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Do decentralized solar mini grids improve energy access for small enterprises in Goma, Democratic Republic of the Congo?

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ABSTRACT

Electricity access is essential for small enterprise operations and economic development in low- and middle-income countries (LMICs). The Democratic Republic of the Congo (DRC) has one of the lowest electrification rates globally, placing undue constraints on the country's small enterprises. Efforts are currently underway to improve electricity access in the DRC and throughout sub-Saharan Africa using decentralized solar mini grids. Their effect on small enterprise energy access and enterprise operations remains largely unexplored, particularly in urban settings. We address this gap by evaluating the impact of a recently established solar mini grid on small enterprise operations in an un-electrified district in the city of Goma. We use a case-control study design to assess the adequacy of electricity supply in a sample of 128 qualitatively similar small enterprises. Cases include enterprises connected to a newly constructed solar mini grid operated by a private energy service provider. The control group includes enterprises connected to the long-standing parastatal utility grid. We analyze indicators of electricity availability and usage, reliability, perceived affordability, overall satisfaction, and value to construct a profile of electricity access and supply characteristics across the two groups. We find that electricity from the solar mini grid provides significantly improved energy access compared to the existing public utility evidenced by more hours of electricity, consistently strong voltage levels, and fewer outages. However, solar energy is more expensive. Our results confirm that investment in decentralized solar mini grids is a viable solution to improve electricity access for small enterprises in African cities. DRC is heavily investing in decentralized solar mini grids as an alternative to building out grid connectivity.

Introduction

Access to electricity is widely considered essential to small enterprise performance and economic development in low- and middle-income countries (LMICs) (Blimpo & Cosgrove-Davies, 2019; Jeuland et al., 2021; Little, 1987; Rud, 2012; Scott et al., 2014; Tybout, 2000). Electricity access remains low in LMICs, particularly in sub-Saharan Africa where half of the population lives without electricity (IEA, 2022). In the Democratic Republic of the Congo (DRC), the electrification rate is approximately 20 % (IEA et al., 2022), leaving 80 million people without power (World Bank, 2022a). Results from the World Bank's 2013 Enterprise Survey reflect the constraints of poor energy supply as small enterprises cited electricity, including limited availability and poor quality, as their greatest operational obstacle (World Bank, 2014).

In the DRC, electricity is produced from several sources but is dominated by hydropower generation (IRENA, 2021), most of which is distributed by government parastatal Société Nationale d'Électricité (SNEL). SNEL operates several power stations throughout the country and primarily supplies large urban centers and industries (ACERD, 2021; MRHE RDC et al., 2016; World Bank, 2020). In recent decades, SNEL has sought to increase grid access across the country (World Bank, 2020). Despite these efforts, SNEL's capacity has remained consistent while the DRC continues to experience rapid population growth (World Bank, 2020). Further, over the past few decades, the country's existing grid

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infrastructure has deteriorated due to chronic mismanagement, underinvestment, and lack of maintenance (Tshitenge, 2019). SNEL currently generates only 55 % of its installed capacity (World Bank, 2020).

Like other sub-Saharan African countries, significant urban-rural disparities exist in the DRC, with 41 % of people in urban areas having access to electricity compared to only 1 % in rural communities (IEA et al., 2022). In urban areas, where 46 % of DRC's population resides (World Bank, 2022b), inadequate energy access is a significant hindrance to community well-being and economic productivity (World Bank, 2018). Although city-dwellers have better electricity access relative to other parts of the country, grid electricity supply in Congolese cities remains notoriously unreliable (Al Katanty, 2022; Amwanga, 2020).

The DRC's market potential for off-grid solar distribution (USAID, 2019) and the high potential for socio-economic development through access to critical energy infrastructure (Casati et al., 2023) have generated substantial interest in solar mini grid development across the country. To date, numerous solar mini grids are under development throughout the DRC (Dzirutwe, 2023; IFC, 2022). While there is extensive research on solar mini grid access for small enterprises in rural settings (Ganguly et al., 2020; Nuru et al., 2021; Obeng & Evers, 2010; Pueyo & DeMartino, 2018), there has been limited academic investigation in urban areas (Pedersen, 2016), particularly in the DRC. This study seeks to address this gap in our understanding of the potential for decentralized solar mini grid infrastructure to supply small enterprises with reliable electricity in the context of a large and growing African city.

Our study focuses on Nuru, a privately owned Congolese energy supplier that has recently taken aim at expanding electricity access in eastern DRC using decentralized solar mini grids with battery storage for extended power. Nuru, formerly Kivu Green Energy, entered DRC's energy market in 2015 as a private decentralized grid-based energy service provider. In February 2020, Nuru launched a 1.3-MW solar mini grid in the city of Goma (Nuru, 2021). Nuru has an ambitious expansion plan with funding secured to develop three additional mini grids, increasing the company's output by 13 times (Bearak, 2023).

As these installations are underway, we conduct an exploratory analysis to lay out some of the early impacts of mini grid development on productive uses in an urban setting. In our study, we examine two modes of electricity provision for small enterprises in Goma by comparing access from Nuru's newly installed 1.3-MW solar mini grid with SNEL's existing grid-based supply. We look at the characteristics and impacts of electricity access delivered by each supplier through the experiences of a sample of 128 qualitatively similar small enterprises.

Literature review

Several empirical studies in LMICs provide evidence that access to reliable electricity improves the financial performance and productivity of small enterprises (Ajibola et al., 2022; Arnold et al., 2008; Olanrewaju & Olanrewaju, 2020; Owusu et al., 2022; Ugembe et al., 2023), contributes to small enterprise growth (Shibia & Barako, 2017), creates new jobs, and improves business opportunities (Nuru et al., 2021). Analyses at the enterprise level show that the economic benefits of electrification affect some sectors more than others (Grimm et al., 2013; Obeng & Evers, 2010). By contrast, research has also demonstrated the detrimental effects of unreliable power supply on enterprise performance. For example, in Nigeria, power outages have negatively affected small enterprise productivity (Moyo, 2012), and contributed to substantial losses in annual sales (Nwanakwere & Uzoeto, 2020).

In some cases, electricity access in LMICs has negatively affected small enterprises through high costs lowering productivity (Eifert et al., 2008), and through unreliable supply (Ugembe et al., 2023). Determinants of electricity adoption and willingness to pay have thus received considerable research attention, often indicating a complex relationship between cost and quality. Pelz et al. (2021) underscore perceived affordability as among the primary reasons for the lack of uptake, suggesting that many financially constrained enterprises forgo grid connections out of concern for affordability. Studies in Senegal (Deutschmann et al., 2021) and India (Ghosh et al., 2017) found that small enterprises were willing to pay more for new electricity sources, but only if they provided sufficient and uninterrupted power supply. In rural India, improved electricity quality was a primary reason for the uptake of mini grid electricity among small enterprises (Ganguly et al., 2020).

Several studies suggest that access to reliable electricity alone may not be sufficient to improve enterprise operations. Enterprises improve their energy utility in the presence of complementary factors such as capacity building, market access, and technical knowledge (Fingleton-Smith, 2020; Terrapon-Pfaff et al., 2018). Similarly, a growing body of research expands beyond the use of finance-based performance indicators to examine the broader impacts of electricity access in LMICs (e.g., how it affects the well-being of small enterprises and the communities that rely on them). For example, in rural India, electricity is linked to improved working conditions and worker well-being, despite no change in incomes (Kooijman-van Dijk, 2012). In rural Uganda, Neelsen and Peters (2011) found that electrification did not contribute to an increase in profits or worker incomes but did have an indirect positive effect on local demand by encouraging community members to move into electrified areas. In rural Benin, electrification led to the development of electricity-reliant enterprises despite no improvement in the profits of existing enterprises (Peters et al., 2011). Pueyo and DeMartino (2018) found a similar result among Kenyan micro-enterprises sourcing solar mini grid electricity, which stayed open longer but saw no significant increase in profits. A study across Bolivia, Tanzania, and Vietnam showed that electrification did not result in higher incomes; however, communities nonetheless benefited from the improved products and services that small enterprises were able to provide (Kooijman-van Dijk & Clancy, 2010).

The empirical evidence presented underscores the multidimensionality of electricity provision in LMICs, revealing improvements in financial performance, enterprise productivity, job creation, and new economic opportunities. However, challenges such as unreliable power supply and high costs pose obstacles to effective energy adoption and usage. This underpins the importance of evaluating energy provision in LMICs with a multidimensional lens to assess supplementary outcomes such as improved enterprise owner and employee well-being, increased enterprise owner agency and decision-making ability, and community health. External factors such as market conditions, particularly the ability of local economies to support infrastructure maintenance, governance structures, and project financing must also be considered as these simultaneously play a critical role in enabling the benefits of energy access (Antonanzas-Torres et al., 2021; Edsand & Bångens, 2024; Malima et al., 2024; Volkert & Klagge, 2022).

Methods

Study design and sampling

We conducted our study in Goma, a large city bordering Rwanda in eastern DRC, situated between Lake Kivu and the Virunga Mountains. Over the past several decades, Goma and the surrounding areas of North Kivu province have been embroiled in a complex regional conflict fueled by political instability and armed group activity. As a result, urban insecurity and crime in Goma today are high (Hendriks & Büscher, 2019). Despite its social and political precarity, Goma remains remarkably resilient, with robust economic activity and active trade with Rwanda (Vlassenroot & Büscher, 2013). Its regional economic importance makes it an ideal setting for small enterprise development.

Four purposively selected city districts are included in this study: Ndosho, Mabanga Sud, Murara, and Mapendo (see Fig. 1). Ndosho is a densely populated district located near Goma's periphery,

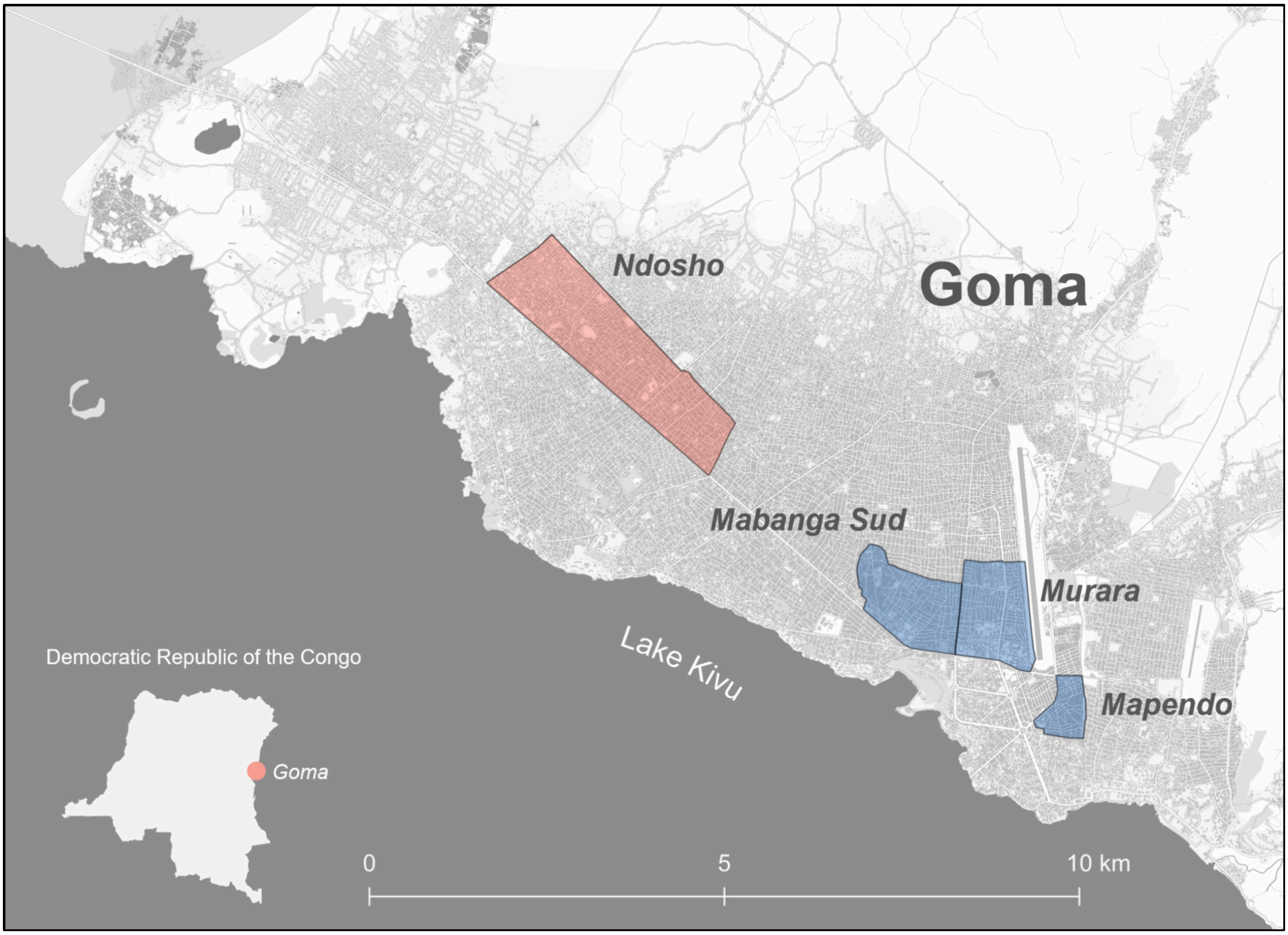

Fig. 1. Map of Goma and the political boundaries of the districts surveyed.

approximately six kilometers from the city center. In 2020, Ndosho obtained grid-based electricity from Nuru's solar mini grid plant (Nuru, 2021). Prior to Nuru's installation, 3 % of Ndosho's population reported access to some form of electricity (Vinck et al., 2017). The districts of Mabanga Sud, Murara, and Mapendo are located closer to Goma's city center. These three districts receive grid-based electricity via SNEL. Overall accessibility rates to some forms of electricity are 67 % (Mabanga Sud), 89 % (Murara), and 55 % in Mapendo (Vinck et al., 2017). The four districts in this study were chosen based on their access to either Nuru or SNEL and the presence of similar types and density of small enterprise commercial activity.

Small enterprises were selected to participate in the study if they had fewer than 10 employees, including the enterprise owner, and relied on electricity as an input to the production of goods and services. The definition of a small enterprise, as well as the differentiation between small and micro-enterprises, varies but ranges from 1 to 19 employees in similar surveys (World Bank, 2014). A representative sample size was determined with a series of power calculations. The total sample includes 128 enterprises of which 52 source from Nuru and 76 source from SNEL (Mabanga Sud = 25, Mapendo = 29, and Murara = 22). Small enterprises were selected using a stratified random sampling protocol applied in each district. We selected streets with known commercial activity and electricity access. To draw our sample, enumerators proceeded linearly from one end of the street to the other to identify enterprises with fewer than 10 employees that required electricity as an input to the production of their goods or services. At each identified enterprise, enumerators flipped a coin to determine whether it should be included in the study. If included, the enumerator would conduct the survey only if the enterprise owner was present, the enterprise had fewer than 10 employees, and confirmation that the enterprise relied on electricity as an input to production.

Respondents were asked a series of structured questions about their electricity supply. We developed our questions following four categories of inquiry used by the World Bank's Energy Sector Management Assistance Program's (ESMAP) Multi-Tier Framework for evaluating electricity access for productive uses (Bhatia & Angelou, 2015). These categories include 1) small enterprise electricity availability and usage, 2) electricity quality and reliability, 3) perceived electricity affordability, and 4) overall satisfaction and value. Additional data were collected on a range of covariates, including general enterprise operations and demographic information on enterprise owners. The survey was administered in either French or Swahili and included only closed-ended questions, with responses in either numeric or Likert-scale format. Non-response was low for the survey, except for a few questions related to enterprise revenue and expenses, which some respondents treated as confidential information. Twenty-seven percent of enterprises declined to answer questions related to revenue and expenses. To account for the non-response to questions of enterprise revenue and expenses, our analysis is presented in two ways. The full Sample ($N = 128$) comprises all survey response data excluding information on enterprise revenue, general enterprise expenses, and electricity expenses, and a sub-sample of 93 enterprises that provides complete information including details on revenue and expenses (Nuru = 38 and SNEL = 55).

This study was conducted in cooperation between the University of Michigan and the Université Libre des Pays des Grands Lacs (ULPGL) in Goma. A team of student enumerators from ULPGL was recruited to conduct the survey using Kobo Toolbox, a web-based survey tool. Enumerators received appropriate training before conducting the survey. The design of the survey included substantial due diligence to develop a robust sampling strategy. We used local input to ensure that the survey maintained social and cultural materiality. The University of Michigan Institutional Review Board and ULPGL's research ethics committee reviewed and approved this study. The survey was conducted over several weeks in September 2021.

Analysis

Our descriptive analysis includes an assessment of electricity access indicators for our full sample of enterprises. Outliers exceeding two standard deviations from the mean were removed from the data. We compare survey responses to a range of questions about energy access among Nuru- and SNEL-connected enterprises using two-sample *t*-tests for continuous response variables and chi-squared tests for categorical responses. We estimate a series of logistic regression models to explore the association between subjective measures of electricity supply quality, perceived affordability, and energy cost-related pressure on enterprise operations. The regression equation is:

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

The dependent variables for our model are binary responses (0 = No; 1 = Yes) to the following prompts: "Do you have sufficient voltage?" (supply quality); "Is your electricity affordable?" (perceived affordability); and "Do electricity costs impose limits on your operations?" (cost-related pressure on operations). Our policy-related independent variable of interest is whether the enterprise is connected to Nuru or SNEL (ES). We control for enterprise net income (NI), electricity expenses (EE), enterprise age (FY), the presence of secondary income sources by the enterprise owner (SI), the education level of the enterprise owner (ED), and the size of the enterprise based on the number of employees (NE). We report odds ratios to examine the likelihood that an enterprise owner agrees with the dependent variables in question. Due to the small size of our sample, categorical control variables with more than two characteristics were recoded into binary variables.

Results

Enterprise characteristics

Most small enterprises are engaged in the sale of goods or the provision of small-scale services (Table 1). Print/copy shops, hairdressers, and convenience stores make up more than half of the total sample. The other enterprise types include music transfer services, tailors/sewing shops, electronics/appliances repair services, mills, pharmacies, bakeries, IT services, jewelry stores, publishers, shoe repair services, and sports betting services. Overall, enterprises exhibit similar characteristics in both study groups. There is no significant difference in the age of the enterprise, although many Nuru-connected enterprises are more recently established. Few enterprises report more than five employees, with 2–4 employees or one employee (the enterprise owner) being most common in both groups. Enterprises report similar numbers of average daily customers and days open per month. However, Nuru-connected enterprises report being open for more hours each day on average.

Demographic data of the enterprise owners show no significant differences between the study groups in the distributions of age, gender, or level of education. The average age of enterprise owners is 34 years. Male enterprise owners make up 60 % of the sample. Most enterprise owners in both groups had completed either secondary school or university-level education. A considerable share of enterprise owners (31 %) report a second income-generating job in addition to the enterprise in question.

In the subset of our sample, we observe substantial differences in enterprise financial performance. Enterprise revenues and net incomes are significantly different between the two groups, with SNEL-connected enterprises reporting higher monthly revenues on average (517 USD) compared to Nuru-connected enterprises (169 USD). Net incomes follow a similar pattern with an average monthly net income of 414 USD among SNEL-connected enterprises and 107 USD for Nuru-connected enterprises. Based on standard deviations, we further observe a wider range of revenues and net incomes among the SNEL sample. Total monthly expenses are not significantly different between the two groups. However, monthly electricity expenses are notably different with Nuru-connected enterprises paying an average of 18 USD and SNEL-connected enterprises paying nine USD on average.

Electricity availability and usage

At the time of this study, most Nuru-connected enterprises had their

Table 1
Enterprise characteristics[a,b].

	Total	Nuru	SNEL
Enterprise type (%)			
Print/copy shop	23	17	26
Hairdresser	18	19	17
Convenience store	16	15	16
Food and beverage stand	12	14	11
Phone charging stations	10	15	7
Other[c]	22	19	24
Year enterprise founded (0/1) (c.f. before 2010)			
2010–2014	25	15	32
2015–2019	41	42	41
2020–2021	24	33	18
Number of employees (0/1) (c.f. one)			
2–4	61	54	66
5–9	5	4	5
Daily customers (number)	31 (19.2)	30 (20)	32 (18.6)
Daily hours open (number)	13 (2.4)	14 (2.6)	13** (2.2)
Days open per month (number)	28 (3)	29 (3.3)	28 (2.8)
Enterprise owner age (years)	34 (9.1)	32 (9.4)	34 (8.8)
Enterprise owner gender (0/1) (c.f. female)			
Male	60	62	59
Enterprise owner highest level of education (0/1) (c.f. no education)			
Primary school	9	10	8
Secondary school	60	67	55
University level	29	19	36
Enterprise owner has secondary income source (0/1) (c.f. no)			
Yes	31	35	28
N	**128**	**52**	**76**
Financial data (sub-sample)			
Monthly enterprise revenue (USD)	375 (739.9)	169 (138.3)	517*** (932.3)
Monthly net income (USD)	289 (612.5)	107 (82.4)	414*** (771.6)
Monthly enterprise expenses (USD)	86 (169.6)	62 (73.2)	103 (211.3)
Monthly electricity expenses (USD)	13 (9.9)	18 (9.9)	9*** (8.2)
N	**93**	**38**	**55**

[a] *P*-values indicate difference between Nuru and SNEL denoted ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
[b] Standard deviations in parentheses.
[c] "Other" includes music transfer services, tailors/sewing shops, electronics/appliances repair services, mills, pharmacies, bakeries, IT services, jewelry stores, publishers, shoe repair services, and sports betting services. The full sample maintains a similar distribution as the sub-sample above with no significant difference between Nuru and SNEL.

connection for one year or less, whereas more than half of SNEL-connected enterprises had their grid connection for more than one year (Table 2). Both groups display similar off-grid electricity usage before switching to grid-based sources. Liquid-fuel generator use was most prevalent in the total sample (46 %), followed by standalone solar panels (24 %). More than a quarter of the total sample (27 %) indicate no prior electricity source before adopting either Nuru or SNEL.

Nuru-connected enterprises report receiving an average of 22 h of electricity each day whereas SNEL-connected enterprises report an average of 5 h. Similarly, Nuru-connected enterprises report using an average of 16 h of their daily available electricity. SNEL-connected enterprises use 6 h on average. Enterprises in the SNEL group report using slightly more electricity than their reported availability, a response that may have been skewed by the use of alternative off-grid electricity sources. When asked if the enterprise has enough electricity to operate successfully, 81 % of Nuru-connected enterprises and 13 % of SNEL-connected enterprises said yes.

Quality and reliability

We assess relative voltage levels subjectively. Respondents were asked if the voltage levels are dim, strong, or fluctuate (Table 3). The results show that 77 % of Nuru-connected enterprises report strong voltage levels, 15 % report fluctuating voltage levels, and 8 % report dim voltage levels. On the other hand, 25 % of SNEL-connected enterprises report strong voltage levels, 54 % report fluctuating voltage levels, and 21 % report dim voltage levels. When asked if the voltage levels are strong enough for successful enterprise operations, 60 % of Nuru-connected enterprises and 21 % of SNEL-connected enterprises agreed.

We asked respondents to approximate the number of power outages experienced in a month of standard operations. On average, Nuru-connected enterprises report two outages, a significant difference compared to SNEL-connected enterprises, which report 29 outages on average. The duration of power outages is also significantly different, lasting 2 h on average with Nuru and 13 h with SNEL. During power outages, 25 % of Nuru-connected enterprises and 55 % of SNEL-connected enterprises report using a generator for backup power.

Limitations to enterprise operations due to power outages appear to be minimal and consistent across both sample groups. We find that 37 % of SNEL-connected enterprises and 17 % of Nuru-connected enterprises report limits to enterprise operations. We see a difference in enterprises reporting limited working hours due to power outages (32 % with SNEL and 12 % with Nuru). Customer-facing operations are minimally affected by outages. Most enterprises (76 %) report that they do not have to turn away customers due to power outages, a consistent pattern across both groups.

Table 2
Electricity availability and usage.[a,b]

	Total	Nuru	SNEL
Time using Nuru or SNEL (0/1) (c.f. no response)			
One year or less	57	87	37
More than one year	41	14	61***
Electricity source before Nuru or SNEL (0/1) (c.f. other)			
Generator	46	39	51
Solar panel	24	27	22
None	27	31	25
Daily electricity available (hours)	12 (9.4)	22 (5)	5*** (4)
Daily electricity used (hours)	10 (7.3)	16 (5.7)	6*** (5.2)
Do you have enough electricity available to operate your enterprise successfully? (0/1) (c.f. no)			
Yes	41	81	13***
N	**128**	**52**	**76**

[a] P-values indicate difference between Nuru and SNEL denoted ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
[b] Standard deviations in parentheses.

Table 3
Electricity quality and reliability.[a,b]

	Total	Nuru	SNEL
Voltage level (0/1) (c.f. dim)			
Strong	46	77	25***
Fluctuates between dim and strong	38	15	54
Voltage level is strong enough to operate your business to operate your enterprise (0/1) (c.f. no)			
Yes	37	60	21***
Monthly power outages (number)	18 (17.4)	2 (2.1)	29*** (14.7)
Duration of a power outage (hours)	8 (8.1)	2 (3.2)	13*** (6.9)
Alternative electricity source used during a power outage (0/1) (c.f. other)			
Generator	43	25	55***
None	32	48	21
Enterprise operations are limited from power outages (0/1) (c.f. sometimes)			
Yes	29	17	37*
No	52	62	46
Working hours are limited from power outages (0/1) (c.f. sometimes)			
Yes	23	12	32**
No	59	73	49
Customers need to be turned away during power outages (0/1) (c.f. sometimes)			
Yes	9	12	7
No	76	76	75
N	**128**	**52**	**76**

[a] P-values indicate difference between Nuru and SNEL denoted ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
[b] Standard deviations in parentheses.

Affordability, value, and satisfaction

We provide a series of subjective measures to understand perceived electricity affordability, value, and satisfaction (Table 4). We note that Nuru-connected enterprises indicate that their electricity is affordable (64 % agree, and 25 % disagree). With SNEL-connected enterprises, we find that 11 % agree, and 82 % disagree. Most enterprises in both study groups indicate that electricity costs do not limit operations. While there

Table 4
Perceived electricity affordability, satisfaction, and value.[a,b]

	Total	Nuru	SNEL
Electricity supply is considered affordable (0/1) (c.f. no)			
Yes	32	64	11***
Cost of electricity limits enterprise operations (0/1) (c.f. no)			
Yes	30	33	28
Electricity usage is limited to save money (0/1) (c.f. sometimes)			
Yes	21	42	7***
No	70	48	84
Electricity supply value for money (0/1) (c.f. good)			
Fair	32	64	11***
Poor	61	23	87
General satisfaction with electricity supply (0/1) (c.f. very satisfied)			
Satisfied	34	71	9***
Unsatisfied	38	12	55
Very unsatisfied	21	2	34
Electricity supplier's customer service (0/1) (c.f. good)			
Fair	27	48	13***
Poor	63	33	84
N	**128**	**52**	**76**

[a] P-values indicate difference between Nuru and SNEL denoted ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
[b] Standard deviations in parentheses.

is no significant difference across both groups, we note that a substantial proportion of both Nuru- (33 %) and SNEL-connected enterprises (28 %) report that electricity costs limit their operations.

To assess whether cost-related pressures may play a role in electricity usage, we asked if small enterprises limit their usage to save money. We find that 42 % of Nuru-connected enterprises limit their electricity to some degree to save money. This is significantly different than SNEL-connected enterprises, of which only 8 % indicate limiting electricity to save on costs.

Nuru-connected enterprises report significantly higher levels of satisfaction compared to those using SNEL. Eighty-seven percent of enterprises connected to Nuru are either satisfied or very satisfied with their electricity supply compared to only 9 % of SNEL-connected enterprises. Similarly, enterprises using SNEL report far higher levels of dissatisfaction, with 90 % indicating they are either dissatisfied or very dissatisfied. We also asked about the electricity product's value for money and the value of the electricity company's customer service. Responses from SNEL-connected enterprises to both questions are overwhelmingly and consistently negative compared to Nuru, which are more varied but nonetheless more positive.

Is mini grid solar associated with electricity reliability and affordability?

We run a series of logistic regression models to explore the association between Nuru's electricity service provision and indicators of energy access related to supply quality, perceived affordability, and energy cost-related pressure (Table 5). We observe strong positive associations between enterprises sourcing from Nuru and indicating sufficient supply quality (voltage). We see that increasing electricity costs are further associated with sufficient quality, driven by the higher cost of Nuru. Perceived affordability is strongly associated with using Nuru's services. Younger enterprises, those among the Nuru sample without prior grid connection, and enterprise owners with a secondary income source are more likely to perceive Nuru-sourced electricity as more affordable. Contrasting perceived affordability, an indicator of overall satisfaction, we see that higher costs also impose several limits on enterprise operations. Likewise, scaling enterprises with two or more employees exhibit signs of cost-related pressures on operations. While there is a strong association between Nuru, electricity quality, and perceived affordability, the cost-related pressure from greater electricity expenses and employee compensation shows clear limitations to operations as costs increase.

Table 5
Association between Nuru electricity service provision, reliability, and affordability.[a,b]

	Has sufficient voltage	Electricity is affordable	Electricity costs limit operations
Electricity source: Nuru (c.f. SNEL)	6.36*** (3.96)	18.33*** (14.77)	1.09 (0.64)
Monthly net income (USD)	1.41 (0.35)	1.12 (0.32)	0.87 (0.2)
Monthly electricity expenses (USD)	2.18* (0.97)	1.46 (0.79)	2.56** (1.06)
Enterprise founded 2020–2021 (c.f. founded before 2020)	0.48 (0.33)	3.64* (2.83)	2 (1.3)
Enterprise owner has secondary income source (c.f. no secondary income)	1.65 (0.96)	4.71** (3.35)	1.69 (0.92)
Enterprise owner is university educated (c.f. secondary school or less)	0.79 (0.47)	1.27 (0.88)	1.86 (1.02)
Enterprise owner has two or more employees (c.f. fewer than two employees)	0.65 (0.45)	1.9 (1.44)	3.72* (2.53)
N	**93**	**93**	**93**

[a] ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
[b] Odds ratios reported with standard errors in parentheses.

Discussion

We find clear differences in the quantity and quality of electricity supplied by Nuru and SNEL. Nuru provides four times as much daily electricity as SNEL, allowing its enterprises to use more than twice as much daily grid-based electricity and stay open longer. Nuru-connected enterprises further report significantly greater energy quality with far fewer outages. Nearly two-thirds of enterprises indicate that voltage levels are strong enough to meet daily operational needs. By contrast, SNEL-connected enterprises are persistently mired with fluctuating voltage levels, compounding the burden of a severely limited daily supply.

Our results identify serious unmet energy needs across the SNEL sample, exemplified by a strong preference for more daily supply. We presume that the low usage among SNEL-connected enterprises is unlikely by choice but rather the result of frequent power outages and limited provision, with remaining needs met using alternative energy sources. More than half of the enterprises connected to SNEL indicate generator usage during power outages, which appear to happen almost daily and last many hours. Outages may not solely be SNEL's responsibility. Unlawful electricity connections are common throughout the DRC (Mbungu et al., 2023), which further adds to poor power quality. While energy stacking may provide adequate supply in principle, the frequent use of multiple energy sources incurs additional costs for fuel and equipment. Notwithstanding the potential impact of equipment failure, purchasing fuel for generators and equipment maintenance adds layers of inconvenience to meet daily energy needs.

In tandem with the differences in quantity and quality, we observe a stark contrast across measures of perceived affordability and value. Whereas Nuru-connected enterprises indicate affordable supply and value for money, we observe a near-opposite set of responses among the SNEL sample. While this is very likely a reflection of the varied energy quantity and quality, additional factors may also be at play. For one, Nuru-connected enterprises had no prior grid connection, so their assessment of affordability and value is relative to alternative energy sources used before Nuru. Similarly, enterprises connected to SNEL are likely to make their assessment alongside costs for alternative sources. While there is no difference between our samples saying that electricity costs limit operations, we see that significantly more enterprises in the Nuru sample limit energy usage to save money. Even with significantly higher levels of perceived affordability and value for money, we find that Nuru's costs add some economic pressure to enterprises. Nonetheless, these results suggest a strong preference for improved energy provision.

We also see a large difference across satisfaction indicators. Nuru-connected enterprises report high levels of satisfaction with both their energy supply and the supplier's customer service. While energy quantity and quality are likely pushing these results, we also see a greater capacity from Nuru to service supply issues. Consider, for example, the difference in power outage duration. The average outage from Nuru is 2 h, while the average outage from SNEL is 13 h. While Nuru's infrastructure is more modern, the company's ability to quickly address supply issues undoubtedly contributes to greater satisfaction. If we use satisfaction as a measure of well-being, we can consider that Nuru's higher-quality services provide customers with greater overall ease – a peace of mind that does not require attention to frequent and lengthy outages or the use of alternative energy sources. Nuru-connected enterprises are paying for convenience, and our results show that enterprises are willing to pay.

Our analysis reveals significant disparities between Nuru and SNEL in terms of electricity supply, quality, affordability, and customer satisfaction. Nuru's provision of reliable, high-quality services, albeit at a higher cost, underscores the value customers place on convenience and reliability, contrasting with SNEL's persistent challenges in meeting energy needs and maintaining customer satisfaction.

This study provides a valuable exploration of emerging energy transitions in urban DRC; however, there are some limitations to this work. First, the data were collected in 2021 during the global COVID-19 pandemic. By the time of the study in September 2021, COVID-19 restrictions had eased, including movement across the Grande Barrière, Goma's port of entry from Rwanda. While Goma had begun its return to business-as-usual economic activity by the time of the study, we acknowledge that the impact of the pandemic may have influenced some results, particularly concerning enterprise revenue and expenditures. Other survey questions were designed to elicit generalized results and are less likely to be influenced by the pandemic. Altogether, we believe our results are generalizable to other settings and time periods. Second, our analysis is primarily descriptive and relies on a relatively small sample. Future studies should use quasi-experimental study designs using baseline and end-line data and collect data across control and treatment groups to allow for attribution of the causal impacts.

Conclusions

As Africa urbanizes there will be a rapidly growing demand for electricity services. Small enterprises will continue to play a critical role in the economic growth and vitality of Africa's cities. The potential for decentralized renewable technologies to replace, augment, or leapfrog current energy infrastructure is exciting and necessary as pressure mounts to expand energy access with low-carbon technologies. This study compares indicators of energy access for small enterprises in Goma, DRC connected to a decentralized solar mini grid (Nuru) or parastatal grid infrastructure (SNEL). The enterprises that fall within our sample are typical of those found throughout African cities and trading centers and therefore provide valuable insights into how decentralized solar systems may benefit the economic development and growth in similar settings across Africa for millions of small enterprises.

Drawing on the World Bank's Energy Multi-Tier Framework for evaluating electricity access for productive uses, we find that enterprises connected to Nuru receive higher-quality electricity that enables greater daily usage. Although Nuru's service comes at a higher cost, enterprises report strong levels of satisfaction, value for money, and affordability. Conversely, SNEL-connected enterprises remain highly unsatisfied, which is likely the result of poor energy provision that includes limited daily supply and frequent outages. Our analysis shows that enterprises are willing to pay for the added convenience of high-quality energy provision. We conclude that decentralized solar mini grids, when providing a reliable energy supply, are a viable solution in settings where existing grid infrastructure is unreliable.

The potential for decentralized solar mini grids to provide primary supply or to augment existing electricity infrastructure should be further studied. Our study suggests that solar mini grids are an important new mode of electricity service provision for urban centers. Future studies should use quasi-experimental study designs using baseline and end-line data, and collect data across control and treatment groups to allow for attribution of the causal impacts. The financial aspects of solar mini grids also merit attention in future research. While our study illustrates that solar mini grids provide an effective strategy for meeting the energy requirements of enterprises operating in urban areas, the high cost of energy services is likely a barrier to some.

The positive assessment of decentralized solar mini grid energy warrants considerable attention given to energy policies at local and national levels. In 2014, the DRC liberalized the energy sector to expand energy access throughout the country (World Bank, 2020). This has, in part, led to the recent proliferation of decentralized mini grids across the country, including Nuru. Legal provisions enabling sector liberalization using low-carbon energy technologies should be further considered. Additionally, appropriate investments, incentive structures, and financial support should be a high priority for governments to expand energy access and reduce costs for end users.

CRediT authorship contribution statement

Joshua Thompson: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Ruffin Bindu Ramazani:** Conceptualization, Data curation, Investigation, Project administration, Writing – original draft. **Cyrus Shannon Sinai:** Conceptualization, Formal analysis, Visualization, Writing – original draft. **Kennedy Kihangi Bindu:** Conceptualization, Data curation, Investigation, Project administration, Writing – original draft. **Pamela Jagger:** Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

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