et al. (2018) found that energy is only one of several critical inputs alongside capacity building, information, and market access necessary for socio-economic development. Likewise, results from a qualitative study of energy usage among enterprises in Kenya demonstrate that insufficient knowledge on energy for improved enterprise operations inhibits enterprises from maximizing their electricity access (Fingleton-Smith, 2020). These studies suggest that one or several partially mediating variables may be absent from assessing the full effects of electricity access on enterprise performance.

There is evidence that electricity supplier-consumer dynamics may play a role in strengthening the effect of essential mediating variables. For example, Ogeya et al. (2021) found that integrating user experiences into the business model of a solar mini-grid system in Tanzania is crucial to mitigate disuse and prevent energy stacking.[1] Such evidence points out the impact of supply-side factors that improve electricity access and energy-use behaviors.

Overall, these results demonstrate several contexts in which small enterprises can maximize their electricity access through complementary factors and that supply-side supports are critical for optimal electricity usage and connection retention.

Electricity Access in the DRC

It is important to point out that the DRC's current state of electricity generation and distribution is unique and deeply intertwined with the country's political and economic narrative. Electricity access in the DRC is exceedingly scarce and is generally obtained from myriad sources but is dominated by hydro-power generation (International Renewable Energy Agency, 2021). Non-grid-

[1] Energy stacking is a practice whereby multiple different energy sources are used to meet daily energy needs.

based electricity is commonly obtained via freestanding electricity sources such as liquid-fuel generators, standalone solar panels, and other makeshift energy solutions; however, information on their proliferation and use is sparse.

The DRC's grid-based electricity is mainly generated and distributed by the Société Nationale d'Électricité (SNEL), a parastatal national utility that primarily generates hydro-electric power, supplying the DRC's large urban centers and industries (Kusakana, 2016). SNEL was established in 1970 as part of an ambitious national utility project that consolidated and reorganized existing public and private energy suppliers into a centralized government-controlled utility (Lukamba-Muhiya and Uken, 2006). Since 1978 SNEL has operated as a public company under Law 78/002, later becoming a limited liability company (société à responsabilité limitée – SARL) in 2009 and a limited company (société anonyme – SA) in 2014 with the DRC state as the sole shareholder (World Bank 2020b).

SNEL has become increasingly unreliable with deteriorating energy infrastructure due to substantial non-investment and highly disreputable leadership (Tshitenge, 2019). This particularly affects the DRC's urban centers, as inadequate energy infrastructure exacerbates the high rates of urban poverty and low levels of economic productivity (World Bank, 2018). This problem has been heightened for decades because SNEL has operated as the DRC's sole official electricity supplier due to federal laws enabling non-competition; however, this changed in 2014 when the federal government passed Law 14/011, which promotes the expansion of electricity into unelectrified areas and encourages competition within the national energy sector (Leganet, 2014). Since this change, several new electricity supply services have emerged, including Nuru, which has focused on developing the DRC's solar-electric potential throughout the country.

Nuru, formerly Kivu Green Energy, entered eastern DRC's energy market in 2015, intending to provide high-quality, renewable electricity to low-income communities using solar mini-grids. In June 2017, Nuru began commercial operations of its first project, a 0.055MW solar mini-grid including a PV system, battery storage, and diesel genset capacity in the city of Beni. In February

2020, Nuru launched a 1.3MW solar mini-grid (PV, battery storage, and diesel genset) in the city of Goma, and in June 2021, Nuru expanded further with two solar mini-grids totaling 0.338MW (PV, battery storage, and diesel genset) in the cities of Faradje and Tadu.[2] SNEL's presence, alongside the recent emergence of solar mini-grid electricity in Goma, allows for a suitable comparison between two different modes of electricity service provision for small enterprises.

Current Literature Gaps

Previous research on electricity access for small enterprises in low- and middle-income countries has generally focused on various enterprise performance indicators, electricity uptake and willingness to pay, and complementary factors contributing to optimal electricity usage. Although some studies have examined enterprise electricity access from solar mini-grids, the literature on this topic remains sparse. Additionally, considerable research has focused on electricity access for small enterprises in rural areas, with less attention to urban settings. Lastly, there is limited information on electricity access in the DRC, particularly in the peer-reviewed scientific literature. This study addresses some of these gaps by examining solar mini-grid electricity access for small enterprises in urban eastern DRC.

Figure 1. Aerial view of Nuru's 1.3MW solar mini-grid system in Goma

Image credit: Zion Photographie

[2] Information about Nuru's operations was obtained through personal communication with the company from November 2020 through April 2022.

Methods

Study Design

We examine electricity access for small enterprises that have recently begun sourcing electricity from Nuru's 1.3MW solar mini-grid in Goma, DRC. A case-control design is used to observe electricity access among two independent samples of enterprises; cases are enterprises connected to Nuru, and controls are enterprises connected to SNEL. The longstanding presence of SNEL as the DRC's primary source of grid-based electricity makes it an ideal candidate for a baseline control from which to assess Nuru. We compare cases and controls in four qualitatively matched neighborhoods in Goma. Enterprises in the previously un-electrified neighborhood of Ndosho now rely on Nuru for electricity, and enterprises in the neighborhoods of Mabanga Sud, Mugunga, and Mapendo rely on SNEL. The neighborhoods in this study were selected because of their similar characteristics of urbanicity and commercial activity.

This study was conducted in partnership with the Université Libre des Pays des Grands Lacs (ULPGL) in Goma and the Centre de Recherche sur la Démocratie et le Développement en Afrique (CREDDA), a research center on democracy and development in Africa housed at ULPGL. This study was reviewed and approved by the University of Michigan Institutional Review Board (IRB) and the Ethics Committee at ULPGL. We declare no conflicts of interest.

Study Area

We conducted this study in the city of Goma in eastern DRC. Goma is a large city in North-Kivu province with an estimated population exceeding 900,000 people (Institut National de la Statistique: Direction Provinciale du Nord-Kivu, 2015). Goma sits along the shore of Lake Kivu to the south, Virunga National Park to the north and shares an international border with the city of Gisenyi, Rwanda to the east. Over the past decades, North Kivu has been embroiled in a complex regional conflict propped up by political instability and armed group activity. As a result, urban insecurity and crime in Goma are high (Hendriks and Büscher, 2019). Despite the social and political precarity, Goma is marked by its overall resilience, active trade with Rwanda, and considerable economic potential (Vlassenroot and Büscher, 2013).

Goma is comprised of eighteen neighborhoods, four of which are part of this study: Ndosho, Mabanga Sud, Murara, and Mapendo. Ndosho is a densely populated neighborhood with peri-urban and urban characteristics on the periphery of Goma, approximately six kilometers from the city center. Mabanga Sud, Murara, and Mapendo exhibit urban characteristics and are located near Goma's city center. Ndosho had no prior grid-based electricity until Nuru's solar mini-grid installation. Household-level data from Goma report pre-Nuru electrification rates of 3% in Ndosho (Vinck et al., 2017). This is presumably non-grid-based electricity obtained from freestanding electricity sources such as liquid-fuel generators, standalone solar panels, and other makeshift electricity sources. The other three neighborhoods with access to SNEL's electricity report electricity access rates of 67% in Mabanga Sud, 89% in Murara, and 55% in Mapendo (Vinck et al., 2017). However, these data capture overall electricity access and should not be assumed to be solely from SNEL. The neighborhoods of Mabanga Sud, Murara, and Mapendo were selected as control sites for this study because their characteristics of urbanicity and commercial activity are very similar to those in Ndosho. This resulted in a sample of similar enterprise types with qualitatively matched enterprise-level characteristics (see Table 1 and Table 2).

Sampling and Data Collection

The data for this study were collected by first selecting several road segments with known commercial activity in each neighborhood. Then, along each road segment, small enterprises were randomly selected for sampling using a coin flip as a randomization tool. This procedure required survey enumerators to go to each small enterprise on a road segment and sample the enterprise if the coin flip was heads or move on to the next enterprise if the coin flip was tails. If an enterprise owner declined to be sampled, the procedure was repeated at the next enterprise. This procedure was performed until a total sample of 128 small enterprises was obtained. The sample included (N = 52) small enterprises sourcing electricity from Nuru and (N = 76) small enterprises sourcing electricity from SNEL. The appropriate sample size for this study was determined by a series of power analyses done prior to sampling.

Survey responses were collected by a group of three enumerators from ULPGL using KoBo Toolbox[3] for data entry. Responses were only obtained from enterprise owners after they had confirmed that their electricity is sourced from either Nuru or SNEL, and that the enterprise had less than ten employees, including the enterprise owner.[4] Table 1 presents a summary of the enterprises sampled and their representative proportions within the sample. The majority of small enterprises are engaged in the sale of small goods and the provision of various services. Print/copy shops, hairdressers and convenience stores made up more than half of the total sample.

Table 1. Summary of enterprise types sampled

Enterprise type	**Proportion of the sample**		
	Total (N = 128)	**Nuru (N = 52)**	**SNEL (N = 76)**
Print/copy shop	22.7%	17.3%	26.3%
Hairdresser	18.0%	19.2%	17.1%
Convenience store	15.6%	15.4%	15.8%
Food/drink sales	11.7%	13.5%	10.5%
Phone charging	10.2%	15.4%	6.6%
Music transfer	4.7%	1.9%	6.6%
Tailor/sewing shop	3.9%	1.9%	5.3%
Electronics/appliance repair	2.3%	3.8%	1.3%
Mill	2.3%	5.8%	-
Pharmacy	2.3%	1.9%	2.6%
Bakery	1.6%	-	2.6%
IT service	1.6%	-	2.6%
Jewelry store	0.8%	-	1.3%
Publisher	0.8%	1.9%	-
Shoe repair	0.8%	1.9%	-
Sports betting	0.8%	-	1.3%

Due to rounding some columns may not add to 100.

[3] KoBo Toolbox is a digital survey platform for humanitarian data collection.

[4] The definition of a small enterprise varies in the literature. It is generally defined by the number of employees, total assets or revenue. There is sometimes an additional distinction made between micro and small enterprises based on these metrics. For this study, the focus is on enterprises with less than ten employees as these are commonplace in Goma.

Outcome Measures

We asked respondents to answer a series of questions about their electricity access, measured using five electricity access indicators: 1) small enterprise electricity usage and availability, 2) electricity quality and reliability, 3) electricity supplier communications, 4) electricity affordability, and 5) overall satisfaction and perceived value. These indicators were selected based on ESMAP's Multi-Tier Framework for evaluating electricity for productive uses (Mikul and Nicolina, 2015). Additionally, data on a range of covariates were collected, including general enterprise operations and demographic data on the enterprise owner. We use enterprise operational characteristics and demographic data on the enterprise owner to confirm that baseline characteristics were similar across our case and control groups of small enterprises.

Survey Design

Most of the survey comprised questions with continuous numeric responses and Likert-scale questions with the option for one best-fit response. No open-ended questions were used other than to indicate the type of enterprise. The survey was written in English and translated into French and Swahili by a group of translators at ULPGL. The Swahili translation included the use of the regional Swahili dialect. In Goma, it is common for individuals to speak either French, Swahili or both. It is also common to use select terms across both languages. Thus, in order to accommodate multiple language preferences, the survey included each question and response option in French and Swahili. Additionally, survey enumerators were trained on the research objectives and could provide clarifying information if a question may have been unclear. The survey questions and response options were read out loud by the enumerators, who also documented responses in KoBo Toolbox.

Analysis

Our study examines electricity access indicators among similar groups of small enterprises sourcing electricity from two different sources: Nuru and SNEL. The analysis includes two components: a descriptive analysis that examines question responses across all five electricity access indicators and a series of logistic regression models that more closely examine the relationships between electricity supply, affordability, and enterprise operations. The small enterprises outlined in Table 1 are the unit of analysis for this study, and are compared as a single group based on electricity access from either Nuru or SNEL. Thus, any conclusions drawn from this study are not specific to any single enterprise or enterprise type.

Survey Non-Response

Due to the sensitive nature of some survey questions, respondents had the option to refuse an answer. Overall, non-response was not a significant problem for most of the survey. However, questions about enterprise revenue, general enterprise expenses, and electricity expenses had many non-responses. In numerous observations, a respondent agreed to disclose one or two values related to revenue and expenses but not all three. Because of a large number of non-responses to questions about enterprise revenue, general enterprise expenses and electricity expenses, we divide the data for this report into two groups for analysis. Data Group A (N = 128) comprises all survey response data except for information on enterprise revenue, general enterprise expenses, and electricity expenses. Data Group B (N = 93) is reduced to include all survey data whereby responses to enterprise revenue, general enterprise expenses, and electricity expenses are also all present. Group B contains (N = 38) observations for Nuru and (N = 55) observations for SNEL.

Descriptive Statistics

Our descriptive analysis compares survey responses between Nuru- and SNEL-connected enterprises. We use independent t-tests for two samples for continuous response variables, applying the Welch approximation for unequal variances. We report the mean and standard deviation in parentheses for all continuous variables. In addition, we use chi-squared tests with Yates' continuity correction for categorical response variables. We report the proportion of responses for each categorical variable.

The descriptive analysis first examines baseline enterprise characteristics and demographic data on small enterprise owners. These data are displayed in Table 2 and include data from the full sample (Group A). We also perform a separate analysis of enterprise financial characteristics, which is displayed in Table 3 and includes data from Group B. The remaining tables of descriptive analysis (Table 4 through Table 8) focus on the five electricity access indicators, each of which uses data from the full sample (Group A).

Regression Analysis

The second part of the analysis includes a series of logistic regression models that more closely examine the association between indicators of electricity access and electricity source (Nuru or SNEL) while controlling for enterprise-level characteristics. The logistic regression models use four survey questions that have each been recoded to binary dependent variables. In the survey, these questions initially obtained responses on a three-point scale with possible responses of "agree," "indifferent," or "disagree." For the logistic regression, the answers have been modified such that "agree" is equal to one and all other responses are equal to zero. The following four questions have been modified in this way and are included in the regression models: 1) "Do you have enough electricity to operate your enterprise successfully," 2) "Is the voltage level of your electricity strong enough to operate your enterprise successfully," 3) "Is your electricity supply affordable for your enterprise," and 4) "Does the cost of electricity limit your enterprise operations?" The first two questions focus on understanding the overall electricity supply quantity and quality. The first question measures the sufficiency of the overall electricity supply and the second question focuses in on the supply voltage. These questions are used in the regression models to examine the quantity and quality of the electricity supply. The third and fourth questions focus on the affordability of electricity. Question three assess the general perception of electricity affordability and question four assesses whether the overall cost of electricity is perceived to place any limits on enterprise operations. We report odds ratios to examine the likelihood of agreeing with each of the four questions used as dependent variables.

In total, three regression models are used to examine the aforementioned dependent variables and each model uses data from Group B. The first model combines Nuru- and SNEL-connected enterprises in the same model with an additional control for the electricity supplier (N = 93). Models two and three decompose the data to examine responses based on the electricity supplier. Model two focuses only on Nuru-connected enterprises (N = 38) and model three focuses only on SNEL-connected enterprises (N = 55).

Six control variables are used in each model with the exception of model one, which has the additional control for electricity supplier. The control variables were selected to include several key enterprise operations variables, financial and income-related variables, and enterprise owner demographic characteristics. Due to the small sample size of Group B, categorical control variables with more than two characteristics were all converted to binary variables. The regression models are as follows with control variables described below:

Model 1: $Ln\left(\frac{P}{1-P}\right) = \beta_0 + \beta_1(ES) + \beta_2(NI) + \beta_3(EE) + \beta_4(FY) + \beta_5(SI) + \beta_6(ED) + \beta_7(NE) + \varepsilon_i$

Models 2 and 3: $Ln\left(\frac{P}{1-P}\right) = \beta_0 + \beta_1(NI) + \beta_2(EE) + \beta_3(FY) + \beta_4(SI) + \beta_5(ED) + \beta_6(NE) + \varepsilon_i$

- *Electricity Source (ES):* A control variable that is only used in model one. Results are for Nuru-connected enterprises. SNEL-connected enterprises are the omitted factor.
- *Net Income (NI):* An approximation of net income in a normal month determined by subtracting enterprise expenses from enterprise revenues. Values are in USD.
- *Electricity Expenses (EE):* Reported electricity expenses in a normal month. Values are in USD.
- *Founding Year (FY):* An approximation for the year in which the enterprise was established. This was initially a categorical response variable with four categories (see Table 2). It has been reduced to a binary variable in which the results display enterprises founded within 2020 and 2021 and the omitted factor includes enterprises founded before 2020.

- *Secondary Income (SY):* A binary variable indicating whether an enterprise owner has a secondary income-generating job in addition to the enterprise in question. Displayed responses indicate that the enterprise has a secondary job; the omitted factor is for no secondary job.
- *Education Level (ED):* This variable indicates the highest level of education obtained by the enterprise owner. The initial response options included four categories (see Table 2). These were reduced to binary options in which the displayed response includes enterprise owners who have completed university-level education and the omitted factor includes all other educational levels.
- *Number of Employees (NE):* A variable indicating the approximate number of employees at the enterprise. This variable initially included three response categories (see Table 2) and were reduced to a binary variable for the model. In this case, the results indicate responses from enterprises with two or more employees (up to nine total). The omitted factor indicates one employee, the enterprise owner.

For each regression model we calculate odds ratios for our outcome variables to delineate associations between question response and our control variables. Standard errors are displayed in parentheses.

Results

Small Enterprise Characteristics

Summary statistics of small enterprise operations and demographic data of the enterprise owners are provided in Table 2. Overall, small enterprises exhibit similar characteristics in both groups. The majority of Nuru-connected enterprises (86.5%) have had their electricity connection for one year or less. The 13.5% of Nuru-connected enterprises that reported an electricity connection for more than one year are likely among the first adopters of Nuru after it began its service in Ndosho in February, 2020. More than half of SNEL-connected enterprises, 60.5%, have had their grid connection for more than one year and 36.8% reported having their grid connection for one year or less.

Prior to obtaining grid-based electricity, 38.5% of Nuru-connected enterprises reported using a generator, 26.9% reported using a solar panel, and 3.8% reported using other types of electricity sources. Among Nuru-connected enterprises, 30.8% indicated no prior source of electricity. Of the SNEL-connected enterprises, 51.3% reported using a generator prior to obtaining their grid connection, 22.4% reported using a solar panel and 1.3% reported using other electricity sources. Additionally, 25.0% of SNEL-connected enterprises reported no prior electricity before their grid connection.

Further enterprise characteristics indicate that the majority of small enterprises were established within the last decade. Based on sample proportions, Nuru-connected enterprises appear to be slightly younger than SNEL-connected enterprises. Nearly all enterprises in both groups are sole proprietorships with very few enterprises indicating that they are managed with partners (e.g., operating as a limited liability company). Few enterprises reported having more than five employees, with 2-4 employees, or one employee (the enterprise owner) being most prevalent in both samples. Enterprises in both groups report similar numbers of average daily customers and days open per month; however, Nuru-connected enterprises reported significantly longer average daily hours open. Demographic data of the enterprise owners showed no differences in the distributions of age, gender, and level of education. The majority of enterprise owners in both groups had completed either secondary school or university level education. Furthermore, a considerable proportion of enterprise owners in both samples reported having a second income-generating job.

Table 2. Enterprise characteristics

	Total (N = 128)	Nuru (N = 52)	SNEL (N = 76)	P-value
Time using Nuru or SNEL				0.000***
One year or less	57.0%	86.5%	36.8%	
More than one year	41.4%	13.5%	60.5%	
Refuse to answer	1.6%	0.0%	2.6%	
Electricity before Nuru or SNEL				0.459
Generator	46.1%	38.5%	51.3%	
Solar panel	24.2%	26.9%	22.4%	
Other	2.3%	3.8%	1.3%	
No	27.3%	30.8%	25.0%	
Number of employees				0.293
One (enterprise owner)	34.4%	42.3%	28.9%	
2 - 4	60.9%	53.8%	65.8%	
5 - 9	4.7%	3.8%	5.3%	
Enterprise structure				0.160
Sole proprietorship	93.8%	98.1%	90.8%	
Managed with partners (SARL/SAC/SNC)	2.3%	1.9%	2.6%	
Other	3.9%	0.0%	6.6%	
Year enterprise was founded				0.119
Before 2010	9.4%	9.6%	9.2%	
2010 - 2014	25.0%	15.4%	31.6%	
2015 - 2019	41.4%	42.3%	40.8%	
2020 - 2021	24.2%	32.7%	18.4%	
Enterprise building owned or rented				0.323
Owned	18.8%	25.0%	14.5%	
Rented	77.3%	71.2%	81.6%	
Refuse to answer	3.9%	3.8%	3.9%	
Daily number of customers				0.431
Mean (SD)	31.1 (19.2)	29.5 (20.0)	32.2 (18.6)	
Daily hours open				0.012**
Mean (SD)	13.2 (2.4)	13.8 (2.6)	12.7 (2.2)	
Days open per month				0.503
Mean (SD)	28.4 (3.0)	28.6 (3.3)	28.2 (2.8)	
Enterprise owner age in years				0.213
Mean (SD)	33.5 (9.1)	32.3 (9.4)	34.3 (8.8)	
Enterprise owner gender				0.936
Female	39.8%	38.5%	40.8%	
Male	60.2%	61.5%	59.2%	

Table 2. Continued

	Total (N = 128)	Nuru (N = 52)	SNEL (N = 76)	P-value
Enterprise owner highest level of education				0.210
No education	2.3%	3.8%	1.3%	
Primary school	8.6%	9.6%	7.9%	
Secondary school	60.2%	67.3%	55.3%	
University level	28.9%	19.2%	35.5%	
Enterprise owner secondary income source				0.517
Yes	30.5%	34.6%	27.6%	
No	69.5%	65.4%	72.4%	

***p < 0.01, **p < 0.05, *p < 0.1.
P-value for categorical variables: Pearson's Chi-squared test with Yates' continuity correction.
P-value for continuous variables: Welch's two-sample t-test.
Standard deviation for continuous variables in parentheses.
Due to rounding some columns may not add to 100.

Small Enterprise Financial Data

A summary of enterprise financial information is displayed in Table 3. The data in this table are obtained from data Group B – the data subset whereby enterprise revenue, expenses, and electricity expenses were all provided by the survey respondent. All values are reported estimates for a normal month of enterprise operations and are given in USD. The data indicate that enterprise revenue and net income are on average significantly higher among SNEL-connected enterprises; however, large standard deviations among SNEL-connected enterprises indicate a much wider range of revenue and incomes compared to Nuru-connected enterprises. Whereas total enterprise expenses are not significantly different, results show that electricity expenses are significantly higher among Nuru-connected enterprises, indicating a much larger proportion of total expenses going to electricity among Nuru-connected enterprises.

Table 3. Enterprise finances (Group B)

	Total (N = 93)	Nuru (N = 38)	SNEL (N = 55)	P-value
Monthly revenue (USD)				0.009***
Mean (SD)	374.6 (739.9)	168.9 (138.3)	516.6 (932.3)	
Monthly expenses (USD)				0.190
Mean (SD)	85.9 (169.6)	61.7 (73.2)	102.5 (211.3)	
Monthly net income (USD)				0.005***
Mean (SD)	288.7 (612.5)	107.2 (82.4)	414.1 (771.6)	
Monthly electricity expenses (USD)				0.000***
Mean (SD)	12.7 (9.9)	17.9 (9.9)	9.1 (8.2)	

***p < 0.01, **p < 0.05, *p < 0.1.
P-value for continuous variables: Welch's two-sample t-test.
Standard deviation for continuous variables in parentheses.

Electricity Usage and Availability

Electricity usage and availability were assessed using self-reported estimates of the hours of electricity used and available on any given day. Further questions were asked to determine the sufficiency of the existing electricity supply. These data are summarized in Table 4. The results indicate that Nuru-connected enterprises reported receiving on average 22.2 hours of electricity each day and SNEL-connected enterprises reported receiving 5.4 hours on average. In a similar pattern, Nuru-connected enterprises report using 15.7 hours of electricity on average and SNEL-connected enterprises report using 5.9 hours on average. SNEL-connected enterprises reported using slightly more hours of electricity than is available to them. This is likely a reporting error, but it does indicate that SNEL-connected enterprises are on average using all of their available electricity.

When asked if an enterprise has enough electricity to operate successfully, 80.8% of Nuru-connected enterprises and 13.2% of SNEL-connected enterprises agreed. However, when asked if enterprises would like to use more electricity, the majority of both Nuru and SNEL-connected enterprises agreed; 71.2% of Nuru-connected enterprises and 60.5% of SNEL-connected enterprises reported a preference for more electricity. Overall, Nuru-connected enterprises are more likely to report having enough electricity relative to SNEL-connected enterprises, however, the general preference for more electricity is similar across both groups.

Table 4. Electricity usage and availability

	Total (N = 128)	Nuru (N = 52)	SNEL (N = 76)	P-value
Daily hours of electricity available				0.000***
Mean (SD)	12.2 (9.4)	22.2 (5.0)	5.4 (4.0)	
Daily hours of electricity used				0.000***
Mean (SD)	9.9 (7.3)	15.7 (5.7)	5.9 (5.2)	
Do you have enough electricity to operate your enterprise successfully?				0.000***
Agree	40.6%	80.8%	13.2%	
Indifferent	9.4%	9.6%	9.2%	
Disagree	50.0%	9.6%	77.6%	
Would you prefer to use more electricity?				0.003***
Agree	64.8%	71.2%	60.5%	
Indifferent	11.7%	19.2%	6.6%	
Disagree	23.4%	9.6%	32.9%	

***p < 0.01, **p < 0.05, *p < 0.1.
P value for categorical variables: Pearson's Chi-squared test with Yates' continuity correction.
P value for continuous variables: Welch's two-sample t-test.
Standard deviation for continuous variables in parentheses.
Due to rounding some columns may not add to 100.

Electricity Quality and Reliability

Electricity quality and reliability were determined through self-reported data on voltage levels and power outages. The results are summarized in Table 5. These data show that 76.9% of Nuru-connected enterprises report strong voltage levels, 15.4% report fluctuating voltage levels and 7.7% report dim voltage levels. Conversely, 25% of SNEL-connected enterprises report strong voltage levels, 53.9% report fluctuating voltage levels and 21.1% report dim voltage levels. When asked if the voltage levels are strong enough for successful enterprise operations, 59.6% of Nuru-connected enterprises agreed and 19.2% disagreed. Among SNEL-connected enterprises, 21.1% agreed and 67.1% disagreed.

Small enterprises were asked to report the estimated number of power outages experienced during a normal month. Results indicate that Nuru-connected enterprises reported 2.2 outages on average and SNEL-connected enterprises reported an average of 28.8 power outages in a normal month. The duration of power outages was also significantly different, with an average time of 1.5 hours per outage for Nuru-connected enterprises and 13.2 hours per outage for SNEL-connected enterprises. During power outages, 25.0% of Nuru-connected enterprises and 55.3% of SNEL-connected enterprises report using a generator. Furthermore, 26.9% of Nuru-connected enterprises and 23.7% of SNEL-connected enterprises report using another source of electricity during a power outage.

To further assess the impact of power outages on small enterprises, three questions were asked about power outages and their impact on enterprise operations, working hours, and attention to customers. Based on the data, SNEL-connected enterprises were more inclined to suggest that power outages limit their enterprise operations, however, these results were not statistically significant. Still the data show that 17.1% of SNEL-connected enterprises reported that power outages always limit their enterprise operations, followed by 19.7% saying that power outages often limit operations, and 17.1% saying that outages sometimes limit operations. This pattern differed among Nuru-connected enterprises, of which 7.7% reported that outages always limit enterprise operations, followed by 9.6% saying that outages often limit operations and 21.2% saying that outages sometimes limit enterprise operations.

A statistically significant difference was found between Nuru and SNEL-connected enterprises with regard to power outages limiting working hours. Among SNEL-connected enterprises, 13.2% reported that outages always limited working hours, followed by 18.4% reporting that outages often limit working hours, and 19.7% reporting that outages sometimes limit working hours. This pattern was not observed among Nuru-connected enterprises of which 3.8% reported that power outages always limit working hours, followed by 7.7% reporting that outages often limit working hours, and 15.4% reporting that outages sometimes limit working hours. When asked if power outages cause enterprises to turn away customers, approximately two-thirds of respondents in both samples reported no, and very few indicated that this occurred more than sometimes.

Table 5. Electricity quality and reliability

	Total (N = 128)	Nuru (N = 52)	SNEL (N = 76)	P-value
How is the voltage level of your electricity?				0.000***
Usually dim	15.6%	7.7%	21.1%	
Usually strong	46.1%	76.9%	25.0%	
Fluctuates from dim to strong	38.3%	15.4%	53.9%	
Is the voltage level strong enough to operate your enterprise successfully?				0.000***
Agree	36.7%	59.6%	21.1%	
Indifferent	15.6%	21.2%	11.8%	
Disagree	47.7%	19.2%	67.1%	
Approximate number of monthly power outages				0.000***
Mean (SD)	18.0 (17.4)	2.2 (2.1)	28.8 (14.7)	
Approximate duration of a power outage in hours				0.000***
Mean (SD)	8.4 (8.1)	1.5 (3.2)	13.2 (6.9)	
Alternative electricity source used during power outages				0.001***
Generator	43.0%	25.0%	55.3%	
Other	25.0%	26.9%	23.7%	
No	32.0%	48.1%	21.1%	
Are your enterprise operations limited because of power outages?				0.172
Always	13.3%	7.7%	17.1%	
Often	15.6%	9.6%	19.7%	
Sometimes	18.8%	21.2%	17.1%	
Rarely	15.6%	21.2%	11.8%	
No	36.7%	40.4%	34.2%	
Are your working hours limited because of power outages?				0.049**
Always	9.4%	3.8%	13.2%	
Often	14.1%	7.7%	18.4%	
Sometimes	18.0%	15.4%	19.7%	
Rarely	11.7%	17.3%	7.9%	
No	46.9%	55.8%	40.8%	
Do you have to turn customers away because of power outages?				0.736
Always	2.3%	1.9%	2.6%	
Often	6.3%	9.6%	3.9%	
Sometimes	15.6%	13.5%	17.1%	
Rarely	8.6%	7.7%	9.2%	
No	67.2%	67.3%	67.1%	

***p < 0.01, **p < 0.05, *p < 0.1.
P-value for categorical variables: Pearson's Chi-squared test with Yates' continuity correction.
P-value for continuous variables: Welch's two-sample t-test.
Standard deviation for continuous variables in parentheses.
Due to rounding some columns may not add to 100.

Electricity Supplier Communications

Electricity supplier communications was examined by asking small enterprises if they generally receive any communications about power outages from either Nuru or SNEL. The results from these questions are shown in Table 6. Nuru-connected enterprises reported receiving more notifications than SNEL-connected enterprises. Overall, 86.5% of Nuru-connected enterprises reported that power outages were scheduled, as opposed to 3.9% of SNEL-connected enterprises. Additionally, 84.6% of Nuru-connected enterprises reported that they received a notification before an outage and 59.6% reported receiving communications during an outage notifying the approximate time before power is restored. No indication of communication prior to an outage or updates during an outage were observed among SNEL-connected enterprises.

Table 6. Electricity supplier communications

	Total (N = 128)	**Nuru (N = 52)**	**SNEL (N = 76)**	**P-value**
In general, are your power outages scheduled?				0.000***
Yes	37.5%	86.5%	3.9%	
No	61.7%	11.5%	96.1%	
Refuse to answer	0.8%	1.9%	0.0%	
When power outages are scheduled, do you generally receive a notification before the outage?				0.000***
Yes	34.4%	84.6%	0.0%	
No	64.8%	13.5%	100.0%	
Refuse to answer	0.8%	1.9%	0.0%	
Do you receive updates from your electricity company during power outages that notify you how long it will take before electricity is restored?				0.000***
Yes	24.2%	59.6%	0.0%	
No	75.8%	40.4%	100.0%	

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
P value for categorical variables: Pearson's Chi-squared test with Yates' continuity correction.
Due to rounding some columns may not add to 100.

Electricity Affordability

Four questions asked about perceived electricity affordability and are outlined in Table 7. Results indicate that 63.5% of Nuru-connected enterprises agree that their electricity is affordable and 25.0% do not agree that their electricity is affordable. In comparison, 10.5% of SNEL-connected enterprises agree that their electricity is affordable and 81.6% do not agree that their electricity is affordable.

There is no significant difference in reporting that the cost of electricity limits enterprise operations. The majority of Nuru-connected enterprises (55.8%) and SNEL-connected enterprises (65.8%) indicate that electricity costs do not limit enterprise operations. Still, a substantial proportion of enterprises, 32.7% of Nuru-connected enterprises and 27.6% of SNEL-connected enterprises, indicate that electricity costs do limit their business operations. When asked if enterprises limit the use to save money, 32.7% of Nuru-connected enterprises and 1.3% of SNEL-connected enterprises responded that they do so always. On the contrary, 23.1% of Nuru-connected enterprises and 67.1% of SNEL-connected enterprises indicated that they do not limit the use of electricity to save money. The distributions of responses are significantly different and indicate that Nuru-connected enterprises are more inclined to limit their electricity usage to save money. The results further indicate a greater propensity to monitor electricity consumption among Nuru-connected enterprises of which 23.1% indicated that they always monitor their consumption compared to 2.6% of SNEL-connected enterprises. However, the majority of enterprises in both samples (59.6% of Nuru-connected enterprises and 67.1% of SNEL-connected enterprises) indicated that they do not monitor their electricity consumption.

Table 7. Electricity affordability

	Total (N = 128)	Nuru (N = 52)	SNEL (N = 76)	P-value
Is your electricity supply affordable for your enterprise?				0.000***
Agree	32.0%	63.5%	10.5%	
Indifferent	8.6%	9.6%	7.9%	
Disagree	58.6%	25.0%	81.6%	
Refuse to answer	0.8%	1.9%	0.0%	
Does the cost of electricity limit your enterprise operations?				0.438
Agree	29.7%	32.7%	27.6%	
Indifferent	8.6%	11.5%	6.6%	
Disagree	61.7%	55.8%	65.8%	

Table 7. Continued

	Total (N = 128)	Nuru (N = 52)	SNEL (N = 76)	P-value
Do you limit the use of electricity to save money?				0.000***
Always	14.1%	32.7%	1.3%	
Often	7.0%	9.6%	5.3%	
Sometimes	9.4%	9.6%	9.2%	
Rarely	18.8%	25.0%	14.5%	
No	50.8%	23.1%	69.7%	
Do you monitor how much electricity you consume?				0.005***
Always	10.9%	23.1%	2.6%	
Often	4.7%	3.8%	5.3%	
Sometimes	8.6%	7.7%	9.2%	
Rarely	11.7%	5.8%	15.8%	
No	64.1%	59.6%	67.1%	

***p < 0.01, **p < 0.05, *p < 0.1.
P value for categorical variables: Pearson's Chi-squared test with Yates' continuity correction.
Due to rounding some columns may not add to 100.

Electricity Satisfaction and Value

The overall satisfaction and the perceived value for money were measured using the three questions outlined in Table 8. The responses to these questions indicate that 71.2% of Nuru-connected enterprises, the majority, are satisfied with their electricity. Additionally, 15.4% are very satisfied, 11.5% are unsatisfied, and 1.9% are very unsatisfied with their electricity. The majority of SNEL-connected enterprises, 55.3%, are unsatisfied with their electricity. Further, 34.2% of enterprises are very unsatisfied and 9.2% are satisfied. There were no SNEL-connected enterprises that reported being very satisfied with their electricity and 1.3% declined to answer the question. The distributions of these responses are significantly different, indicating that Nuru-connected enterprises are more inclined to report overall satisfaction with their electricity and SNEL-connected enterprises are more inclined to report dissatisfaction.

The perceived value for money was asked with two questions to assess the value of the electricity product and the electricity company's customer service. Results show that 63.5% of Nuru-connected enterprises report the value for money of the electricity product to be fair. Additionally, 13.5% of Nuru-connected enterprises report that the value for money is good, and 23.1% report the value for money as poor. The majority of SNEL-connected enterprises, 86.8%, reported the value for money to be poor. Further, 10.5% of SNEL-connected enterprises indicated that the value for money is fair and 1.3% reported it as good. A similar pattern was observed in the responses to the value for money of the electricity company's customer service. In this case, 48.1% of Nuru-connected enterprises reported the value for money as fair, 19.2% reported it as good and 32.7% reported the value as poor. Among SNEL-connected enterprises, 84.2% reported the value for money of the electricity company's customer service to be poor, 13.2% indicted it as fair and 1.3% reported it as good. The distributions for both value for money questions are statistically significant, indicating that Nuru-connected enterprises are more inclined to report value to be fair or good, and SNEL-connected enterprises are more inclined to report the value to be poor.

Table 8. Electricity satisfaction and value

	Total (N = 128)	**Nuru (N = 52)**	**SNEL (N = 76)**	**P-value**
Overall, how satisfied are you with your electricity?				0.000***
Very satisfied	6.3%	15.4%	0.0%	
Satisfied	34.4%	71.2%	9.2%	
Unsatisfied	37.5%	11.5%	55.3%	
Very unsatisfied	21.1%	1.9%	34.2%	
Refuse to answer	0.8%	0.0%	1.3%	
How would you rate the value for money of your electricity product?				0.000***
Good	6.3%	13.5%	1.3%	
Fair	32.0%	63.5%	10.5%	
Poor	60.9%	23.1%	86.8%	
Refuse to answer	0.8%	0.0%	1.3%	
How would you rate the value for money of your electricity company's customer service?				0.000***
Good	8.6%	19.2%	1.3%	
Fair	27.3%	48.1%	13.2%	
Poor	63.3%	32.7%	84.2%	
Refuse to answer	0.8%	0.0%	1.3%	

***p < 0.01, **p < 0.05, *p < 0.1.
P-value for categorical variables: Pearson's Chi-squared test with Yates' continuity correction.
Due to rounding some columns may not add to 100.

Small Enterprise Characteristics Associated with Electricity Affordability and Reliability

To further explore how sourcing electricity from Nuru compares with SNEL, a series of logistic regressions are run that reflect the association between indicators of electricity affordability and reliability while controlling for enterprise-level characteristics. The first regression model uses the combined data for Nuru and SNEL with the electricity source as a control. The results are displayed in Table 9.

Nuru-connected enterprises exhibit greater odds of reporting having enough electricity, sufficient voltage, and suggest that their supply is affordable.

Across the entire sample, there is a significant association between increasing enterprise net income and greater odds of reporting having enough electricity. Similarly, having a secondary income-generating job in addition to the enterprise in question is significantly associated with higher odds of reporting that electricity is affordable. In line with this pattern, there is a significant association between having two or more employees and increased odds of reporting that electricity costs limit business operations. This model also exhibits patterns indicating that increasing electricity expenses are associated with higher odds of reporting sufficient voltage levels as well as higher odds of suggesting that electricity costs limit enterprise operations. Additionally, more established enterprises are more likely to report that their electricity is affordable.

Table 9. Regression of full sample

	Has enough electricity	**Has sufficient voltage**	**Electricity is affordable**	**Cost limits operations**
Electricity source: Nuru *(c.f. SNEL)*	104.10*** (102.398)	6.35*** (3.957)	18.33*** (14.769)	1.09 (0.644)
Monthly net income (USD)	2.95*** (0.992)	1.41 (0.349)	1.12 (0.315)	0.87 (0.195)
Monthly electricity expenses (USD)	1.58 (0.953)	2.18* (0.971)	1.46 (0.792)	2.56** (1.059)
Enterprise founded 2020 - 2021 *(c.f. Founded before 2020)*	1.01 (0.834)	0.48 (0.327)	3.64* (2.832)	2.00 (1.295)
Secondary income source *(c.f. No secondary income)*	1.43 (1.077)	1.65 (0.956)	4.71** (3.354)	1.69 (0.915)
University education *(c.f. Secondary school or less)*	0.49 (0.382)	0.79 (0.474)	1.27 (0.879)	1.86 (1.016)
Two or more employees *(c.f. Less than two employees)*	0.93 (0.797)	0.65 (0.445)	1.90 (1.441)	3.72* (2.527)
	N = 93	**N = 93**	**N = 93**	**N = 93**

***p < 0.01, **p < 0.05, *p < 0.1.
Standard errors in parentheses.

To further understand the association between indicators of electricity access and electricity source, the regression above is decomposed into two further models by electricity supplier. Across both regression models (Table 10 and Table 11) there is a significant association between increasing net income and greater odds of reporting having enough electricity. Net income is the only control variable that is significant among both Nuru- and SNEL-connected enterprises. A significant association between increasing electricity expenses and higher odds of reporting sufficient voltage levels is only seen among Nuru-connected enterprises. Also, increasing electricity expenses among SNEL-connected enterprises is significantly associated with greater odds of reporting that the cost of electricity limits enterprise operations.

Nuru-connected enterprises display a significant association between having a secondary income-generating job and reporting that electricity is affordable. Within the same measure, SNEL-connected enterprises are more likely to suggest that their electricity supply is affordable if they have a university-level education. Nuru-connected enterprises are more likely to report that electricity costs limit enterprise operations if the enterprise has two or more employees and if the enterprise was founded before 2020.

Table 10. Regression of Nuru-connected enterprises

	Has enough electricity	**Has sufficient voltage**	**Electricity is affordable**	**Cost limits operations**
Monthly net income (USD)	4.66** (2.889)	1.43 (0.544)	1.43 (0.576)	1.76 (0.858)
Monthly electricity expenses (USD)	2.13 (2.331)	7.68** (7.179)	1.38 (1.065)	1.29 (1.038)
Enterprise founded 2020 - 2021 *(c.f. Founded before 2020)*	4.18 (5.929)	0.60 (0.526)	4.72 (5.096)	9.13* (12.241)
Secondary income source *(c.f. No secondary income)*	7.44 (12.297)	3.52 (3.222)	10.31** (11.153)	1.62 (1.562)
University education *(c.f. Secondary school or less)*	0.15 (0.224)	1.34 (1.238)	0.41 (0.405)	0.78 (0.732)
Two or more employees *(c.f. Less than two employees)*	1.06 (1.191)	0.63 (0.579)	4.15 (3.780)	20.73** (27.768)
	N = 38	**N = 38**	**N = 38**	**N = 38**

***p < 0.01, **p < 0.05, *p < 0.1.
Standard errors in parentheses.

Table 11. Regression of SNEL-connected enterprises

	Has enough electricity	**Has sufficient voltage**	**Electricity is affordable**	**Cost limits operations**
Monthly net income (USD)	2.62** (1.213)	1.46 (0.515)	0.90 (0.436)	0.67 (0.207)
Monthly electricity expenses (USD)	1.49 (1.140)	1.43 (0.842)	1.47 (1.565)	3.27** (1.831)
Enterprise founded 2020 - 2021 *(c.f. Founded before 2020)*	0.40 (0.633)	0.17 (0.251)	35.46 (79.790)	0.85 (0.923)
Secondary income source *(c.f. No secondary income)*	0.90 (0.942)	1.65 (1.550)	7.77 (17.478)	1.71 (1.468)
University education *(c.f. Secondary school or less)*	0.64 (0.698)	0.44 (0.420)	20.44* (35.782)	2.68 (2.020)
Two or more employees *(c.f. Less than two employees)*	0.61 (0.984)	0.27 (0.324)	0.24 (0.385)	0.71 (0.782)
	N = 55	**N = 55**	**N = 55**	**N = 55**

***p < 0.01, **p < 0.05, *p < 0.1.
Standard errors in parentheses.

Discussion

The results above provide several important observations on the current state of electricity access in Goma. Below, we summarize our findings and discuss the potential for solar mini-grids in the DRC. We also provide recommendations for further research and the implications of our findings for policymakers.

Uptake of Grid-Based Electricity

Across both samples, we see that most small enterprises switched to grid-based electricity from freestanding electricity sources, generally either generators or standalone solar panels. Particularly unique is the uptake of SNEL's electricity despite the overwhelming discontent with its product and service among respondents. The prevailing switch to grid-based electricity could suggest that grid-based supply offers notable improvements in power and convenience over freestanding electricity sources, even when grid-based supply is poor.

We also remark on the large number of Nuru-connected enterprises founded between 2020 and 2021, as this is the same time that Nuru began operations in Ndosho. These results could suggest that a considerable number of enterprises emerged due to Nuru's development in Ndosho. In such a case, we would observe a similar outcome to Peters et al. (2011), who found that electricity access resulted in the development of electricity-reliant enterprises in Benin.

We can conclude that grid-based electricity supply conceivably provides improved electricity such that small enterprises are willing to switch from freestanding sources such as generators and standalone solar panels. Additionally, we presume that the introduction of grid-based electricity access to previously un-electrified areas engenders electricity-reliant small enterprise development.

Small Enterprise Performance and Wellbeing

Our results show several findings on non-financial indicators of small enterprise performance and general wellbeing that are related to electricity quantity and quality. However, we do not find any effect of electricity access on small enterprise financial performance.

One of the most important findings relates to the greater quantity of electricity available to Nuru-connected enterprises. Results show that Nuru-connected enterprises use significantly more hours of electricity than SNEL-connected enterprises, and Nuru-connected enterprises are significantly more likely to report having enough electricity to operate their enterprises successfully. These results may indicate that Nuru-connected enterprises have a greater electricity-related capability to operate as needed. Further, we infer that SNEL-connected enterprises may engage in energy stacking to meet their electricity needs or allocate electricity-reliant activities to supply times. This could indicate that Nuru-connected enterprises must make fewer electricity-related trade-offs to meet their energy needs. It is also possible that Nuru-connected enterprises are using more hours of grid-based electricity for low-power uses such as evening and nighttime lighting. Finally, notwithstanding specific use cases and the possibility of energy stacking, it is evident that Nuru-connected enterprises are using more electricity from a single electricity source compared to SNEL-connected enterprises. This leads us to assume greater electricity independence among Nuru-connected enterprises, which we contend contributes to the overall wellbeing of enterprise owners and employees.

Quality-based performance indicators yield similar results. We find that Nuru-connected enterprises are significantly more likely to report having the voltage levels necessary for successful enterprise performance. Correspondingly, SNEL-connected enterprises report insufficient voltage levels for enterprise operations. It thus appears that voltage levels are an essential factor for enterprise performance and that low levels demonstrably impact desired enterprise performance. Interestingly, we observe a different outcome regarding average monthly power outages. Our results show that SNEL-connected enterprises report high numbers of monthly power outages, often lasting multiple hours. Conversely, Nuru-connected enterprises report significantly fewer and shorter power outages. Despite these results, limited evidence indicates that power outages negatively impact enterprise performance aside from working hours. However, this should not undermine the impact of recurring power outages. In numerous studies, we see that small enterprises are willing to pay more money for fewer power outages (Ghosh et al., 2017; Deutschmann et al., 2021). We thus assert that frequent power outages presumably act as a nuisance, negatively impacting the wellbeing or peace of mind of enterprise owners and employees. Altogether, we deduce that low voltage levels and frequent power outages are problematic for small enterprises. However, it appears that low voltage levels presumably pose more issues for small enterprise performance.

We do not find any noteworthy effect of electricity access on small enterprise financial performance. Our results show that Nuru-connected enterprises pay significantly more for their electricity and generate lower average net incomes. However, the difference in enterprise incomes is likely due to marked differences in neighborhood wealth characteristics, with Ndosho exhibiting substantially higher levels of household-level asset-based poverty than Mabanga Sud, Murara, and Mapendo (Vinck et al., 2017). It is thus possible that SNEL-connected enterprises can charge more money for their products and services. Based on these results, we observe similarities to the findings by Terrapon-Pfaff et al. (2018), whereby additional exigencies such as improved markets may be more critical to enterprise incomes and may also be more pivotal in maximizing improved electricity access.

Electricity's Value

Even with lower incomes and higher electricity expenses, we observe a strong pattern of greater satisfaction, value for money, and perceived affordability among Nuru-connected enterprises compared to SNEL-connected enterprises. One reason for this may be the difference in the overall time of the connection, as Nuru-connected enterprises have had their electricity access for less time and are reporting positive results from a new electricity connection. However, this theory is assumed unlikely given the significant pattern of differences in electricity quantity and quality, and in particular, the intense dissatisfaction of SNEL by its customers. Therefore, a more robust theory surmises that Nuru's higher reported quantity and quality of electricity and improved supplier communications play a critical role in creating greater satisfaction among Nuru-connected enterprises.

We find that Nuru-connected enterprises are significantly more likely to report that their electricity is affordable, report greater overall satisfaction with their electricity, and are also more likely to report their electricity as fair value for money. We find these results despite significant differences in electricity expenses and enterprise incomes. Furthermore, we see no indication that electricity costs limit enterprise operations across both samples, but Nuru-connected enterprises have a greater propensity to limit electricity usage to save money. We suggest that the greater availability and improved quality of Nuru's electricity are the core determinants pushing the trends in satisfaction and value.

Additionally, we hypothesize that electricity supplier communications play a pivotal role in the perceived value of electricity access. We found that none of the SNEL-connected enterprises in our sample received any notifications about scheduled power outages before an outage and no updates on the time before power restoration. We infer that Nuru's improved communications about power outages conceivably contribute to the higher reported levels of satisfaction and value among Nuru-connected enterprises, thereby suggesting a far improved electricity supplier-consumer dynamic by Nuru.

Altogether, these data display a robust pattern of associating improved electricity quality with affordability, greater satisfaction, and value for money. Our results indicate that small enterprises appear willing to pay the price for improved electricity access and that there is apparent value in accessible, high-quality electricity. We further assume that factors such as convenience and comfort, or the lack thereof, add to the observed trends in our results.

Possible Financial Constraints

Our results do not indicate that electricity costs – particularly Nuru's higher electricity costs – pose any critical financial constraints for small enterprises. However, the results from our regression models provide a possible indication of cost-related pressure. We see this, for example, among the increased odds of Nuru-connected enterprises reporting electricity affordability when enterprise owners have secondary income-generating jobs. Also, younger enterprises and those with two or more employees have significantly greater odds of suggesting that electricity costs limit operations. Likewise, increasing electricity expenses are associated with higher odds of reporting that electricity costs limit enterprise operations among SNEL-connected enterprises.

We can deduce that there is a space in which electricity costs begin to act as an enterprise constraint; however, this appears very different between Nuru- and SNEL-connected enterprises. In the case of Nuru-connected enterprises, a possible explanation for the regression outcomes includes overall lower enterprise incomes as these would plausibly affect younger enterprises and those needing to pay employees.

On the other hand, the case for SNEL-connected enterprises is more unusual as they have higher average incomes and lower electricity costs and yet report high odds of electricity costs limiting operations as those costs increase. We could hypothesize this to be a supply- and quality-related result in which enterprises report costs limiting operations due to insufficient and low-quality electricity. This may also be inferred by the greater odds of university-educated owners of SNEL-connected enterprises reporting that their electricity is affordable as they could be more aware of the cost-quantity and -quality relationship.

Overall, we do not find that electricity costs constrain small enterprises; however, we note particular circumstances such as low enterprise incomes and poor electricity supply and quality that could possibly exert financial pressure on small enterprises in the event of price changes or other economic shocks.

Policy Recommendations

Our results indicate that SNEL's electricity product and service are generally insufficient and unsatisfactory for small enterprises in Goma. On the other hand, we demonstrate that Nuru's solar mini-grid electricity provides small enterprises with an improved electricity product and service, yielding significantly greater levels of satisfaction and perceived value.

Based on these results, we first recommend policies that promote further expansion of solar mini-grids, particularly in un-electrified urban areas of the DRC. Second, we strongly recommend a policy environment to improve the condition of SNEL's energy infrastructure and strengthen its operations. Additionally, we suggest that development banks and other international funding agencies further prioritize sustainable energy investments in SSA and the DRC.

Study Limitations and Recommendations for Further Research

Our study presents robust cross-sectional findings on electricity access for small enterprises. However, cross-sectional data also present a number of limitations, and we therefore recommend using longitudinal data in the future to obtain more relevant results on electricity access from solar mini-grids in the DRC. Furthermore, we recommend expanding the variable selection to capture more electricity-use behaviors such as energy stacking and time-use of electrical appliances to further understand existing electricity needs and their change over time. Likewise, we recommend using additional variables to capture community-level impacts of small enterprise electricity access. Lastly, we recommend broadening the scope of analysis to examine the impact of solar mini-grid electricity at the regional and national levels, as such data are instrumental for robust policy development.

Conclusion

Our study assessed the impacts of improved electricity access from a solar mini-grid on small enterprises operating in the city of Goma, DRC. We employed a case-control study design to examine the electricity experiences of small enterprises connected to a solar mini-grid by Nuru and the DRC's primary national grid supplier, SNEL. Using a set of five electricity access indicators, we constructed a detailed profile of the electricity experiences of 128 small enterprises. Our results provide critical insights into the existing energy context for small enterprises as well as further recommendations for improved electricity access in the DRC.

First, we found that most small enterprises switched to grid-based electricity from freestanding electricity sources such as liquid-fuel generators and standalone solar panels, suggesting that grid-based electricity provides enhanced capacity over freestanding sources.

Second, we found significant differences in each electricity source's reported quantity and quality, resulting in observable impacts on enterprise performance. We found that Nuru's solar mini-grid electricity provided far more hours of electricity with stronger voltage levels and fewer power outages. Congruent to these observations, we found that Nuru-connected enterprises used significantly more electricity and were more likely to report having the voltage levels required for successful enterprise operations. Despite these results, we noted that Nuru-connected enterprises are generating lower incomes than SNEL-connected enterprises, although this is likely due to external factors such as neighborhood wealth characteristics.

Third, we found that Nuru-connected enterprises were significantly more likely to suggest their electricity is affordable and reported greater overall satisfaction with their electricity. Furthermore, Nuru-connected enterprises were significantly more likely to report fair value for the cost of their electricity. We observed these results despite Nuru's higher average electricity costs.

We also observed that electricity costs exerted some pressure on enterprise performance, especially for lower-income enterprises, but we did not find that higher costs are a significant constraint. Altogether, we infer that improved electricity access through greater availability, improved quality, and improved supplier communications likely results in significant differences in perceived affordability, satisfaction, and value for money for small enterprises operating in Goma.

Our results shed light on the unsatisfactory state of electricity access for small enterprises in the DRC and the potential for solar mini-grids to meet critical gaps in access. Therefore, we recommend developing policies to encourage the implementation of solar mini-grids, particularly in un-electrified urban areas. We also recommend a policy environment to improve the condition of SNEL's energy infrastructure and strengthen its operations.

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