A Microfinance Model for the Adoption of Decentralized Solar Systems in Urban Informal Settlements: Evidence from India

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ABSTRACT

Over 140 million migrant labourers in India contribute approximately 10% to the nation's GDP, yet many struggle to access essential services, including affordable energy solutions. This paper focuses on the role of microfinance institutions (MFIs) and non-profit organizations in providing affordable green energy solutions to low-income migrant workers residing in urban slums. It highlights the financial and infrastructural challenges these workers face in accessing electricity and LPG, often relying on costly informal sources. Using a unique dataset of 100 migrant workers from Delhi NCR, the study contrasts their energy costs with those of urban homeowners, revealing significant disparities. The paper proposes that partnerships between MFIs and non-profits can bridge these gaps by offering financial models that enable the installation of solar energy systems. By adapting successful case studies from rural areas, the paper suggests a scalable model tailored to the dense, transient, and informal nature of urban slums. This collaboration could lead to more sustainable and affordable energy access, improving the economic well-being and quality of life for migrant workers.

Key Words: *Microfinance, Solar Energy, Energy Economics, Urban Slums, Green Finance, Equitable Access, Informal Economy, India, Renewable Energy Transition*

INTRODUCTION

India is ranked as the fifth fastest-growing economy in the world with an annual GDP growth rate of 6.8% (IMF, 2024). India's economic progress is largely supported by its considerable and dynamic workforce, including a significant segment of inter-state and intra-state migrant labourers. There are over 140 million Indian migrant labourers who contribute 10% to the Indian GDP, their work being primarily concentrated to sectors such as domestic work, construction, mining and factory labour. (Sattva Knowledge Institute, 2023) Despite their crucial role in India's growing economy, a majority of migrant workers are unable to avail the benefits of essential services including government schemes and banking facilities (John et al, 2020). The access to government schemes for interstate migrant workers ranges from only 0.5% to 27.5%, indicating that migrant workers cannot access more than 72.5% of government- provided schemes. This issue roots from migrant labourers' lack of permanent address, limited financial capacity, and in some cases nomadic lifestyles (UNCTAD, 2021), which in turn inhibits their ability to integrate into the formal economic system. This hinders their quality of life, including limited access to education, banking, housing, water and energy (Jayaram et al, 2020). Focusing on the aspect of access to energy in particular, migrant workers in urban slums are forced to rely on informal and expensive sources of energy such as unsubsidized liquified petroleum gas (LPG) and grid electricity which adds to their financial burdens and bills. Microfinance institutions (MFIs) play a pivotal role in enhancing the financial ecosystem for underserved migrant labour, as reflected by their increasing prominence in developing economies where access to traditional banking services is limited. The concept of microfinance gained international prominence through the work of Dr. Muhammad Yunus and the establishment of Grameen Bank in Bangladesh in 1983. Grameen Bank's innovative approach demonstrated that providing small loans to the poor, who typically lack collateral, could lead to significant improvements in their economic conditions. Furthermore, the Reserve Bank of India defines microfinance institutions as "those which provide thrift, credit and other financial services and products of very small amounts mainly to the poor in rural, semi-urban or urban areas for enabling them to raise their income levels and improve living standards." Therefore, MFIs aim to promote financial inclusion and empower economically disadvantaged populations. MFIs also collaborate with non-profit organizations to fulfil these objectives and expand outreach in rural communities (Roy, 2009). The microfinance landscape in India has already witnessed several collaborations between MFIs and non-profits aimed at providing equitable opportunities to low-income populations. These collaborations include a joint program between Grameen Bank and Basix to provide livelihood support to rural communities (Grameen Foundation, 2011) as well as a partnership between Equitas Small Finance Bank and Hand-in-Hand India to provide business training to low-income women entrepreneurs. These initiatives demonstrate the scope of MFI collaborations in increasing economic accessibility in India and emerging economies alike. However, the contribution of microfinance (i) to the green energy sector (ii) to migrant labour, is a novel concept, and thus there exists a dearth in available material on the same. This paper attempts to fill these gaps by exploring the extent to which microfinance institutions can leverage collaborations with non-profit organizations to provide underserved migrant communities with cheaper access to green energy solutions. The originality of this research is fundamentally twofold. First, it contributes to literature on green microfinance in the setting of urban slums. We utilize a unique dataset of 100 migrant workers living in urban slums in Delhi NCR to provide empirical evidence about the limited access to affordable energy solutions. We then employ a t-test to compare these results to those of urban homeowners. Second, we study the models used by 3 MFI and non-profit collaborations. We then modify these models to understand their scope in the context of green energy solutions for migrant workers in urban slums. These results could potentially address the energy needs of migrant workers more sustainably and affordably.

LITERATURE REVIEW

The role of microfinance institutions in promoting renewable energy access is significant and has been prominently studied in the context of developing countries where energy is scarcely accessible. In fact, approximately 675 million people across the globe lack access to modern energy services, such as electricity. Over 2.3 billion people rely on traditional use of fuels and grid electricity for cooking, lighting and domestic heating (International Energy Agency, 2023). Grid electricity is often erratic and inconsistent in rural areas, and experiences frequent power failures. A paper published by IOP in 2019 cites the cause of these failures as the significant gap between urban and rural power service levels (IOP, 2019). The unreliability of rural grid electricity can also be explained by geographical isolation, insufficient supply and power theft (Mudaheranwa 2019). Another significant barrier to rural electrification is the high cost of electricity and customers' inability to pay power bills in full in a timely manner. Lastly, the ecological implications of traditional electricity are dire, as evidenced by the fact that 34 billion tonnes of carbon dioxide is produced by burning of fossil fuels to generate electricity (World Nuclear Association, 2024). Developing nations acknowledge the vitality of clean energy sources for long-term economic sustainability, but limited supply and access to resources creates an opportunity cost between environmental protection and economic development (Mohiuddin, 2006). As renewable energy technologies have advanced, they have been recognized as a balanced solution to reduce trade- offs between economic development and environmental protection by providing reliable and cheap access to non-polluting energy. In the context of developing communities, solar energy has been recognized as a reliable energy source with the easiest infrastructural set-up (SolarNRG, 2022), making it highly prominent in current literature. However, given its high installation of cost, solar energy has a financial barrier associated with it. Overcoming these barriers would require intervention in the form of government policies, provision, livelihood programs and financial support (Renewable & Sustainable Energy Reviews, 2022). Existing literature reviews multiple initiatives undertaken by MFIs to promote renewable energy consumption. One such initiative is Shikhar Microfinance's (SMPL) program to support decentralized renewable energy in Rajasthan, India (Shakti Foundation, 2018). SMPL developed an energy lending portfolio by designing energy-specific loans and products to distribute to SMPL's existing and new consumers. The firm designed two types of loans, one for solar pumps and one for solar home lighting systems. This paper also highlights a five-point strategy for MFIs to implement to ensure successful energy-specific loan rollouts. First, is choosing the right energy enterprise partner that shares a vision and provides reliable products. In the past, MFIs have partnered with reputed solar enterprises such as SELCO (SELCO Foundation, 2024), Shakti Foundation (Shakti Foundation, 2018), and the Solar Village Project (Solar Village, 2022) and have produced successful outcomes. Moreover, MFIs must invest in training of staff to ensure they are well-versed with both aspects of the schemes: the solar energy solutions as well as the microfinance offerings. The importance of solar training for MFIs has also been highlighted by SNV's Green Microfinance Program, an initiative that rolled out extensive training sessions for its microfinance partners to ensure that credit officers have sufficient knowledge about solar technology (SNV, 2016). Furthermore, the paper highlights the importance of attractive incentives for consumers, as well as staff. Monetary incentives such as rebate or additional access to the MFI's financial services can be provided to consumers to incentivize them to avail the loans. A paper by Energypedia suggests that MFIs can conduct awareness campaigns and provide access to savings accounts in order to engage their audience (Energypedia, 2014). It is also necessary for cooperating agencies and governments to provide incentives and support to MFIs themselves, in order to stimulate them to undertake green energy projects in the first place. A majority of microfinance institutions are reluctant to bear the risk of giving out loans for new technologies, making intervention by external organizations highly vital. Existing literature highlights the role of organizations, including cooperating agencies, governments and non-profits in mitigating risks for MFIs by offering guarantees and technical assistance to the institutions in the pilot stages of the project. One example of such an intervention is the CleanStart program by the UN Capital Development Fund (UNCDF) and UN Development Programme (UNDP). This global initiative by the UN aims to create microfinance opportunities to promote renewable energy accessibility. (UNCDF, 2012). The paper presents CleanStart's business model which aims to provide (i) technical services; (ii) risk capital grants; and (iii) concessional loans. Within its technical services, CleanStart firstly, provides awareness and confidence building workshops to incentivize MFIs to undertake solar energy projects, and secondly, brokers partnerships between MFIs and energy suppliers as well as MFIs and consumers. This paper highlights the role of cooperating organizations, in this case the United Nations, in guiding and supporting MFIs to fund renewable energy projects.

THEORETICAL FRAMEWORK & HYPOTHESES

Access to affordable energy solutions for migrant workers

Access to energy for migrant workers is primarily determined by their type and place of residence. As of 2020, most migrant workers in Delhi did not have access to 'adequate housing' as per international human rights law and standards (Ayushmaan, 2020). Adequate housing is defined as "the right of every woman, man, youth and child to gain and sustain a safe and secure home and community in which to live in peace and dignity." 86 percent of participants in the study had been living in rented rooms, including informal settlements (known as Clusters). The Delhi Urban Shelter Improvement Board (DUSIB) estimates that there are 675,000 households in Delhi's slums and informal settlements. Access to the two primary energy sources which are (i) electricity for lighting, heating, cooling and operating appliances (ii) LPG (liquified petroleum gas) cylinders for cooking are likely to be limited and expensive in urban slums and informal settlements due to lack of connectivity and prominence of illegal markets. This has led to the formulation of two preliminary hypotheses.

H1: *The mean electricity price paid by migrant workers in informal settlements is higher than that paid by urban homeowners.*

The price paid for electricity by its consumers should be determined by the consumers' electricity usage over a specified period, which is reflected by their meter. However, there are many households in Delhi NCR that may lack an electricity meter. DUSIB found that of the 675,000 households in Delhi's slums and informal settlements, 25 percent to 30 percent lack formal electricity meters (DUSIB, 2023). Therefore 200,000 to 300,000 households in Delhi alone, consume electricity without meters to track their actual consumption. This allows landlords to overcharge their tenants for electricity usage, often by setting a predetermined electricity fees that can be significantly higher than what residents would pay by the meter. Moreover, electricity consumption differs from household to household and depends on a number of factors including number of residing members, income level of the household, age of residents, and usage patterns (Audenaert, 2011). Therefore, it is unfair to set a standardized electricity fees for all households in a building or complex and is likely to lead to houses being overcharged for electricity usage.

H2: The mean LPG price paid by migrant workers in informal settlements is higher than that paid by urban homeowners.

Informal settlements are likely to lack direct access to LPG (liquified petroleum gas) connections (required for cooking), as evidenced by the statistic that only 50% of urban slum households in India use LPG, either due to poor cylinder delivery or lack of LPG connection (CEEW, 2021). This forces migrants, living in urban slum conditions, to purchase LPG cylinders from illegal, black markets that may sell them for higher prices.

Solar energy as an alternative energy solution

Solar energy can act as an effective alternative to traditional fuel-based electricity and LPG for migrant workers. While its connectivity is still under development, the affordability of solar energy, excluding initial installation costs, is far better than that of traditional energy sources. It is thereby important to evaluate the scope of solar energy as an alternative energy source for migrant workers in urban slums under two primary criteria: scope for connectivity and affordability. In terms of its connectivity, solar energy is still emergent in slums but is being highly encouraged by government as well private initiatives. The Micro Solar Dome (MSD) government initiative that was implemented in Delhi, 2018 has already installed 25,000 domes in slums of Kolkata, Delhi, Pune and Bhopal (Thakur, 2018). Similarly, Project Brighten seeks to provide safe and sustainable access to solar energy to the people of Dharavi Slum, Mumbai- the 3rd largest slum in the world (IDSSA, 2021). These initiatives demonstrate the high potential for solar energy installation in urban slums. However, there arises a challenge involving space constraints in the installation of solar panels in slums. A study on the energy consumption trends of slum areas identifies the most common appliances used by the average slum household to calculate the average energy consumption per household per day (kWh) which came to 4.19 kWh (Shukla, 2019). Moreover, solar panels typically generate 4.5 kWh per kW of installed capacity per day under ideal conditions in Delhi NCR. These mean estimates have been utilized to calculate the average amount of space required to generate solar power for each slum household.

Table 1: *Space Required to Generate Solar Power in Average Slum Dwelling*

Parameter	***Calculation***	***Value***
Daily Energy Requirement	-	$4.19\ kWh$
Average Daily Production	-	$4.5\ kWh\ per\ kW$
Required Capacity	$\frac{4.19\ kWh/DAY}{4.5/DAY\ per\ KW}$	$0.93\ kW$
Space Requirement	$0.93\ kW \times 100\ sq.ft.$	$93\ sq.ft.$

The size of an average house in informal settlements and slums is between 100-125 sq. ft. (Rathore, 2023), which makes it difficult for households to allocate space up to 93 sq. ft. for solar panel installation. Therefore, while individual rooftop installations may be challenging, community solar installations may be more feasible. The establishment of solar mini grids that can provide electricity to a cluster of homes using a centralized solar array is an effective means to distribute solar energy to households in urban slums. Second, it is important to evaluate the affordability of solar energy systems. While the average initial cost of installation per kW is Rs. 50,000 with an operational cost of Rs. 2,000 (Bluebird Solar, 2023), the cost of electricity is less than half of that of traditional fuel-based electricity. While the average cost of fuel-based electricity is Rs. 8/kWh, solar energy costs only Rs. 3.5/kWh, making it more affordable in the long run. Specifically, solar energy has a payback period of 4 years for a 1kW installation. Moreover, if installation costs are subsidized by the government or funded by external organizations, it will make solar highly cost-effective for underserved populations, including migrant workers. This evaluation thereby suggests that solar energy can act as an effective alternative to electricity generated from fuel in urban slums, under two preliminary conditions. Firstly, that it is implemented at a community-level with a centralized system, and secondly that installation costs are reduced via private funding or government subsidy.

H3: *Installation of solar energy solutions in informal settlements will bring down energy prices paid by migrant workers.*

The above evaluation demonstrates that the cost of electricity generated by solar energy is more than half of that of electricity generated by traditional fuels. We predict that the installation of solar energy solutions by private or government organizations can aid in bringing down energy prices paid by migrant workers.

Roles of MFIs and Non-Profits

Solar energy is an effective, sustainable, and cost-effective energy solution that can act as an alternative to traditional electricity as well as LPG. However, given the high installation cost of solar panels, it can be challenging for low-income migrant workers to implement these systems. Moreover, migrant workers will be unwilling to invest such large sums of money for infrastructural changes in their temporary homes. That is where the role of external organizations and institutions comes into place. Intervention by external organizations that could provide financial support, funding or accessible loans to the migrant population for solar installation can be a powerful way to ensure sustainable installation and utilization of solar energy. Scope for intervention primarily lies in the hands of three types of institutions: the government, banks or non-banking financial companies (NBFC), and non-profit organizations. While multiple government initiatives have been implemented in India to expand solar energy outreach to slums, there is an opportunity cost associated with government funding and subsidy. Therefore, there is a limit to which governments can allocate resources and money to solar energy solutions for low-income migrant workers, as they have to cater to other populations and sectors as well. Banks and other financial institutions can act as powerful instruments in financing solar projects through credit, loans and funds. In fact, it would be most appropriate for organizations like MFIs to finance projects that cater to migrant workers. MFIs specialize in microcredit, providing smaller loans at lower interest rates to economically weaker populations. Therefore, the outreach of these institutions to underserved populations is likely to be greater, allowing for such a project to be more impactful. Additionally, MFIs can easily adapt and modify their lending models to cater to the needs of specific low-income groups, including migrant workers. Nevertheless, MFIs lack specialized knowledge about the feasibility of solar energy installations in informal settlements and can solely provide financing for these projects. It is important to involve entities with greater expertise and knowledge of solar energy solutions in particular. Lastly, we need to consider the potential role of non-profits and non-governmental organizations in actualizing these projects. While the funds of non-profits are often scarce and limited to finance such projects at scale, there are multiple organizations that specialize in provision and installation of solar energy. A few examples of non-profits involved in solar energy projects for Indian rural communities include Selco, Shakti Sustainable Energy Foundation, Vasudha Foundation and ProjectChirag. Moreover, these organizations exhibit higher levels of motivation in facilitating underserved communities with work that is both impactful and sustainable (Jansson, 2015). This strong motivation and work ethic is likely to be reflected in the quality of solar energy installations that involve non-profit organizations. Finally, non-profits are likely to be more involved in the lives of those they are serving, as a result of which their outreach is large. Therefore, the expertise, motives and large outreach of NGOs and non-profits highlight the indispensability of their role in solar energy projects for underserved migrant workers. This paper will evaluate the scope and potential effectiveness of collaborations between MFIs and non-profit organizations in facilitating the installation of solar energy systems in urban slums that cater to the temporary residences and limited financial abilities of migrant workers.

METHODOLOGY

Survey

To establish the need for MFI intervention in providing a sustainable power source to low-income migrant workers, this paper aims to highlight the current challenges faced by migrant workers with regard to energy accessibility. This is required to establish the problem and need for a solution. Therefore, a survey was conducted with 100 low-income migrant workers residing in urban slums across Delhi NCR. The sample consists of 60 women and 40 men with occupations ranging from domestic worker, school-support staff, housekeeping staff, construction worker, driver, gardener and guard. The demographic components of the survey included asking respondents about their (i) gender; (ii) occupation; (iii) monthly income; (iv) migration status; and (v) current place of residence. These factors are important to identify additional variables and recognize certain trends, and whether they are concentrated to specific regions or occupations. The next section of the questionnaire surveyed respondents about their (i) LPG supply source; (ii) price of LPG per cylinder; (iii) price of electricity per unit (iv) electricity bill for 3 months prior to the survey; (v) electricity meter; and (vi) recipient of their electricity bill. This information plays a vital role in understanding the current level of energy accessibility in urban slums as well as the financial factors associated with it. A second survey was conducted with a sample of 100 middle class individuals living in official residential colonies across Delhi NCR. The same questionnaire was replicated to survey this sample of adults. The data gained would be used to compare the energy accessibility levels and prices paid by middle class workers living in permanent residences, with those for low-income migrants. This comparison would highlight the potential disparity in energy accessibility between migrants living in urban slums and middle-class adults living in permanent colonies. Therefore, this information is necessary to highlight the extent to which the problem affects migrant populations in urban slums specifically.

Sample Representativeness

Both of our samples of 100 migrant workers as well as 100 middle class adults is representative of the larger population of adults in Delhi NCR (National Capital Region) which includes Delhi, Gurgaon, Faridabad, Noida and Ghaziabad. 36% of our sample of migrant workers resides in Delhi, 28% resides in Gurgaon, 16% resides in Faridabad, 14% resides in Noida, and 6% resides in Ghaziabad. Moreover, the incomes of the migrant workers range anywhere between Rs. 9000 to Rs. 23,000 per month with an average income of Rs. 14,848. This figure is close to the average income of the larger population of Indian destitutes which is Rs. 13,700 per month (Statista, 2024).

Similarly, within our sample of 100 middle class adults, 42% reside in Gurgaon, 33% reside in Delhi, 14% reside in Noida, 8% reside in Faridabad, and 3% reside in Ghaziabad. The average income of this sample is 6.3 lakhs per month, which is close to the average income of the larger population of upper-middle class Indians which is 5 lakhs per month.

Secondary Research

Furthermore, the paper proposes a collaboration between MFIs and non-profits to install solar energy systems in urban slums as a solution. A set of 20 research papers discussing the role of MFIs and non-profits in promoting renewable energy accessibility were consulted to understand the potential of this solution. Next, three specific projects undertaken by MFIs and non-profits to promote solar energy access were identified and extracted from this research. The selected initiatives include the *Community Mini-Grid Installation in Karnataka by SELCO India and Canara Bank*, *BrightLife by Prosper and FINCA Uganda* and the *SHS Program by Grameen Shakti and Grameen Bank Group*. These are projects undertaken by non-profits and funded through microcredit, that target underserved communities across the globe. While not all initiatives are exclusively funded by MFIs, they incorporate aspects of microcredit, offering insights into the broader role of MFIs. The projects were studied in greater detail using blogs, research papers and data published by their respective organizations. Insights into these initiatives were ultimately presented as case studies involving a description and evaluation of the project. Since there does not exist a specific index or assessment tool to evaluate a microfinance and non-profit project, this paper employed a 3-point evaluation inspired by Zwikael's model in his paper titled "Evaluating the Success of a Project and the Performance of Its Leaders" (Zwikael, 2019). The three factors assessed are relevant to involvement of MFIs and non-profits in solar energy projects and include (i) financial structure; (ii) community impact; and (iii) long term sustainability.

Unstructured Interview

Followed by this, an unstructured interview with the head of a microfinance institution in India was conducted where in the expert was interviewed about the potential challenges MFIs would face in funding solar energy projects for low-income migrant workers. An understanding or the barriers to such a project is vital in order to propose an effective model that overcomes the same. Insights from the case studies and interviews were ultimately collated into a new model that presents a feasible approach to be undertaken by MFIs and non-profits in order to facilitate solar energy accessibility for Indian migrant workers in urban slums.

FINDINGS

The key findings from our survey demonstrate a need for a cheaper source of energy for electricity and cooking. As of 2024, the electricity charges in Haryana are Rs. 2 per unit for up to 50 units, Rs. 2.5 per unit for 51-150 units and Rs. 5.25 per unit for 151-250 units. In Delhi, there are no electricity charges for consumption under 200 units, and the charge for 201-400 units is Rs. 4.5 per unit. However, no low-income migrant interviewed is paying below Rs. 6 per unit of electricity, with a majority paying Rs. 10 per unit.

Table 2: *Price paid per unit of Electricity by Migrant Workers across Delhi NCR*

Price per Unit of Electricity (Rs.)	Number
10	26
8	6
6	1

This discrepancy exists due to the fact that a majority of these migrant workers are paying electricity bills to their landlords, who have set prices as high as Rs. 10 per unit. This highlights the need for a centralized source of electricity that charges consumers fairly. Moreover, LPG prices paid by a majority of migrant workers are marginally higher than standardized LPG prices. As of June 2024, a 14.2 kg LPG cylinder costs Rs. 811.50 when bought via gas connection in Delhi NCR. However, a majority of informal settlements and urban slums lack access to LPG connections, thereby forcing migrant workers to purchase LPG cylinders from black markets where they can cost almost double of what they do when bought via LPG connection. In fact, 79% of the respondents pay a price higher than the standardized LPG price of Rs. 811.50 as evidenced in the following table.

Table 2: *Price paid per LPG Cylinder by Migrant Workers Across Delhi NCR*
(Note: The prices reflected are for a standard 14.2 kg Cylinder)

LPG Price per Cylinder (Rs.)	Number
811.50	7
1,000	5
1,100	6
1,200	7
1,300	5
1,400	2
2,100	1

Based on the above findings, the average price of electricity paid by low-income migrants with an average monthly salary of Rs. 14,848.48 is Rs. 9.52 per unit whereas the average LPG price paid by them is Rs. 1,123.65 per cylinder. Comparing these values to the electricity and LPG prices paid by upper middle-class individuals living in official residential colonies, with an average monthly salary of Rs. 5.9 lakhs, we find that the average price of electricity is Rs. 6.90 per unit and the average LPG price is Rs. 817.50 per cylinder for the upper middle-class group.

***Figure 1**: T-Test for Difference in Mean Electricity Price between Low-income Migrants and Middle-Class.*

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} = \frac{6.90 - 9.52}{\sqrt{\frac{0.349^2}{100} + \frac{1.0038^2}{100}}} = \frac{-2.62}{0.10627} = t \approx -24.65$$

Degree of Freedom: $df = (n_1 - 1) + (n_2 - 1) = (100 + 100 - 2) = 198$

Critical t-value for $df = 198$ and $\alpha = 0.05$: $t_{critical} = 2.000$

Since $|t| = 24.65$ is much greater than $tcritical = 2.000$, the p-value will be significantly lower than 0.05.

This indicates a highly significant difference between the mean electricity prices paid by low- income migrant workers and middle-class individuals.

***Figure 2:** T-Test for Difference in Mean LPG Price between Low-income Migrants and Middle-Class.*

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Degree of Freedom: $df = (n_1 - 1) + (n_2 - 1) = (100 + 100 - 2) = 198$

Critical t-value for $df = 198$ and $\alpha = 0.05$: $t_{critical} = 2.000$

Since $|t| = 11.81$ is much greater than $tcritical = 2.000$, the p-value will be significantly lower than 0.05.

In both the cases of electricity and LPG prices, the p-value is significantly lower than α=0.05, which indicates a highly significant difference between the mean LPG and electricity prices paid by low-income migrant workers and those paid by middle-class individuals. Moreover, the ratio of average income to average LPG and electricity prices paid by both groups represents a significant disparity in the affordability of energy between different sections of society. Assuming that an average low-income household consumes 150 kWh of electricity per month and an average middle-class household consumes 580 kWh per month (CPR, 2021), the average middle-class consumer spends 0.68% of their monthly income on electricity, where are the average low-income consumer spends 10.00% of their monthly income on electricity, despite electricity consumption being significantly higher for the average middle-class household. Similarly, the average middle-class consumer spends 0.15% of their monthly income on purchasing an LPG cylinder whereas the average low-income household spends 7.57% of their monthly income on the same. Therefore, the survey results exhibit the dire need for intervention, specifically through an improved energy solution that is affordable and suitable to migrant workers living in urban slums. Due to the informal nature of these settlements, many are not officially recognized by government agencies and thus lack regulatory permissions and access to centralized electricity and LPG connections. It is therefore vital to install an alternative energy source such as solar energy that is more reliable, affordable and suitable to vulnerable migrant populations.

This conclusion is supported by the comparison between mean solar energy prices per unit of electricity with grid electricity prices per unit of electricity. Assuming that a solar PV system has a life of at least 25 years, the per unit levelized cost of solar energy is Rs. 7 per kWh for the next 25 years, while the per unit levelized cost of electricity for low-income workers is Rs. 9.51 per kWh. This implies that solar energy is significantly cheaper than electricity when upfront installation costs are eliminated.

This paper proposes that the most effective means of intervention would be for non-profit organizations to collaborate with MFIs to introduce affordable and accessible approaches for low-income migrant workers to gain access to solar energy. This proposal has been supported by the assessment of three previously undertaken collaborations between non-profits and MFIs to promote solar energy in rural areas. The findings have been presented below as a case study and evaluation of each collaboration.

Community Mini-Grid in Karnataka by SELCO India funded by Canara Bank

Funded by Canara Bank, SELCO India installed a solar mini-grid system in a residential colony for migrant labourers in Karnataka. The collaboration between SELCO India and Canara Bank represents the scope of partnerships in providing sustainable energy solutions to underserved communities in India. SELCO India is a non-profit organization founded in 1995 by Dr. Harish Hande (Mitkowski, 2009). SELCO aims to improve the quality of life of rural communities through affordable solar energy. SELCO specializes in solar home systems, solar water heaters, and other solar-powered appliances (Solutions- Selco India, 2021). The project was funded by Canara Bank, an Indian public sector bank, based in Bangalore, India. Canara Bank funded the project under its Agriculture and Rural Credit Schemes program that is dedicated to empowering rural progress and financial growth (Canara Bank Agriculture and Rural Credit Schemes- 2015).

Background

A residential apartment for migrant labourers in Karnataka lacked access to centralized electricity. This forced residents to use kerosene for light at a cost of Rs. 150-200 per month. Kerosene is difficult to procure and poses many health-related risks including respiratory and digestive problems (ATSDR, 2014). Residents also paid an additional Rs. 60-70 for mobile charging. Moreover, the site was not recognized as a formal settlement by government agencies, and any alternate electric service provider would charge a minimum fee for each meter even if electricity was not consumed. Therefore, a solar mini-grid system was implemented as it offers reliable power supply, has low operational costs, and works off the grid. Furthermore, lack of space on the roofs of the houses and shading in certain areas, made a centralized mini-grid system ideal as compared to the installation of individual solar systems on each house. Specifically, the system contained 1.2 kW solar PV panels with eight 200Ah batteries and powered all 75 houses across the building. The system fulfils the energy requirement of all 75 houses, which includes powering a 3W LED and mobile charger in 60 of the houses, and powering two 3W LEDs, mobile charging, a 14W fan and 30W TV in the remaining 15 larger houses.

Financial solution

SELCO India tied up with Canara Bank to provide a loan for Rs. 4,14,000 to the owner of the building. The loan is to be repaid over 5 years at 21% interest. Canara Bank suggested that the owner take Rs. 140 per month from all migrant residents to recover loan costs. This fee is reasonable as it is lower than the previous cost of kerosene and mobile charging, for a more reliable and safer source of energy.

Community impact

Approximately 400 people benefit from the electrification of the 75 households in this community, including the migrant workers and their families. Furthermore, the solution allows households to save money otherwise spent on kerosene and mobile charging, while also enhancing their safety and health by preventing constant exposure to kerosene.

Long-term sustainability

The houses are primarily occupied by temporary migrant workers who stay for a few months at a time, resulting in a constantly changing resident population. Installing a centralized mini-grid system, rather than individual solar systems, provides a sustainable solution. It ensures a consistent power supply to all houses, regardless of the frequent turnover of residents and variations in power consumption. The centralized system is operated and maintained by the building owner and funded by small fees collected from the residents. This approach eliminates the risk of the vulnerable and temporary migrant residents being held accountable for the maintenance and energy supply of the system, which would be a concern if individual systems were installed in each household. The monthly fee collected to help cover the loan repayment, is also fair and affordable for all residents as opposed to electricity or kerosene costs. Finally, solar energy is highly reliable when compared to decentralized electricity or kerosene, ensuring a consistent power supply over the long run.

Prosper by BrightLife funded by FINCA Uganda

Launched in 2019, by BrightLife and FINCA Uganda, Prosper is an initiative that allows low- income Ugandans to access a variety of clean energy products provided by its parent company BrightLife. Additionally, the initiative offers financial solutions including savings and credit products via FINCA Uganda. Both BrightLife and FINCA Uganda are subsidiaries of the Foundation for International Community Assistance (FINCA International), a global pioneer in microfinance established in 1984. BrightLife brings solar energy to thousands of low-income households in Africa through innovative financial models, while FINCA Uganda creates opportunities for loans and microcredit to support Propser's underbanked clients.

Background

BrightLife was launched when nearly 90 percent of Ugandans lived without electricity. BrightLife aimed to provide affordable solar lanterns, solar home systems and cooking stoves to increase access to renewable energy. While BrightLife hit its milestone of impacting 1,00,000 lives in Uganda in 2018, a huge obstacle impeding many from accessing renewable energy was the financial barrier. Henceforth, Prosper was launched by BrightLife in collaboration with FINCA Uganda, a national microfinance institution, to increase access to energy and finance.

Financial solution

Prosper divides its financial models into three stages. First, is the Light-Up stage, wherein customers purchase any solar home system from BrightLife using a Pay-As-You-Go model, which spreads the payment over a period of 12 months. This allows low-income households to easily purchase the solar systems by breaking down the cost into manageable monthly payments. This is followed by the Prosper stage, wherein customers who repay their loans in full and on time receive a 20 percent refund as an incentive for timely repayment. This also makes the customers eligible to join FINCA Uganda and thus gain access to its financial services. Third, is the Grow stage wherein the 20 percent rebate is deposited, with the customer's consent, into a FINCA Uganda savings account. This deposit serves as collateral and therefore the customer is pre-approved for a loan from FINCA Uganda of up to Rs. 55,000. This financial model thereby fulfils two objectives: (1) increasing access to solar energy through small monthly payments, and (2) enabling BrightLife to credit test customers that FINCA Uganda otherwise may not reach.

Community impact

By 2020, Prosper had impacted 1000 lives with solar energy solutions across Uganda. Three months after its launch, it was found that a total 200 to 250 people were signing up for the program per month. At this rate, Prosper is likely to have impacted at least 15,000 people since its inception. Alongside, all of these people were provided with the opportunity to have their credit score assessed, making many eligible to join FINCA Uganda, where some have been able to access loans ranging up to Rs. 45,000.

Long-term sustainability

Prosper's pay-as-you-go model is financially sustainable by breaking down the upfront cost for customers into manageable monthly payments over 12 months. The 20% rebate incentivizes timely repayments and is deposited into a FINCA Uganda savings account, which helps customers build collateral for future loans and ensures long-term financial stability. However, the 12-month repayment period may be a financial strain for some, hindering their ability to repay the loan on time and thus access the rebate. Furthermore, BrightLife ensures centralized maintenance of the solar energy systems which provides consistent service delivery, and increases user-friendliness for its customers, but ongoing maintenance and customer support, especially after expansion, are very technical and crucial for long-term success. These aspects must be handled correctly to ensure that this model is sustainable. Lastly, Prosper reduces reliance on harmful kerosene, supporting environmental sustainability and improving community well-being across rural areas in Uganda over the long run (WHO, 2014).

Solar Home Systems Program by Grameen Shakti funded by Grameen Bank Group

Grameen Shakti was established in 1996 by the Grameen Bank Group with the intention of providing electricity to rural communities in Bangladesh at an affordable cost. The Grameen Bank Group was the first microcredit organization in the world, founded in 1983 in Bangladesh. It's subsidiary, Grameen Shakti launched the Solar Home Systems Program, which has installed more than 1.8 million SHS across rural Bangladesh. Although Grameen Shakti runs independently as a social enterprise, a large amount of its funding and loans comes from its parent company Grameen Bank. The SHS program therefore exemplifies an impactful collaboration between a social enterprise and a microfinance institution in the provision of solar energy systems.

Background

In the early 1990s only 45% of the Bangladeshi population had permanent access to electricity. This severely impacted the economic and social lives of rural people. In 1995, Professor Mohammad Yunus undertook a project to install and test 20 units of SHS in Bangladesh. The success of this project led to the establishment of Grameen Shakti and the SHS program to provide electricity to the people of rural Bangladesh at an affordable cost. After its inception, Grameen Shakti focused on leveraging experience and funds from Grameen Bank to increase its outreach. Over a short course of time, the number of Bangladeshis with access to electricity rose to 92% out of which 13% can be attributed to the SHS program by Grameen Shakti.

Financial solution

The SHS program utilizes two primary models. First the use of microcredit to support low-income households in the installation of SHS and second the free of cost provision of SHS in certain rural areas. During its initial stages, the SHS program extracted funding from Grameen Bank and the Grameen Trust to disseminate free of charge solar home systems across rural Bangladesh. After further expansion, Grameen Shakti tied up with Grameen Bank to promote the purchase of solar energy systems rather than just their provision. Grameen Shakti uses Grameen Bank's existing model of providing collateral-free loans to low-income individuals, targeted specifically at solar energy installation. This approach allows consumers to pay for the system in instalments over a 2–3-year period. Therefore, the SHS program's financial model assists in provision of solar home systems, as well as encourages low-income workers to spend on solar energy using microcredit.

Community impact

Since its inception in 1996, the SHS program has installed more than 1.8 million SHS across Bangladesh. This large network of solar home systems generates 300 MWh electricity every day. The project has benefited over 8 million rural people, making energy accessible and affordable. With over 18,00,000 units installed, the SHS program accounts for 25 percent of the world share in installation of solar home systems. Moreover, the impact of this project has extended beyond mere energy provision to areas such as rural education and income generation. Previously used kerosene lamps were not sufficient for studying, but the introduction of solar electricity resolved this situation significantly, facilitating better education for students. Grameen Shakti has quantified this impact as a potential return of \$80-\$150 per month as a result of improved educational opportunities with SHS. Furthermore, SHS has allowed rural shops to extent business hours, resulting in greater income generation. Lastly the health impact of the initiative is likely the most significant. SHS has replaced 184,845,132 tons of kerosene consumption with solar energy systems, thereby preventing health-related risks caused by kerosene emissions.

Long-term sustainability

The long-term sustainability of the SHS program is exemplified by its well-integrated financial model and significant community impact. Funded primarily through Grameen Bank's microcredit system, the program allows low-income households to access solar home systems on a manageable instalment basis, making this solution financially viable and therefore sustainable in the long run. The SHS program's long-term sustainability is evident in its extensive reach since its inception in 1996, impacting over 8 million lives. Furthermore, the initiative provides reliable electricity as a means to improve education, generate income, and reduce health risks associated with kerosene usage. The collaboration between the social enterprise Grameen Shakti and its parent company and MFI Grameen Bank demonstrates a scalable and replicable solar energy model for rural communities.

Challenges

While the case studies have proven successful in their target rural communities, there will arise certain challenges in implementing a similar model in urban slums and informal settlements where geographic and demographic factors differ significantly. The potential challenges along with the strategies to overcome them have been identified in the next section of the paper, in order to facilitate the formulation of a new model that effectively caters to the needs of migrant populations in urban slums.

1. **High Population Density**

Slums and informal settlements in urban areas are often densely populated. India's largest slum Dharavi itself has a population density of over 3.4 lakh/km2 (Kaushal, 2021) emphasizing the limited amount of available space in such settlements. The average size of a house in Dharavi is 110 square feet (Gulankar, 2020) and the average solar panel require 17.5 square feet of space (O'Brien, 2020). Assuming the average slum household power consumption to be 150 kWh, each household will require 3-4 panels which will take up anywhere from 52.5 square feet to 70 square feet of space. These space constraints make it difficult to implement individual solar home systems in slum areas. A solution to this problem would involve implementing a decentralized mini grid that can serve multiple households from a single installation.

Lack of Legal Recognition

Approximately half the slums in India are not recognized by the government and have a non-notified status (Arise India, 2020). This creates barriers to legal rights and basic services such as access to energy. The lack of legal recognition may introduce regulatory issues involving the installation of solar grids or home systems in informal settlements. Involvement from a non-profit is crucial in overcoming this problem. Along with basic advocacy, non-profits can reach out to local authorities and governments as credible organizations to obtain temporary permissions for implementing the project. Additionally, non-profits can assist residents in documenting their presence and energy requirements to highlight the community's need for energy services (Mahila Housing Trust, 2023).

2. **High Mobility of Residents**

Insights from the above case studies have been synthesized to formulate a new model the proposes the installation of solar energy systems for urban migrant workers. The objective of this model is to provide affordable and accessible solar energy to low-income migrant workers living in urban slums and informal settlements in Delhi NCR through a partnership between a non-profit organization and a microfinance institution.

Proposed Model

Key Components

The first component in the case studies that can be applied to this model is the partnership structure. The partnership structure will consist of a non-profit organization and a microfinance institution. The non-profit will be responsible for educating building owners and community regulators about the need for solar energy, implementing the solar energy solutions and providing technical support to its users, as has been done by Grameen Shakti in their SHS program. Furthermore, the MFI will be responsible for devising financial solutions that cater to migrant workers lacking permanent addresses, such as collateral free loans, microcredit, and payment in monthly instalments to make the solar energy systems affordable for low-income households. The second component of the model is the target community. Unlike the solutions in the case studies, this model does not target rural areas and instead is directed towards slums and informal settlements located in urban areas, where regulatory permissions are typical stricter (Burra, 2005). Another limitation that arises in urban slums is the high population density which makes the installation of individual solar home systems difficult due to limited space and shading issues. Furthermore, given the high mobility of migrant workers in urban slums it is important to implement a centralized model that can be managed by a local entity such as building owners, ensuring continuity of service regardless of resident turnover. In recognizing these challenges, this model suggests a centrally controlled solar energy solution, similar to the mini-grid system installed by SELCO India in

Karnataka. The third component of this model is the solar energy systems. Given the limited space in urban slums and transient lifestyles of migrant workers the most ideal solar solution would be to install a centralized mini-grid that can supply power to multiple households from a single, central location. This approach is advantageous to densely populated slums where spatial capacity for individual houses is limited. Therefore, a central location within the settlement can be allocated to installing the solar mini grid. The mini grid will then be connected to individual households using two primary components: wiring and transformers (Reyn, 2011). The model proposes that the mini grid should be installed by local authorities and landlords. Foreseeing that certain challenges will arise in convincing these entities to install solar energy systems, MFIs must intervene by offering these entities financial incentives.

The final component of this model is the financial solutions. The financial solutions used in the three case studies have been extracted and adapted to the financial capacities of migrant workers as well as local authorities and landlords in urban slums to suggest a unique payment plan. The installation of the mini-grid system by local authorities and landlords in the settlements will be challenging given that many not prioritize the welfare of the migrant workers. This is where MFI intervention is necessary. MFIs must devise manageable loans that can be paid by these entities through periodic instalments. Furthermore, the model suggests that the entities can collect a fixed fees from its migrant workers every month in order to recover the initial installation cost. MFIs can determine the fees amount by setting a cap lower than the existing electricity and LPG bills being paid by the migrant workers. This financial model is feasible as it is fair to both the authoritative entity as well as the migrant residents. In order to further incentivize local authorities into installing the solar mini-grid, MFIs can provide a rebate of a certain amount to the entity, that can be distributed between the homeowner and the tenants. Therefore, the proposed financial model incorporates a mini-grid owned by an authoritative entity in the settlement, along with a pay as-you-go model that allows the owner to pay off the amount in monthly instalments, by collecting a fee from its tenants.

Implementation Strategy

The implementation strategy divides the program into 4 phases based on an approach similar to that utilized by the models in the case studies.

1. **Needs Assessment:** This stage involves conducting a thorough needs assessment to understand the energy requirements and living conditions of the target community along with the financial capabilities of the homeowner or local authority who is responsible for the installation.
2. **Selection of Mini-Grid:** Based on the assessment, an appropriate size for the mini-grid will be determined, based on which a central location within the informal settlement will be allocated for the installation of the grid system.
3. **Formulation of Financial Model:** Based on the size and model of the mini grid, as well as the credit score of the responsible entity, the MFI involved will devise a payment plan, suggestively a loan that allows the entity to pay off the amount in monthly instalments at a fair interest rate. MFIs must provide a fair repayment period and lower interest rate to incentivize the installation. MFIs can further involve themselves in this process by suggesting a fixed fees that the homeowner or local authority can collect from its low-income tenants to pay the instalments. It is important that the MFI sets the fees amount to ensure that the party in power does not exploit its tenants with a greater fees amount.
4. **Installation of Solar System:** The non-profit organization will monitor the installation of the solar system and will be responsible for ensuring its connectivity, reliability and power supply. Furthermore, the non-profit should educate tenants about the benefits of utilizing solar energy as well as offer technical assistance and maintenance to the owner as when required. This ensures that neither the homeowner/local authority nor the tenants are held accountable for the functioning of the solar mini grid.

This implementation strategy can be used for the pilot phase of the project in select urban slums. Followed by this, insights and takeaways from the pilot phase can be utilized to refine the model for further expansion into other urban slums and informal settlements.

CONCLUSION

As the world advances, increasing attention is given to the challenges and needs of underserved communities, leading to the emergence of solutions for these problems. Microfinance institutions represent one such solution, helping underserved communities overcome financial barriers and limitations that restrain their ability to improve their quality of life. In today's world, a huge aspect of quality of life is accessibility to reliable energy sources. Not only is energy vital to sustain one's livelihood and daily activities, but consistent access to energy can improve productivity and generate a higher income for households (Zahid, 2008). This paper recognizes the importance of access to a reliable and sustainable source of energy and establishes a gap within this area in context to low-income migrant workers residing in urban slums. Our findings highlight the significant disparity in energy prices paid by the underserved community of migrant labour and upper middle-class individuals, thereby recognizing the financial barriers pertaining to energy access. In recognizing the increasing prevalence of MFIs in providing financial assistance to low-income communities, the paper proposes a solution involving intervention by both MFIs and non-profits to increase energy access. The scope and viability of this solution is highlighted by the three initiatives that were evaluated, all of which present a viable financial solution, demonstrate high levels of community impact and can be sustained over the long run. We therefore emphasize the indispensable role played by microfinance services and non-profits in providing sustainable and financially feasible energy to underserved communities. Our proposed model draws inspiration from the frameworks of previously undertaken initiatives and adapts them to make them suitable to the transient lifestyles of migrant workers and living conditions of urban slums. The challenges identified under these circumstances include space constraints due to high population density, lack of sustainability due to high mobility of residents and regulatory issues caused by lack of legal recognition. These barriers have been considered to formulate a feasible model that encourages MFIs to allocate financial resources towards partnerships with non-profits in order to mitigate the severity of the current energy crisis and promote reliable, sustainable and financially viable access to energy for low-income migrant workers living in urban slums.

DECLARATION

All authors declare that they have no conflict of interest.

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