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Does involvement of local community ensure sustained energy access? A critical review of a solar PV technology intervention in rural India

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ABSTRACT

The solar photovoltaic (PV) technologies offer a sustainable solution to energy-poor communities. Adoption and sustained use of solar PV merit participation of local communities in planning and implementation. The literature on off-grid solar PV interventions that do not take the approach of involving communities point towards the difficulties experienced in reaching the bottom of the pyramid (BoP) communities as wells as in supply chain and after-sales service. Similarly, there is a gap in scientific literature that explores community inclusive initiatives to foster sustained uptake of solar PV technologies. Our study fills this gap, and discusses: 1) pathways to engage with rural poor communities to promote solar off-grid access, and 2) the impact of engaging with these communities particularly women, on their energy security and livelihood opportunities. We study a two-phased intervention in rural poor setting in Dungarpur district of Rajasthan state in India. The intervention can be broadly classified into two phases: (i) the distribution of solar study lamps to rural school students and mothers, wherein the lamps were assembled and maintained by the local community (self-help group networks), (ii) the entrepreneurship development of local community members towards continued livelihood through solar. We adopted mixed methods approach to collect and analyze the quantitative data from beneficiary households, while qualitative data were collected from SHG members. Our findings demonstrate the utility of localized intervention and the significance and challenges of engaging local communities. The consumers used these solar lamps for multiple activities and prefer solar over grid electricity for basic lighting. The voltage fluctuations or poor quality of electricity supply influences the preference to solar over the conventional grid. Local services enabled continued functioning of lamps, thereby increasing consumer confidence. The intervention built capacity of and created continued livelihood opportunities for local women in these communities, resulting in their economic and social growth. Appropriate capacity building and support to the SHG federations can channelize clean energy interventions at required speed, quality, and coverage. In the context of energy poor BoP communities of the Global South, our research provides key determinants impacting development of community-centered renewable energy interventions, crucial for the realization of Sustainable Development Goal 7.

1. Introduction

The potential that off-grid solar photovoltaic (PV) technologies offer in providing a solution to energy-deprived, bottom of the pyramid (BoP) rural communities is well recognized (Hil Baky, Rahman, & Islam, 2017; Mandelli, Barbieri, Mereu, & Colombo, 2016; Pode, 2013). Nonetheless, its adoption and sustained use remain a challenge (Hirmer & Cruickshank, 2014; Ulsrud, Rohracher, Winther, Muchunku, & Palit, 2018). Sufficient existing literature on off-grid solar PV interventions in the Global South discuss their technical, economic, institutional, socio-cultural, policy, and environmental barriers, and prescribe measures to overcome them (Chaurey & Kandpal, 2010; Friebe, von Flotow, & Täube, 2013; Karakaya & Sriwannawit, 2015; Yaqoot, Diwan, & Kandpal, 2016). Increasingly, the need for the 'participation of local communities' in planning and implementation has been emphasized (Choragudi, 2013; Emili, Ceschin, & Harrison, 2016; Singh et al., 2018; Yaqoot et al., 2016). Studies continue to recommend the involvement of local stakeholders in the implementation of

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off-grid solar PV technologies (Holtorf, Urmee, Calais, & Pryor, 2015), specifically highlighting the importance of local technicians to provide after-sales service (Barman, Mahapatra, Palit, & Chaudhury, 2017). This article presents a reflective, analytic interpretation of the localization efforts in an action-oriented intervention for providing off-grid solar energy access in the BoP community that holds potential towards contributing towards the realization of Sustainable Development Goal 7.

There has been limited evidence-based empirical studies that analyze community-based participatory off-grid solar initiatives in the Global South (Brunet, Savadogo, Baptiste, & Bouchard, 2018). As Lemaire (2018) points out, despite more than four decades of existence of small decentralized solar PV systems in developing countries, not much evidence is available about its beneficial impacts given a small number of systems disseminated and the poor viability of solar projects at that time. It is only in the past 15 years that the scaling up of solar systems has taken place in a limited number of countries, the most notably being Bangladesh and Kenya.

In the context of the prominence gained by the participatory approach that emphasize engagement of local people in the intervention in order to increase the prospects of sustainability (Cieslik, 2016), we briefly discuss the diverse and dispersed nature of multiple players as well as the approach adopted by them regarding community involvement and their impacts in the Global South. Multiple players including government, non-governmental organizations (NGOs), and private enterprises are promoting various solar energy based models towards providing reliable electricity access to the BoP communities in rural areas. These models offer diversity in the financial arrangements, such as subsidy, grant, rental, fees for service, pay as you go, cash and credit sales as well as end-user ownership, which could be individual, community, or enterprise (Singh, 2016). Moreover, some of these models undertake the approach of 'not involving communities in the implementation', while others have adopted the approach of 'involving communities as the key stakeholder in the implementation'. In the light of the ability of the solar intervention in providing electricity access to rural BoP communities, we discuss a few models that did not involve the community in implementation followed by models that had community involvement at its core. The comparison of impacts created by both these models are also discussed briefly.

An empirical study conducted in Sri Lanka on the project that implemented Solar Home Systems (SHSs) via market-based micro-financing showed that despite the microloan facility of three-years the product was unaffordable for the poor households given its high cost (Laufer & Schäfer, 2011). Although the benefit of the intervention was an improved quality of life, the users were dissatisfied with the limited capacity of SHSs and frequent functionality issues, specifically inoperable equipment. The dependency on the solar firms located at afar was evident due to the lack of knowledge at the local level. These concerns called for adequate maintenance service, robust technologies, and the need for technological knowledge at the local level (Laufer & Schäfer, 2011). A study in Kenya, by Jacobson (2007), where the solar market is largely unsubsidized showed that rather than the rural poor, the rural middle class has benefited from solar electricity. Solar electricity enabled the use of connecting devices (T.V., mobile phone), but did not have much of an impact on education, income generation, economic productivity, poverty alleviation, and sustainable development (Jacobson, 2007). The impact assessment study by Naah (2015) of SHSs implemented in Ghana by Ghana Energy Development and Access Project (GEDAP) showed that benefits such as brighter lighting, cheaper option for charging mobile phones, improved health-care services could not influence the solar users since 50% of them preferred grid-tied electricity. The users expected SHS to be competitive in terms of system capacity and quality of services. Moreover, accessing the SHS was unaffordable for people without the support of the heavy subsidy, while other threats included lack of supply chain, low technical know-how, rapid grid extension, and high- interest rates charged by the banks resulting in social exclusion (Naah, 2015). Another study of the same project by Steel, Anyidoho, Dadzie, and Hosier (2016) pointed out that despite the positive response to SHS from the people, threats to sustained market growth emerged due to breakdown and weak supply chain with lack of immediate availability of replacement parts. The critical complaint consumers had was delays in repairs caused by the lack of local technicians. Jolly, Raven, and Romijn (2012) have studied five business initiatives in India, which they found to be successful in terms of replication, geographical expansion, organizational growth, and increased customer base. However, these initiatives could not reach the BoP communities given these communities' lack of credibility in the market since they lack the assets. The impacts observed in the interventions discussed above are primarily in terms of betterment in quality light and quality of living as well as the exclusion of the BoP communities, which are echoed in the comprehensive review of the research by Lemaire (2018) on the impacts of small decentralized solar PV systems in the Global South. Furthermore, gaps are noticed in research about operations and interactions between users and installers on the ground, job creation at a local level by solar companies and retailers, long-term social impacts on community (for example the increased inequalities between those who can afford solar systems and those who cannot), and SHS value chain (Lemaire, 2018).

We now discuss models that adopted the approach of 'involving communities as the key stakeholder in the implementation'. The Barefoot College, based in Tilonia-Rajasthan in India has, since, 1989, involved and trained local village people, mainly women, across South Asia, Africa, and Latin America to become Barefoot Solar Engineers. This initiative has enabled illiterate and semi-literate rural women to fabricate, install, maintain, and repair Solar PV systems, thus creating employment opportunities (Kapoor, Pandey, Jain, & Nandan, 2014; Numminen & Lund, 2016; Pascale, Urmee, Whale, & Kumar, 2016; Sharma, 2007; Winther, Ulsrud, & Saini, 2018). Another example is of solar PV mini-grid project started in 1996 in the villages of Sagardeep Island in the state of West Bengal, India, by the West Bengal Rural Energy Development Agency (WBREDA), a state government agency (Chakrabarti & Chakrabarti, 2002; Hiremath, Kumar, Balachandra, Ravindranath, & Raghunandan, 2009). Well-established technology and simple operation and management system facilitated the community involvement (Chaurey & Kandpal, 2010). As Moharil and Kulkarni (2009) have elaborated, the rural cooperatives were responsible for the selection of consumers, recovering payments from them, and setting tariff in consultation with WBREDA, while WBREDA provided technical input through junior engineer permanently stationed on the island. The project was funded by a combination of grants, loans, and revenue. The grant was from Government of India (50% grant) and State government (20% grant), while and loans and revenue (together 30%) was from consumers. Kebede, Mitsufuji, and Choi (2014) discuss an NGO-driven program in Ethiopia on the positive implications of local presence and after-sales service on the diffusion of solar technology. Grameen Shakti (GS) in Bangladesh have also demonstrated the potential of a large-scale solar PV intervention with empowerment (capacity building and entrepreneurship of women) and microfinance at its core. The 'Solar Sisters', a social business model in Uganda, Nigeria, and Tanzania, has also had similar success. It has created an entrepreneurial network through engaging local women in many stages, including the decision-making the process, in the large-scale dissemination of solar PV systems (Heuër, 2017). Community financing of renewable energy projects is significant in ensuring the economic sustainability of these endeavors (Sovacool & Drupady, 2011). There has been a recurrent emphasis to develop a local participatory solar ecosystem so as to provide reliable and clean energy access at scale to the local BoP community (Scott, 2017). Katre, Tozzi, and Bhattacharyya (2019) highlight the significance gained by community owned and managed solutions amongst the different ownership models on one hand and emphasize the need for understanding effective community involvement strategies for the sustained intervention on the other. This study fills these gaps, and discusses: 1) pathways to engage with rural poor BoP communities to promote solar off-grid access, and 2) the impact of engaging with these communities particularly women, on their energy security and livelihood opportunities. It is based on our work with the rural poor BoP community in India to develop a local solar ecosystem through which to provide clean energy access to the larger community.

The manuscript is structured as follows: Section 2 provides an overview of the local community; Section 3 discusses research methods adopted; Section 4 details the intervention process; Section 5 summarizes our key findings; Section 6 discusses these findings, while Section 7 concludes.

2. Community

Among the many possible locations considered, the Dungarpur sub-district block within the Dungarpur district of the Indian state of Rajasthan was chosen for the intervention. The Dungarpur district has 283,556 households and a population of 1,388,552, of which 93.6% is rural, with a 59.5% literacy rate and a sex ratio of 994 (Census of India 2011). The average annual per capita income is Rs. 50,767 (USD 757) with 57% of households living below the poverty line. It has a predominantly rural agriculture-based economy. As per the Census of India 2011, electricity access in the rural Dungarpur sub-district was low at 38.49% with 61.2% of households depending on kerosene as a main source of light. Prior to the intervention, solar penetration in Dungarpur sub-district was insignificant. There are 242 villages in the sub-district and 335 schools with a total enrolment of 49,248 students (grades 1–12). As per the Human Development Report of Rajasthan (2011), the district is at the bottom of human development levels in comparison to other districts of Rajasthan.

The community organization was developed from cluster level federations (CLFs) of women's self-help groups (SHGs) in the sub-district. Four CLFs in Dungarpur sub-district (Antri, Biladi, Jhontri, and Punali) were considered. The CLFs, through their SHG network, reached every village in the sub-district and had created solid social capital through its microfinance and livelihood-based training programs. Each CLF is comprised of 300 SHGs spread over an average of 45 villages with membership almost entirely constituted by tribal women. These autonomous CLFs were created by Rajeevika (Rajasthan State Rural Livelihood Development Program) in 2011 to improve economic opportunities and empower women. Rajeevika regularly monitors all CLF activities. All four CLFs were willing to lead the solar intervention in their cluster, although none of them had any prior experience in solar or technology-oriented implementation programs. The intervention was initiated in February 2016, jointly by the CLFs, Rajeevika and the Intervention Partner (IP).

3. Research method and data collection

A mixed methods approach was adopted for the data collection. This included extensive secondary data of the intervention, mid-course quantitative survey of the consumer households, and qualitative instruments.

- Data on various activities were recorded by the CLFs using record books and digitized using a custom web-based software system. Records were maintained for the trainings, employee services (attendance and payments), inventory of components and lamps, assembly records (including component-wise defectives), distribution records, expense ledgers, income ledgers, and detailed beneficiary records.
- Two rounds of quantitative surveys of the beneficiary households were conducted: a baseline survey prior to the purchase of the solar lamp and an impact survey at about 4 months from the purchase. There were 217 sample households which were randomly selected, spread across 40 villages in all four clusters, and included electrified and un-electrified households. The interviews were conducted in the respondent's house and the majority of respondents were women. The broad areas covered in the survey included demographic information, sources of light, usage of the solar study lamp and user views of the lamp's performance, and their preferred source of light.
- A qualitative approach was utilized through key informant interviews and focus groups discussions conducted with the women members of the community organizations (CLFs). The focus was on understanding the interviewees' perceptions of solar intervention and its implications for their energy security and livelihood opportunities. In addition, four staff from Rajeevika and three staff from IP were also interviewed. We conducted a total of 18 key informant interviews in February 2018 and each interview lasted between 45 and 80 min.

4. Intervention: plan and activities

4.1. Plan

The overall timeline of the activities, along with the phases and key events, are shown in Fig. 1. In the pre-intervention stage from February to May 2016, discussions were held among IP, Rajeevika, and the CLFs to plan the interventions. In these discussions, IP introduced the overall concept of the interventions and the solar study lamp[1] (for use in the first phase). The roles and responsibilities of the different players were finalized, with CLFs and Rajeevika leading the awareness creation and implementation work and IP involved in monitoring and evaluation, with plans developed collaboratively. A tentative target of 10,000 lamps per CLF was set (based on school enrolment and household data) for the first phase. A broad budget plan for the first phase was drawn, wherein both the complete operational expenses[2] (excluding material cost) of the Assembly-cum-Distribution Centres (ADCs) and the monitoring costs of IP were covered from the sales proceeds. The selling price for the solar study lamps was fixed at INR. 200 (~$3)[3]. During the first phase, the CLFs were encouraged to keep aside about INR. 80/lamp ($1.2/lamp) to later invest towards entrepreneurship development activities in solar energy.

4.2. First phase: assembly, distribution, and maintenance of solar lamps

The first phase began with the set-up of 4 Assembly-cum-Distribution Centers (ADCs), one in each cluster. A total of 111 women, shortlisted from among the SHG cadre members, partici-

[1] The solar study lamp consists of 0.5 W LED, 1200 mAh Ni-MH battery, and a control PCB encased in a plastic body with a flexible, adjustable gooseneck. It included a detachable 1-W solar panel.

[2] Operational cost covered manpower and logistics towards assembly, distribution, emoluments to provide free repair-maintenance service, consumables, contingencies, and overheads. The material cost of INR. 350 (~$5.22) per lamp kit, including logistics, was additionally borne I through a CSR (Corporate Social Responsibility) grant.

[3] Assuming INR 67 is approximately 1 USD.

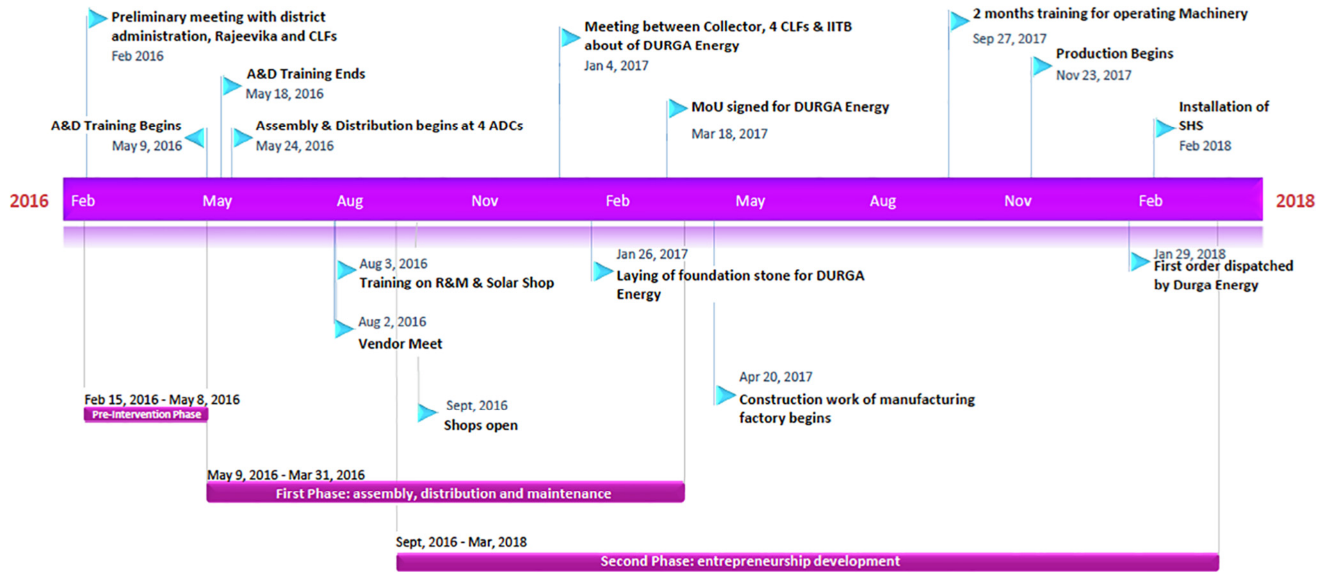

Fig. 1. Timeline of activities in the intervention.

pated in a 10-day intensive training (see Fig. 2). These women had neither prior exposure to technology nor project implementation. The training focused on technical, management, communication, and entrepreneurial skills. The training content was designed considering the semi-literate educational level of the trainees. The trainees were prepared to handle the dissemination of the basic-level solar technology solution to their community. Post-training, a total of 64 women, across all CLFs, were selected and employed as assemblers, distributors, data entry operators, and supervisors at the ADCs. Each ADC had one assembly supervisor, one distribution supervisor, and one bookkeeper. The ADCs/CLFs were provided with an additional 4 weeks of guidance for the initiation of their field operations.

The assembly and distribution activities took place during a 6-month period, from May 2016 to October 2016. Assembly activities began with the receipt of components and tools at the ADCs. The assembly process involved component inspection and testing, gluing, connecting, soldering, screwing, pasting, quality checking of finished lamps, boxing, and packaging (see Fig. 2). The distribution process began with a campaign to build awareness around the solar lamp and its uses and benefits to the community. The distributors launched the campaign by visiting schools, conducting meetings in villages, and through the network of SHGs. The lamps were sold through the schools or to the village households directly (see Fig. 2). The solar lamps sold to school students and their mothers covered 78% of the enrolled students in Dungarpur sub-district. The assembly and distribution activities wrapped up by the end of October 2016 as the rate of distribution slowed due to market saturation.

As per the warranty terms, repair and maintenance activities took place from August 2016 to March 2017. To meet the considerable scale and scope of maintenance activities, 19 women[4] were trained and employed to provide maintenance services in August 2016. Each cluster had one nodal service shop with 3-4 solar *sakhis* associated with it[5]. One of these solar *sakhis* also managed the service shop as its supervisor with each supervisor responsible for the villages in close vicinity of their shop's location, generally in the range of 5–7 km. Each *sakhi* was assigned a specific set of villages/schools to manage. The *sakhis* made periodic and regular visits to schools and villages. The non-functional lamps were repaired[6] either on-site or at the shop, free of cost to the customers (see Fig. 2). Customers also directly approached the shops for their lamp repairs. *Sakhis also* conducted awareness campaigns on the proper way of handling lamps and the availability of free repair services during their village visits.

At the end of the first phase project mode, the CLFs were able to create a combined corpus of about INR 2.4 million ($36,000). This was the operational expenses and overheads incurred during the first phase activities of assembly, campaigning, distribution, repair, and maintenance. On average, an employee earned INR 13,783 (~$197) over a period of 6 months (May–October 2016) for the assembly and distribution of the solar lamps. The solar *sakhis* earned INR.2350 ($35) per month for providing repair services.

4.3. Second phase: entrepreneurship development

The entrepreneurship development activities started with a discussion with CLF members about the business potential of solar shops (that can sell various solar systems) and other related activities such as solar home system installation (see Fig. 1). A meeting between the solar product vendors and CLF women was arranged to expose them to a range of solar solutions and their associated costs, sales and purchasing strategies. The CLFs decided to encourage individual local women entrepreneurs to open solar shops and also considered providing loans to local consumers to buy solar products on a case-by-case basis.

In September 2016, 5 solar shops were opened by 5 different women in all 4 clusters. Each shop made an initial investment of about INR. 20,000 ($298.50). Various solar products such as solar lights, solar lanterns, solar home lighting systems, solar fans, solar torches, solar mobile chargers, and more were procured from vendors and sold in the community. The product prices ranged from $7.00 to $70 and there were no consumer subsidies on any of the products.

[4] Approximately 1 person per 2000 lamps sold. Also, all these women had worked as assemblers/distributors.

[5] Considering the geography of the blocks, Jhontri cluster had 2 service shops, while other clusters had 1 service shop each.

[6] A total of 2483 lamps were repaired during the warranty period until March 2017. The range of repairs included soldering jobs, connector pin fix up, recharging the lamp, cleaning of switch, replacement of switch, replacement of PCB/ battery. Physically damaged lamps were not eligible for free service.

Fig. 2. (clock-wise from left top) (a) The women trainees taught soldering for the first time (b) Assembly line of lamps at the ADC; (c) distribution of lamps at school and recording of beneficiary data; (d) repair camp at a village.

In January 2017, the CLFs collectively decided to invest the corpus generated thus far in starting a solar panel manufacturing company. The company was founded in June 2017[7] and is fully owned and operated by the four Dungarpur CLFs. The company has an annual installed capacity of 2 MWp panel production[8]. Fig. 1 also presents a timeline of activities pertaining to the setup and commissioning of the company's factory. The workforce of the factory, including the supervisory staff, were recruited from the SHG cadre of the four CLFs through a rigorous process. The staff was then provided with industrial exposure visits, a workshop on operations management, intensive in-house training as operators, extensive hands-on practice, and additional trainings in the SHS and solar street light installation. These trainings and hands-on practice spanned over a period of four months until December 2017. The factory is designed to produce panels of less than 100 Wp, as it has labor intensive operations. As of March 2018, the company has produced approximately 25,000 panels of 2.5 Wp each, and tens of 40 Wp and 20 Wp panels. The company has also installed a 10 kWp on-grid solar system for the local municipal corporation. As of March 2018, the company ventured into providing standalone off-grid solar home lighting systems (SHLS) with installation in 10 rural households. The SHLS consists of 5 LED lights of 5 W each, a 100 Wp panel, and a Li-ion battery to provide round-the-clock reliable lighting access. Significantly, these SHLS were purchased by rural households at a market cost of INR. 9900 ($147.76), highlighting the immense value the rural community has for reliable electricity supply.

5. Findings

5.1. Pathways

The pathways in engaging rural communities to promote solar off-grid can be broadly divided into two stages: Capacity building and Entrepreneurship development. Capacity building stage begins with the awareness of and introduction to solar off-grid technology through technical trainings, to both the users within the community and to the community leaders or 'enablers' of technology dissemination (viz. assemblers, distributors, service technicians). The trainings to be followed up with employment opportunities, allowing the trainees to see the immediate value (income) in the skills they learn and also help them in honing their skills. The interaction between the 'enablers' and the users in the community also resulted in mutual confidence building and market sensitization. These activities (training with immediate employment) can be quite easily structured and implemented, especially in a project mode. As a natural progression, the entrepreneurship development stage can then focus on nurturing individual entrepreneurs or community-owned enterprises, towards continued livelihood in solar off-grid in the open market. These are not without challenges, as also encountered at Dungarpur. The solar shops were established with the intention of continuing operations after the second phase ended in March 2017, which did not materialize. The shops were integrated with the solar study lamp repair services with the expectation that (i) the honorarium received through the project would reduce risk and encourage enterprise, (ii) it would allow for market penetration through the solar *sakhis*, and (iii) it would be an opportunity for local communities to understand the solar market. Though it was met with initial success, it did not sustain beyond 8 months due to the CLFs collective decision to invest the generated corpus in starting a solar panel manufacturing company in January 2017. The solar shop entrepreneurs saw great potential in this endeavor since this was a collective activity in which the risk was shared. Thus, this new development can be said to have acted as a trigger that led to the discontinuation of solar shops.

[7] The company, Dungarpur Renewable Energy Technologies Private Limited, is India's first solar panel manufacturing firm to be fully owned and operated by rural tribal women.

[8] The solar potential of Dungarpur district was estimated to be 38 MW, considering the number of un-electrified households, potential water pumping needs, street light requirements, and demand from public buildings. The installed capacity was determined assuming the company can capture 10% of the local market over a period of 4–5 years.

Table 1
A sample of action inquiry of the community organizations.

Phase	Issue	Action	Evaluation
First	The household consumer, esp. the women, worked in poor/no light conditions while doing various domestic duties. The CLFs felt there is a potential need and demand for solar lamp for them	The CLFs recommended that the target beneficiary for the solar lamp sales be expanded to include mothers (women) so that an additional lamp can be purchased by interested households for the exclusive use by the women	It was met with reasonable success, with only 20% of lamps purchased by the mothers. One of the reasons was their unaffordability to purchase more than 1 or 2 lamps (for 2 children first)
First	Among the employees, nursing mothers and mothers with very young children found it difficult to work long hours away from home and their children, lowering productivity and quality	The mothers were allowed to bring their infants to the ADCs, where the members took turns managing them. Frequent breaks were permitted. They were given priority to work on the assembly of lamps rather than distribution which involved travel. Even in assembly, simpler steps were preferred for them	The flexibility allowed increased participation and engagement. The assembly of lamps was completed as scheduled, with overall assembly losses restricted to less than 0.5%
First	Creating awareness among the community about solar lamps. Initially, the sales visits were in schools as the lamps targeted students. Solar lamp distribution was slow	The SHG network had an extensive reach in all villages, along with Village Organizations (VOs). It was decided to campaign and distribute the lamps through this SHG network, apart from visiting schools	Increased awareness at the Households about the solar lamp and the role of SHG federation in the intervention, leading to a higher willingness to uptake the solar lamp. The distribution rate increased to a cumulative total of 36,700+ solar study lamps in a short period of 5.5 months
Second	Women entrepreneurs interested in starting their own solar shop found it difficult/or were hesitant to start. Additional support was sought by them from the CLFs	It was decided that the entrepreneur's shop in the cluster will be the service center hub for that cluster. These women will also be the supervisors for the service activities of the solar lamps, thus increasing their income and reducing risk	The increased income received as lamp repair supervisors provided the required 'cushion' to start their own shops (5 shops opened). The solar *sakhi* network was used for marketing
Second	A large number of women from the community expressed interest in working in the factory. However, they were sceptical of the increased workload due to domestic duties at their home and the factory work	Women employees were also recruited for four hour-shift at the factory, either in the morning shift or the afternoon shift	This encouraged more women to consider working at their factory, and their immediate family and village community were more supportive. Since almost all factory employees were first time workers, this allowed them to ease into that role

It is also noted that the community organizations and its members developed a keen interest and sense of ownership of the intervention over time. A sample of the action inquiry cycle as exhibited by the community organizations (CLFs) is presented in Table 1. The planning to improve practice or overcome potential issues and the implementation of the plan was carried out by the CLFs themselves. The IP team helped with the monitoring and evaluation of the action and its outcomes and generating feedback from discussions with the CLFs.

5.2. Impact on livelihood opportunity

The perceived benefits of the intervention were observed through its impact on technical competence, economic and social outcomes.

- Technical competence: The CLF organizations and the women members had no prior experiences in solar, project implementation, or working in a factory. Through this intervention, they gained competence in handling solar PV technology. The CLFs also expressed higher confidence in taking up implementation-oriented projects in other areas such as education. The women cadre members involved in the intervention were trained and became quite adept in soldering, lamp assembly, and disassembly to identify faults and repair the lamps. Occasions were observed wherein the women trained were able to repair, to some extent, other solar lanterns (non-project lamps). The factory workers, although semi-literate, have exhibited steep learning and mastery of various technical skills such as laser cutting, tabbing, stringing, layup, lamination, sheet cutting, panel testing, and various machine operations. They have also picked up other managerial skills including inventory management, human resource development, marketing, and general administration. Their confidence in their abilities is evident in their capacity to independently install solar home lighting systems (including climbing the rooftops of houses) and to complete the various routine functions required to run the factory.
- Economic aspects: The women involved in the intervention took pride in their capacity to supplement their household's cash income, which was previously earned only by the men in the family. Earning money has also given women a sense of economic independence which was a new experience to them. Some of them could repay their loans, while others used this money to construct a *Pucca*[9] house, or send their children to better schools. Women stated that *"now neither (do) they have to ask for a small amount of money (from) their husbands nor do they have to listen to the taunts for asking (for that) money*". With their self-earned money, they also purchase small things like clothing, food, snacks, and cosmetics for themselves and their families. They also expressed concern over the fact that a significant portion of their earnings is spent on their commute to and from their homes and their workplace (ADC/factory). The community organizations (CLFs) also gained confidence in making significant investments towards clean energy access, both in terms of money, workforce and other resources. Factory employment is now perceived as a sustainable means of securing a livelihood by employees and the community.
- Social and Psychological benefits: For most of the women, association with the intervention gave them a window to step out of their homes for the first time and the opportunity to take up paid employment. Breaking stereotypes through learning technical skills, working on machines and other activities viewed as 'masculine' brought about a change in the way women were perceived in their villages and boosted their confidence. For the women, being associated with this intervention has become a status symbol, which gave them recognition and respect within the family as well as in their village. Wide media coverage of the intervention at the local and national level has further contributed to building trust in the women's efforts amongst

[9] *Pucca* house means a house made from solid or permanent material like burnt bricks, stones, timber, cement, metal sheets, concrete etc.; whereas *Kuccha* house is made from mud, thatch, grass, leaves, reed and similar material; the walls and roof are made from this material.

the community members. After securing jobs as factory workers, an increase in the women's self-worth was observed, which reflected in them taking better care of themselves in terms of their attire, appearance, and health. We were also told of a few cases in which women continued to work in the solar module manufacturing factory despite their husbands being apprehensive or even abusive about their wives working, displaying a sense of resiliency.

5.3. Impact on energy access

In both rounds of data collection, there were only a few households (less than 4%) that reported not purchasing kerosene. As observed in Table 2, from the round I to round II there was a decline in the percentage of households that used kerosene 'only for lighting' purpose, which can be attributed to the presence of the solar study lamp in the house. This decline was further reflected in the changed usage pattern in the categories of 'only cooking' and 'lighting and cooking'.

The users' feedback on solar lamps has been generally positive. It was found that about 85% of the respondents were satisfied with the solar study lamp. Amongst the remaining 15% of respondents who were dissatisfied, 86% cited quality issues, while 14% stated that the solar study lamp did not offer value for money. Amongst the satisfied household, 36% considered it as a good quality of light, 32% thought that it had multipurpose usage, 21% said it resulted in monthly savings, and 8% stated it was easy and convenient to use. It was also found that the solar lamp was used for a variety of purposes including studying, dining, cooking, washing, and performing livelihood activities such as attending to livestock during the night time, milking the cows early in the morning, and running errands. As seen from Fig. 3, the average per day usage of the solar study lamp was almost 30 min more in un-electrified households than electrified households, including for study purposes only. The usage for other purposes was comparable across electrified and un-electrified households.

On asking about the preferred source of light, 74% responded with 'solar', 24% 'conventional grid', and 2% 'kerosene'. High illumination was the reason cited for the preference of solar over conventional grid electricity, while 2% of households preferred the kerosene wick lamp because their solar study lamp was not functioning. Amongst the households that preferred solar, 66% stated the good quality of light as the main reason. However, it needs to be mentioned that the superior illumination is due to LED used in the solar lamp, which would give the same illumination when used for lighting via grid electricity. The experience of the respondents about the grid electricity is frequent voltage fluctuations or poor quality of electricity supply that result in substandard illumination of an incandescent bulb or LED. Hence, this is one major reason that influences the preference for solar as a source of light over the conventional grid, further creating the impression that solar gives good quality light than the grid. Other reasons cited were potential savings in money (12%), health benefits (less irritation to eyes) (11%), the multi-purpose utility of solar (8%), portability of solar products (3%), and unreliable grid connection (1%). The local services provided by the solar *Sakhis* helped keep the lamps in working condition and increased community confidence in the technology, as well as in the CLFs capabilities. However, this positive first-hand experience with the solar lamp did not yet translate into higher transitions to clean energy by the households. The shops (those opened by the local women entrepreneurs) were successful only to a limited extent in selling low-cost handheld solar solutions. The reasons were found to be lack of affordability, the perceived risk in solar ready solutions, and the Indian Government's aggressive drive to provide grid connection to the households. In the open market, people did purchase other small, low-cost use-and-throw solar products in the cost range of \$1.5–\$3. It was also observed that the community was reluctant to buy larger lighting systems (in loan or upfront payments) as they were not considered priorities or value addition. However, after the local company was formed, they were successful in installing 10 solar home systems in March 2018 which were designed to provide light on demand 24/7. Though the cost of the systems was on the higher end on average, ~INR.11500 or \$171 for a 5 LED light system, the households adopted the system as it was now perceived as a complete replacement to grid connection and had the assurance that the local company would take care of any future maintenance issues Although it holds potential, the future role the local company and institutions (viz., CLFs, Rajeevika, IP, District Administration, and other NGOs) will play in helping the larger community adopt clean energy solutions remains to be seen.

Table 2
Percentage of households as per the kerosene usage.

Usage of Kerosene	Round I (baseline)	Round II (4 months after solar lamp introduced)
Only Lighting	52.80%	7.14%
Only Cooking	–	17.62%
Heating Water	–	1.43%
Other	–	0.48%
Lighting & Cooking	47.20%	16.19%
Lighting & Other	–	3.81%
Cooking & Heating water	–	37.14%
Cooking & Other	–	7.62%
Heating water & Other	–	0.95%
Lighting, Cooking & other	–	1.90%
Cooking, Heating water and other	–	5.71%
HH not using Kerosene	*1.38%*	*3.23%*

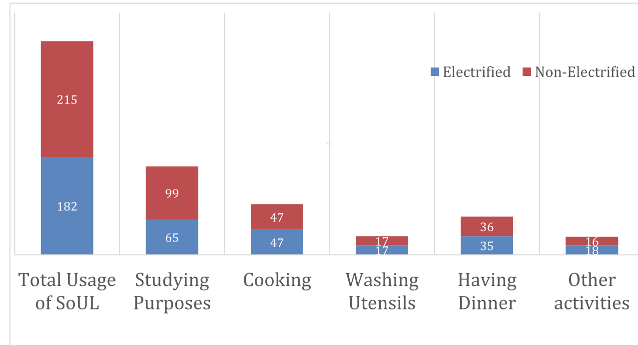

Fig. 3. Average usage (in minutes) per day of the solar study lamp in electrified and un-electrified households.

6. Discussion

Our learnings and reflections on the interventions and the underlying process are shared in this section. It is broadly divided into two sections, the first being devoted to the community organization and the members involved, and the other on the impact on the livelihoods and community's uptake of the intervention.

6.1. Pathways

The community members, most of whom were local women, showed remarkable progress in their ability to learn the technical and managerial skills necessary to lead the intervention, resulting in their economic and social growth. Potential women possess in promotion, maintenance, and management of the solar technology was proved through this intervention, and also in Kenya which earned the confidence of the community. In both cases, local women were instrumental in reaching the underserved BoP communities and thus creating livelihoods for women (Winther et al., 2018). As compared to the interventions that did not involve local communities in implementation and repair-maintenance, this intervention was much better on the accounts of reaching the BoP communities, stronger supply chain and no functionality issues due to presence of know-how at the local level. Hand-holding of operational activities is critical to ensure the successful transfer of knowledge/know-how to the community organization. In the first phase of the project-mode, the dissemination of solar study lamps was done in a systematic manner. However, in the second phase of entrepreneurship (solar shop) activities, it was less structured with minimal hand-holding, which perhaps contributed to the shops' failure to continue. In recognition of this need, a continuous mentoring approach has been adopted to support the local factory. The different organizational structures and management styles of the various organizations involved (CLFs, Rajeevika, and IP) demanded enhanced coordination. The CLFs, having taken on this first-of-its-kind intervention and not having prior experience in this type of work, were expected to exhibit a steep and quick learning curve in developing their professional project management skills. This led to occasions where the action research team was excessively involved in the active implementation which the CLFs. Furthermore, the CLF members involved in the solar intervention expressed the desire for greater autonomy in 'managing their solar activities', especially in managing the remuneration to their own benefit. It will take time and effort to expand their actions to benefit the entire community. Many employees of the solar intervention/shops/factory, especially those in supervisory roles, were found to be the active members or office-bearers of the CLFs (in some cases). This may have resulted in not attracting the best talent from the community. Also, from the CLFs point of view, the budget overruns experienced were largely due to financial indiscretion. This highlights the need for explicit trainings on finance and accounting. A similar experience from Bangladesh where women's cooperative was capacitated reported "insufficient advanced managerial skills as a barrier to scaling up and strategic planning, and rightly pointed out the institutional capacity building at the helm" (Berthaud et al., 2004).

6.2. Energy security and impact on livelihoods

Like other studies, this intervention had an impact on livelihoods in terms of declined consumption of kerosene for lighting and users being satisfied with the quality of light (Lemaire, 2018). However, the differentiating factor was the creation of livelihood and income generation opportunities through the transfer of know-how at the local level to the women who are part of the BoP community. Though there are few off-grid solar interventions that have involved local communities, they all reiterate the significance and positive correlation of local involvement in the diffusion of solar technology (Heuër, 2017; Kebede et al., 2014; Sovacool & Drupady, 2011).

Affordability continues to play a key role in community adoption of solar energy solutions. The uptake of solar study lamps was quite strong at INR.200 (~$3), with about 20% of households getting multiple lamps. However, as the majority were poor, BoP households, many found it difficult to pay upfront for multiple (2 or more) lamps. The solar lamps at its actual market price of about INR.550 ($8.2) would significantly reduce the total number of adopters among the rural households. Other studies have also cited low-income and BoP status of rural households as the impediment in penetration of SHS (Ketlogetswe & Mothudi, 2009; Lemaire, 2009). Winkler et al. (2011) make a "distinction between the affordability of access (e.g., related to the costs of connection) and the affordability of using electricity, further pointing that access in the sense of physical connection does not achieve anything if the electricity is not affordable". Aklin, Cheng, and Urpelainen (2018) have discussed increased inequality, which is a concern that gets ignored when the need for the spread of solar technology in underserved rural areas is advocated. They rightly point that cost plays a vital role in social acceptance. Another study in rural India showed that although people were positive, convinced about the quality and interested in solar, its sale remained low mainly due to credit constraint, while information barrier was not a dominant factor in solar uptake. The study concluded that cost-effective financial access can facilitate the growth of solar technology markets (Urpelainen & Yoon, 2017). Finding in this regard with regard to Bangladesh was consistent as an innovative financing structure was a key factor in the success (Newcombe & Ackom, 2017).

Alongside affordability, our study showed that grid encroachment acts as a hindrance for solar adoption (Azimoh, Klintenberg, Wallin, & Karlsson, 2015; Comello, Reichelstein, Sahoo, & Schmidt, 2017; Glemarec, 2012). Urpelainen (2016) reports similar findings, "given India's emphasis on grid extension to rural areas, many rural villagers appear to have a preference for waiting for subsidized, if unreliable and fluctuating, power supply through the grid. It also appears likely that the poorest households cannot afford even basic electricity services without a subsidy or some other support mechanism." A study conducted in Indonesia reports that although users were pleased with solar, they showed interest in obtaining a grid-connection (Reinders et al., 1999). Thus, subsidy or other support mechanism may remain a requirement for BoP households who cannot even afford basic electricity services (Urpelainen, 2016). A review of renewable energy access initiatives for poor in Asia-Pacific and Africa showed that a conducive policy environment resulted in significant expansion, whereas its absence created a bottleneck (Gabriel, 2016; Glemarec, 2012). The policy support should be in the form of tax reforms, incentives, progressive tariffs regulatory framework, targeted subsidies, mobilizing rural communities to participate in rural electrification, and ensuring gender balance (Diouf, 2016; Haanyika, 2006; Lemaire, 2011).

7. Conclusion

The study demonstrates that local partnership was key in the dissemination of solar technology. The critical role the local partner, which the already established and functioning SHG network, played in the adoption and speedy diffusion of solar study lamps in the first phase was evident. Since government agencies have developed SHG networks across the states of India, they should be leveraged in providing electricity access to rural underserved areas. Other studies drew similar conclusions that perceived trustworthiness and legitimacy of the local level institution is fundamentally important in successful solar adoption and diffusion (Aklin et al., 2018; Alam Hossain Mondal, Kamp, & Pachova, 2010; Katre et al., 2019; Kebede et al., 2014; Sovacool & Drupady, 2011). The invaluable role of local partnership, specifically women, in achieving social and environmental impacts, as well as long-term uptake of green technologies, has been emphasized (Heuër, 2017). The utility of the SHG network in resolving rural electrification issues was also highlight (Diouf, 2016). Our work demonstrates that the SHG network holds the potential to fill the institutional void in the BoP communities for technology dissemination. Appropriate capacity building and support for the SHG federations can create clean energy (and other techno-social) interventions at the required speed, quality, and coverage. The development of a 'local solar ecosystem' anchored by a manufacturing facility with a deeply involved SHG network holds much promise. The activities in Dungarpur are at a critical juncture. The increased and sustainable livelihood opportunities provided to the local community, along with local installation and service, can further motivate the community at large to adopt clean energy solutions.

Declaration of Competing Interest

The authors declare no competing interests.

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