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Research article

Socio-technical assessment of solar photovoltaic systems implemented for rural electrification in selected villages of Sundarbans region of India

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Abstract: The power situation in rural India continues to remain poor with around one-third of the rural population without access to any form of electricity. The consequence of which is kerosene being used as a major source of lighting for un-electrified households as well as households with intermittent access to electricity in rural areas. While grid based electrification has been the most common approach, decentralized renewable energy options especially, solar PV systems have also been adopted as a cost effective mode of electrification. This paper presents the results of socio-technical assessment of solar photovoltaic interventions namely, solar home systems, solar mini-grid and solar AC pico-grids, which have been used to electrify selected villages in Sundarbans region of India. The study is focused on technical, financial, and institutional aspects along with the social impact assessment of PV based electrification in the Sundarbans region. The results of the study elucidate that, in general, the impacts of the solar PV solutions used for electrification have been largely positive, especially benefits of reduced kerosene consumption, ease in studying and cooking and reduced health effects. The study also finds that technology is not the only factor on which the viability of a program depends, but institutional and financial aspects also play a significant role. The need of the hour is to develop a strong institutional framework and enabling policies for achieving higher success rates in PV programs.

Keywords: Solar pico-grids; solar home systems; solar mini-grid; electricity access

1. Introduction

The power sector in India is largely driven by the increased use of conventional sources of power. The use of fossil fuels for power generation is clearly not sustainable due to the exhaustible nature of the fossil fuels and greenhouse emissions associated with their burning. With the world moving towards sustainable development pathways, India has also taken major steps to ensure a shift to renewable sources. The various forms of support by the governments, both federal and provincial, in form of subsidies, incentives and policies have encouraged the entry of private sector and NGOs into the domain of renewable energy based electricity sector.

However, the electricity situation of India, especially in the rural areas is dominated by large number of un-electrified households and/or erratic power supply. Currently, 304 million people in India are deprived of access to electricity [1]. Usually the unconnected household could be classified into three categories [2], which are: (a) those residing in remote inaccessible villages where extending the central grid may be techno-economically infeasible; (b) those residing in unconnected hamlets of grid connected villages; and (c) un-electrified households in villages where the electric poles and grid is existing, where many households are not taking connection due to financial constraints or the perception that electricity services will be inadequate [3]. In addition, lack of targeted programmes and policies, resource constraints and the checkered institutional arrangements also contribute to low energy access levels in some states in India [3,4]. The consequence is that kerosene continues to be used as a major source of lighting by both un-electrified households and households with intermittent access to electricity with around 43 percent of the rural households depending on kerosene for lighting in India [5]. The government has recognised these problems and is making efforts to bridge the gap. While the grid-based electrification has been the common approach, decentralized renewable energy options, especially solar PV systems, have been adopted as a cost-effective way of electrification primarily for areas where it is techno-economically not feasible to extend electricity grid [6,7].

The present study attempted to conduct a socio-technical assessment of solar PV systems for rural electrification in selected regions of Sundarbans, where different type of solar PV solutions have been implemented over the years to provide electricity access. The different types of solar solutions includes solar AC pico-grids[1] installed under the Off-grid Access Systems for South Asia (OASYS South Asia) project which has been implemented by TERI and Mlinda Foundation in West Bengal; solar mini-grid[2] implemented by West Bengal Renewable Energy Development Agency

[1] An AC solar pico-grid comprises a small solar PV panel, a rechargeable battery, a charge controller and an inverter. Generally the capacities of solar AC pico-grids are in the range of 100 Wp to less than 1 kWp and they connect around 5–20 households within a short distance,

[2] Solar AC Mini-grids are designed to generate electricity centrally and distribute the same for various applications to households and small businesses spread within a particular area. They usually supply 220 V 50 Hz 3-phase or single phase AC electricity through distribution network. They consists of: (i) Solar PV array for generating electricity, (ii) a battery bank for storage of electricity, (iii) power conditioning unit consisting of charge controllers, inverters, AC/DC distribution boards and necessary cabling, etc. and (iv) local low-tension power distribution network [6].

(WBREDA); and solar home systems (SHS)[3] disseminated through NABARD financing [8] scheme as well as sold by the private enterprises. The assessment focused on the technical, social, financial, and institutional aspects of each PV solution in order to highlight the various dimensions of PV based rural electrification programs and also study the socio-economic impacts of these interventions.

The paper starts by providing an overview of the rural electrification experiences followed by detailed review of literature. Section 3 describes the methodology followed for this research. The paper then presents the results focusing on functionality, service delivery and institutional structure and project impacts in section 4. Thereafter, section 5 discusses the results and finally, the conclusion & recommendation section summarizes the study and suggests measures to improve the existing models.

2. Literature review

To get a better understanding of the rural electrification scenario in India, literature pertaining to relevant studies in this field was first reviewed. Some of the important findings from contemporary literature are highlighted in this paper. Beginning with the rural electrification scenario through the years, Palit and others, in their paper, focused on the various government policies and programmes and has drawn some key lessons from them [9]. Sadeque and others have thoroughly documented the solar PV programme in Bangladesh, considered to be the largest off-grid programme in the world, and have highlighted that the programme has achieved success due to leveraging of an extensive micro-finance institution network, high population density thereby ensuring economics of scale, a competent and passionate local champion (Infrastructure Development Company of Bangladesh) as the nodal implementing agency, affordable financing and strong emphasis on quality of the systems [10]. Literature also indicates that two of the most commonly used decentralized off-grid solar solutions are solar home systems and solar PV mini-grids. A comparison of the technical as well as economic viability of these two technologies has been studied extensively [11–13]. The challenges faced in implementing the solar PV programmes on technical, financial, service delivery, monitoring and maintenance parameters has been studied through extensive analysis [6,14,15]. While there are number of successes of off-grid electrification projects, past experiences also show that many projects failed because focus has been generally on technical installation without paying sufficient attention to their long-term sustainability [14]. The failure is also often attributed to poor technology management and inadequate governance and financing structures [3,6,16]. Mohapatra and others have also documented the importance of using renewable energy based systems, especially solar PV systems, for rural electrification as a means to reduce CO_2 emissions and indoor air pollution vis-à-vis use of kerosene lamps [17].

The socio-technical impacts of off-grid projects can also be found in the works of many researchers [18–22]. Case studies pertaining to different Indian states, namely Karnataka and Bihar, have been examined and lessons pertaining to the need for flexible and innovative financing have been drawn [23,24]. Papers that lay emphasis on the social relevance of technology implementation

[3] A typical SHS consists of PV module(s) that charge a battery bank to supply DC electricity to run appliances such as CFL/LED lamps, DC fan, TV, etc. The charge controller which is an integral part of the SHS controls the energy inflow and outflow into and from the battery bank [6].

in different regions are also documented and aid in establishing the socio-technical aspects, providing significant direction to the analysis of results in the present study [22,25,26]. Research also shows that deployment of decentralised solar PV options can help to bridge the gender gap [27]. Case studies, focusing specifically on the Sundarbans region, also highlight the different facets of decentralized electrification system and their impacts [7,19–22,28].

3. Materials and Method

3.1. Objectives

The study attempted to do a socio-technical assessment of solar PV systems implemented for electrification in selected villages of Sundarbans region in West Bengal state, India. Specifically, it focused on the techno-social-institutional delivery model of the decentralized solar PV systems deployed for rural electrification in selected villages and attempts to assess the solar PV systems by examining multiple dimensions such as technical design, delivery models, operation and maintenance aspects and financing and tariff structures as well as conducted the socio-economic impact assessment of the PV systems in the selected villages.

3.2. Methodology

Gauging the impact of any project on the lives of the users requires in-depth analysis of the qualitative and quantitative aspects of all the parameters involved. This lays importance on both primary data and secondary data. This study encompassed a wide variety of factors which could be broadly categorized under three areas—technical, financial and social impacts. A detailed survey questionnaire, containing questions pertaining to the above aspects, was prepared. The questions were then segregated to form two separate sets—one for the households and one for the markets. A separate checklist for the Focus Group Discussion (FGD) was also prepared. Household and market surveys were conducted thoroughly, with emphasis on bringing out the consumers' perspectives and aspirations along with quantitative data. FGDs were conducted with members of the households of different Joint Liability Groups (JLG's) in the selected villages. Both the surveys and FGDs were carried out by the authors on a field visit to Sundarbans during the month of February-March 2015. One of the authors, who is a native of Sundarbans, significantly helped in translating the views of people. Also, during individual household surveys the authors were accompanied by the local staff of the Implementing Agency of the pico-grid programme. Additionally, in order to bring out the managerial and institutional issues of the project, discussions with Mlinda Foundation and WBREDA were also carried out.

The solar AC pico-grids, implemented under OASYS South Asia project are present in four villages, namely Brajaballavpur, G-Plot, K-Plot, and L-Plot. Out of these, Brajaballavpur and G-Plot were selected for the field survey as these villages have the largest number of pico-grids. Stratified or purposive random sampling method was used in which the population was divided into small sub-groups and then random sample was taken from each stratum in the same proportion as the stratum with respect to the total population. In the context of this study, the strata were households and shops, from which the samples were selected randomly (according to their proportion) with a confidence level of 95 percent and confidence interval of 4.4. This gave a sample size[4] [29] of 140 comprising both households and shops receiving electricity supply from both pico-grid and SHS beneficiaries and un-electrified households. The site survey was followed by data compilation and documentation which was further analyzed, interpreted and represented through tables and figures. Inferences from these results helped in arriving at the final conclusion.

Table 1. Number of households and shops covered under each solar PV technology.

Selected Villages	Premises with AC pico-grids		Premises with SHS		Un-electrified premises	
	HH	Shops	HH	Shops	HH	Shops
Brajaballavpur	18	6	9	3	7	0
G-Plot	37	19	19	9	13	0
Total	55	25	28	12	20	0

4. Results

The SHS used by the households have typical capacity falling in the range of 20 to 75 Wp, while the systems used in the shops have capacity ranging from 20 to 125 Wp. Both CFL and LEDs bulbs were found used for lighting. In the case of the solar AC pico-grids, the beneficiary households constitutes a part of the JLG with 6 to 10 member households with a common pico-grid providing electricity to each of the member household. While, the larger group with around 10 households is connected to a 225 Wp system, the smaller group consisting of 6 houses is connected to a 150 Wp system. The hours of supply is fixed at 5 hours in the evening. The households are provided three light points with 2 W LED bulbs along with a mobile charging point. The capacities of the market pico-grids are 250 Wp, 500 Wp, 1 kWp, 1.5 kWp and 2 kWp. The market systems are given 5 W or 10 W LED bulbs and a sockets for mobile phone charging, the numbers of which depend on the size of the system being used.

The solar AC mini-grid at Indrapur village in G-Plot has a capacity of 110 kWp. There are three inverters, each with a capacity of 30 kVA. The power plant has a battery bank of 240 V 800 Ah consisting of tubular lead acid batteries. The plant is designed to work for 2 days (including 1 day autonomy). The length of the distribution lines is around 2 km within the village, connecting both household consumers (~ 120 households) and around 180 shops in the market. Initially, it reportedly used to supply on average 27 kW per hour operating for 5 hours daily in the evening, however, after

[4] Sample size (ss) was calculated using the following relation -

$$ss = \frac{z^2(p)(1-p)}{c^2}$$

where: z = z value; p = percentage picking a choice, expressed as decimal; c = margin of error, confidence interval, expressed as decimal. For known population (*pop*), corrected sample size (*css*) becomes

$$css = \frac{ss}{1+\frac{ss-1}{pop}}$$

cyclone *Aila* hit the Sundarbans in 2009, the supply got reduced to only 3 hours.

4.1. Functionality of the solar PV systems

All the surveyed households connected with SHS were found to be functioning. The household system users were found to be running a variety of appliances in the households such as DC fans and televisions while the shops were found using fluorescent lights, computers, DVD players and weighing machines. The solar AC pico-grids are fairly new (between 6 months to 1.5 years old) and all were found to be functional. However, some interruptions and faults were reported by the users during the survey. The solar mini-grid was found to be no longer operational. This plant was in operation for some time before it had to be shut down due to problems with the battery, even though the panels are in working condition. Incidentally, Ulsrud and others [22] have observed that batteries are the weakest link in solar PV mini-grids based on an earlier study undertaken in a different island in the Sundarbans region. Since, the solar mini-grid was found to be non-functional, the user survey was restricted to solar AC pico-grids and the SHS.

4.1.1. Unpredictable interruptions

Out of the total SHS households surveyed, 25 percent reported interruptions of once in a year, 18 percent users reported interruptions of once in a month and 14 percent reported interruptions of more than three times per week (Figure 1).

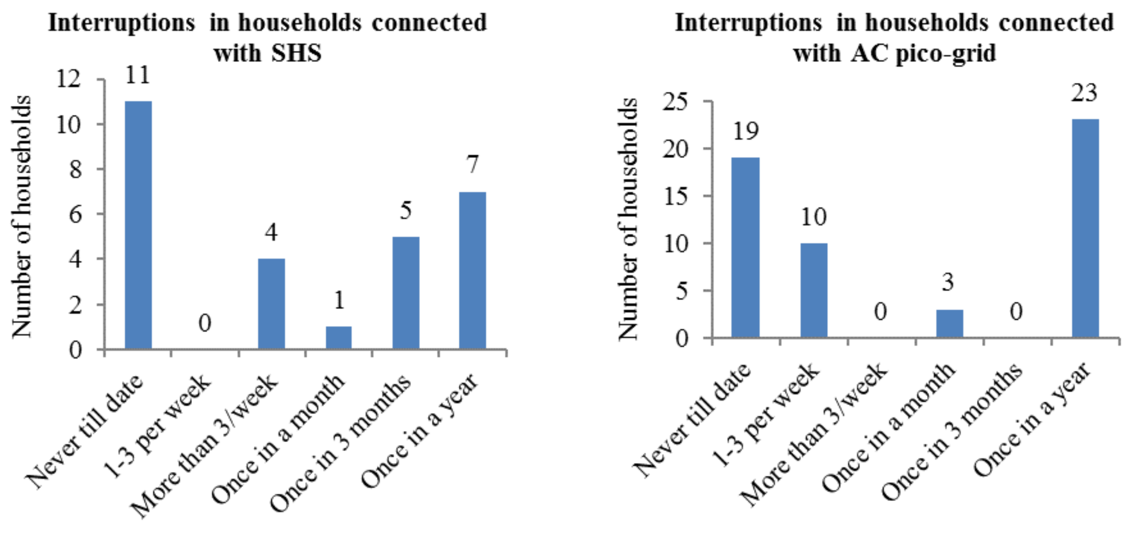

Figure 1. Frequency of unpredictable interruptions.

In the case of pico-grid households, 34 percent of users have not faced any interruptions and 42 percent of users have reported interruptions once in the last one year. These yearly interruptions occurred mainly during the monsoon season. The users have been made aware of these seasonal interruptions by the Project Implementing Agency (PIA) at the time of installation itself. Almost 18 percent of the users have also reported interruptions with a frequency of 1–3 times a week, which are mainly complaints of bulb flickering. Bulb flickering may be caused due to voltage fluctuations which occur if people are drawing more from the system than they are allowed to do as per technical design, i.e., when they plug-in appliances that consume more power. Incidentally, it was observed during the survey that in many of the houses, appliances such as television sets and small fans are present. Another reason for flickering could be the poor quality of bulbs being sold in the region because of their relatively cheaper price.

4.1.2. Types of technical faults

Among all the surveyed SHS beneficiary households, almost 36 percent have reportedly not encountered any technical problems. However, among the types of technical faults faced by the remaining 64 percent, almost 40 percent of them experienced bulb fusing as the most common problem followed by problems of bulb flickering (24%), charge controller not working properly (24%) and bulb damage (12%). Figure 2 depicts the different types of technical faults reported by the users of both SHS and pico-grids.

The faults are usually rectified by the local technicians and the installation agencies. The survey results show that 38 percent of the users felt that the faults were rectified quickly, 29 percent users felt that faults got addressed within a reasonable time period and 29 percent users were of the view that it took a considerable long time to get their faults rectified from the same agency from which they bought the system. The remaining 4 percent claimed that they could never caught hold of the designated technician to get the faults rectified and in such cases, they have fixed the faults themselves or got it done through other local technicians.

In case of pico-grid households, around 35 percent of users have not faced any technical problems till now. Out of the remaining 65 percent of pico-grid users who have faced problems, 67 percent have reported that the most common problem is bulb flickering, 22 percent have complained that the charge controller is not working properly, 11 percent have reported problems with the bulb. In case of pico-grids, there are no voltage fluctuations. The flickering of bulbs was found to be due to faults in the bulbs themselves and not due to voltage fluctuations. In the event of a complaint by the users, 98 percent of those who reported interruptions or other types of technical problems have said that such problems were quickly rectified by the implementation agency's field officers.

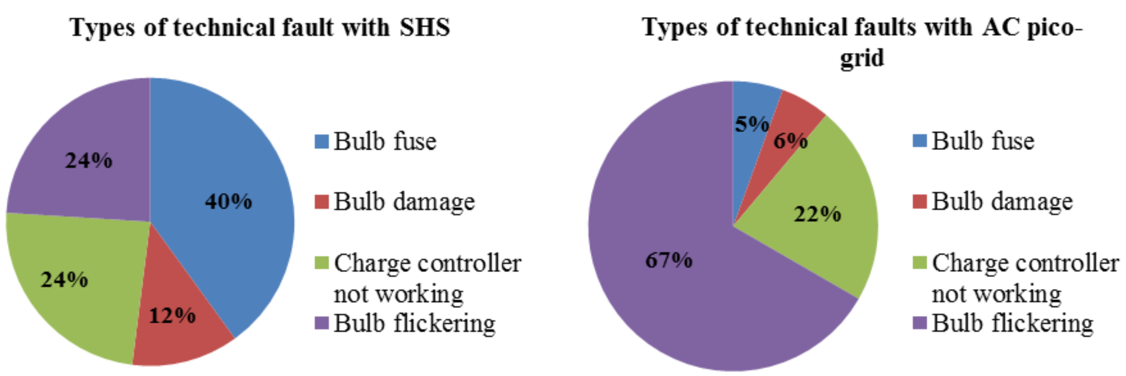

Figure 2. Types of technical faults reported during the survey.

4.1.3. Training and technical knowledge of the users

Almost 40 percent of the surveyed households with SHS denied receiving any training for the operation and maintenance (O&M) of the SHS. They claimed to have learnt the basic maintenance tasks from their neighbors, who were already using such systems. However, in case of shops, majority (67%) of the SHS users reported to have received training for O&M by the installing agency. In pico-grid connected households, the system is kept in the house of one of the members of each JLG and hence, the general understanding was found to be that all the members did not require training for system handling and maintenance. Also, the operators from the installation agency are given the responsibility to ensure proper and timely maintenance and make regular visits to the users, housing the system. A list of do’s and don’ts has also been provided to the beneficiaries. In case of pico-grid connected shops, 50 percent claim to have been trained. They are also of the view that the onus of maintenance related tasks lies with the installation agency only. Out of the 25 shops surveyed it was found that 15 shops had taken connections from other shops, which are having pico-grid systems. Since they are directly not operating the pico-grid system, the PIA has not provided any maintenance training to them.

During the discussion with the PIA, it was found that agency has a set protocol for undertaking training sessions for the technicians as well as the users at the time of system installation. Those who claimed not to have received training may have been absent during those sessions and hence were missed out. Another reason for this can be the presence of trained technicians from the implementing agency in the villages on whom the users depend to get the complaints addressed. This dependency may be the reason why the users are not taking an interest in gaining knowledge about the O&M of the systems.

4.2. Service delivery and institutional aspects

The SHS disseminated in the surveyed areas were found to have been financed under the NABARD scheme, which provides loans including a subsidy of 40 percent (up to 300 Wp) or 30 percent (300–1000 Wp) at an interest rate as per the norms of Reserve Bank of India for a period of 5 years [8] and the balance is self-financed. Also, a number of other vendors sell the SHS to the users, at subsidised rate, under the Ministry of New and Renewable Energy (MNRE) programme. These systems are operated by the beneficiaries and their after-sales services are provided by the vendors from where the systems were procured by the users. However, the maintenance expenditure is borne by the user itself after the expiry of the limited warranty. It was found that majority of the SHS users (61%) are spending less than ₹ 100 (USD 1.50[5]) per year on maintenance and these charges are mostly related to refilling the battery water. Some SHS users have not changed the battery in years as it has been functioning well. In some cases it was found that the users are continuing with the battery even though there are some faults in it such as rusting of battery terminals and sulfation. On being asked the reason, these respondents shared that since the battery was functioning and they were able to use the lights in their house, they are not willing to spend money on rectifying these faults till the battery stops functioning.

In the case of solar pico-grids, the OASYS South Asia project provided around 30 percent of the

[5] One USD = 62.27 INR (as on March 31, 2015)

project cost to Mlinda Foundation i.e., the PIA. The balance amount was taken as loan from NABARD using the concept of JLG in which 5–10 households club together and applies for loan as a group. A nominal sum of ₹ 120 (USD 1.92) is taken to open a group account with the bank. The financial model for the system has been structured in such a way that the consumers become the owners of the system after the entire loan is paid back. NABARD has provided the loan to different JLGs facilitated by the PIA for a period of 5 years at an interest rate of 10 percent. After factoring in the interest and maintenance charges, a fixed monthly instalment of ₹ 180 (USD 2.89) is collected from each household by the implementing agency's local staff. The total amount collected is then paid to NABARD. The date for payment by the JLG is flexible and a delay of 2–3 days is allowed. In case a particular household is not able to pay on time, the group pays on its behalf. The JLG model, thus, attempts to increase the bankability of the individuals who apply for loans collectively, thereby reducing the risk for the financial institution with Mlinda Foundation acting as guarantor against the risk of non-payment. The group system ensures regular payments to the bank and reduces their risks. As for the beneficiaries, such a model provides them with affordable energy access and makes them the system owners eventually. Thus, the JLG model appears to be a win-win situation for all stakeholders involved.

In case of pico-grids in the markets, the systems are owned by individual entrepreneurs and shopkeepers. The system cost is ₹ 275/Wp (USD 4.4/Wp) which includes hardware cost, transportation costs and installation charges. Similar to households, the PIA here has facilitated the shop owners in receiving loans from NABARD, for a period of 5 years at 10 percent rate of interest. However, there is no JLG system in the markets and the monthly instalment paid by each shop owner depends on the capacity of the system at their place. Some shop owners have also given out paid connections to other shops. Figure 3 provides the amount spent each month by the shop owners.

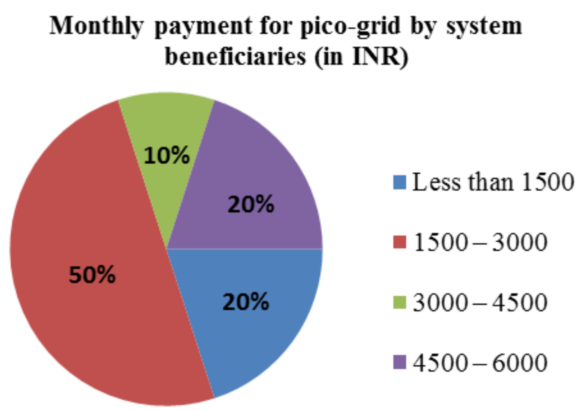

Figure 3. Monthly instalment paid by the shop owners.

The 110 kWp solar mini-grid at Indrapur was commissioned in 2004 by WBREDA and its ownership was subsequently transferred to the local village council. This project had fixed tariffs i.e., for 3 light points, the monthly tariff was ₹ 80 (USD 1.28) and for 5 light points it was ₹ 120 (USD 1.92). At the time of installation, WBREDA had allotted 10 percent of the total project cost for upkeep, maintenance, capacity building and after-sales services. Breakdown maintenance was to be done by the agency that installed the plant till the expiry of the warranty period. All other types of managerial and maintenance work including collection of tariff was supposed to be managed by the beneficiary committee, formed by the users, for which they were given proper training and provided with user manuals.

4.3. Project impacts

This section describes the impact of the solar PV systems on households as well as markets.

4.3.1. Impacts on households

4.3.1.1. Kerosene consumption and expenditure

The impacts of solar PV systems can be seen on various aspects of the lives of the consumers. A comparison of the current and past monthly average kerosene consumption show that the consumption for the SHS users has reduced from 4 liters to 3 liters and for pico-grids users the consumption has reduced from 3 liters to 1.5 liters (Figure 4). The un-electrified households were found consuming 4.6 liters of kerosene per month on an average. The average monthly expenditure on kerosene by SHS users reduced from ₹ 103 (USD 1.65) to ₹ 67 (USD 1.07), whereas, in case of pico-grid users, the kerosene expenditure has significantly reduced by around 75 percent per month. The un-electrified households were found spending ₹ 134 (USD 2.15) per month on kerosene (Figure 5). Though the average expenditure now has increased a little (as in some cases the household is paying for both solar light and kerosene) as compared to use of only kerosene lamps, the quality of light output received from the solar systems is much better than that received from kerosene lamps, making the cost per lumen-hour of kerosene much higher than that of solar lights.[6] It was found during discussions with the users that most of the pico-grid users have started saving money to pay for the instalments, which otherwise they would have spent on other things.

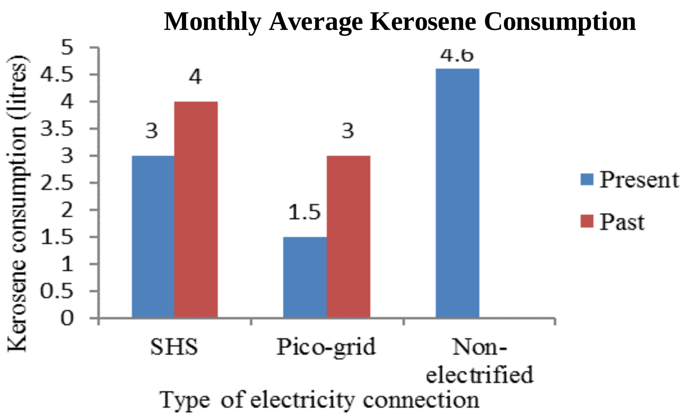

Figure 4. Monthly average kerosene consumption.

[6] A comparison between flame-based and electricity-based lighting systems indicates that the cost of useful energy is ₹ 10.38/k-lumen-h and in PDS price it is ₹ 3.13/k-lumen-h for kerosene wick lamps, while the cost of useful energy for solar lighting systems is much lower than kerosene lamps (less than ₹ 2) [17].

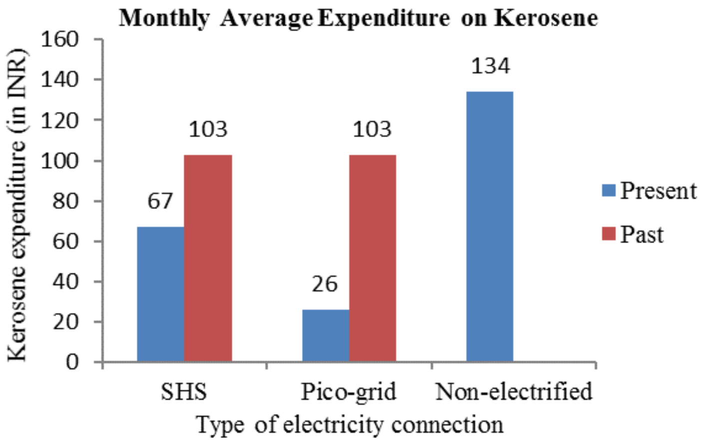

Figure 5. Monthly average expenditure on kerosene.

4.3.1.2. Livelihood activities post electrification

Figure 6 shows the various livelihood activities undertaken by the beneficiary households post solar electricity. It is clear that the impact on additional income generation has not been very significant. Only net mending was found to be done by the pico-grid users on a seasonal basis by some fishermen. Other income generation activities include running tuition classes at home, handicrafts making and renting out rooms which are seen in the households with SHS.

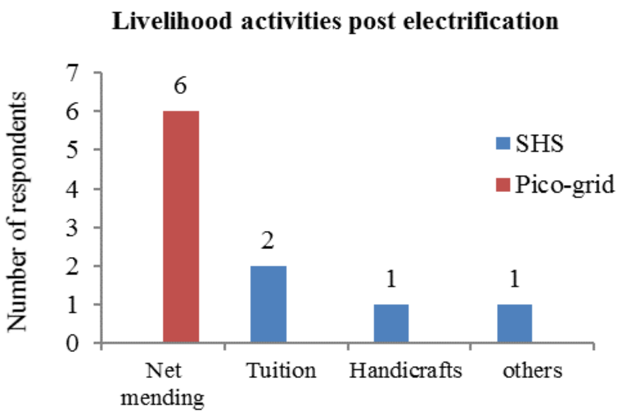

Figure 6. Livelihood activities post electrification.

4.3.1.3. Impact on gender

One of the most significant impacts of lighting is that on gender, i.e. on the lives of the womenfolk. In case of pico-grid users, it was found that 58 percent of the surveyed households are having light in their kitchen, whereas only 32 percent of the SHS beneficiaries are using light in the kitchen. The reasons given by the women for not having light in the kitchen were found to be varied. While some women did not realize that there could be light in the kitchen, some felt it is more important to have light where their children study. Many women were found purposely not taken a connection in the kitchen because they felt that cooking takes just about an hour, which can be easily done with a kerosene lamp rather than using a light point, which otherwise can be used for reading by their children. Out of the 41 beneficiaries having solar light in the kitchen, 80 percent shared that they find it very convenient to cook under the solar light as compared to kerosene lamps (Figure 7).

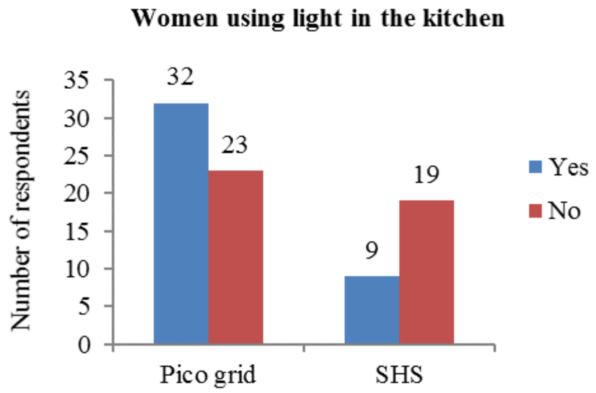

Figure 7. Women using light in the kitchen.

4.3.1.4. Impact on education

The impact of electrification on education is represented by the difference in the study hours of children between the present (using solar light) and past (using kerosene lamps), as shown in Figure 8. It is seen that there is not much difference in the study hours in the households with SHS because it was found that children in the surveyed area mostly study at the common study centres, run by private teachers. Though the children of pico-grid households also go to study centres, their study hours have increased significantly. This may be due to the fact that the pico-grid beneficiaries are financially weaker than their SHS counterparts and cannot afford to take tuition like the children of SHS beneficiaries and therefore, the children study at home.

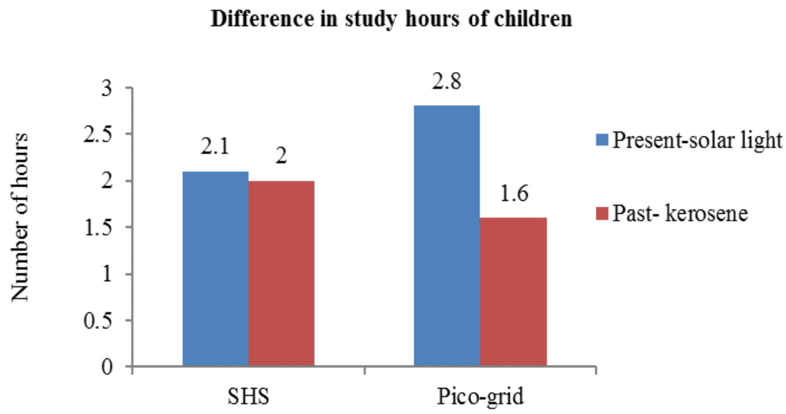

Figure 8. Difference in study hours of children.

4.3.1.5. Health impacts

To understand the health impacts, some proxies were used, even though they might not be the most robust tools. Figure 9 depicts the type of health problems due to usage of kerosene. During the survey, all the households were asked if they have heard of any accidents resulting out from kerosene usage in the past six months irrespective of whether they were still using kerosene or not, to which almost 80 percent of them responded in the positive. They quoted incidents such as fire breakout, children getting hurt from the lamp and children consuming kerosene from the bottle in which it is kept thinking it to be water. This aspect is also corroborated from other similar studies done in India, which have mentioned frequent house burns due to accidental knocking down of kerosene lamps and incidents of many people suffering from burns frequently specifically, the aged ones and children [30,31]. Further, it was noted that kerosene is causing a myriad of health problems. Out of the total households surveyed 75 percent of the users reported health problems due to kerosene (Figure 9). Most of these health problems are experienced by the women as they are using kerosene lamps in the kitchen. Out of the 75 percent of users who reported health problems, 32 percent have made visits to the doctor annually (Figure 10). It was found that 17 percent of the respondents are spending between ₹ 100–200 (USD 1.60–3.21), 21 percent are spending between ₹ 200–300 (USD 3.21–4.81), 10 percent of the respondents are spending between ₹ 300–400 (USD 4.81–6.42) and 52 percent are spending more than ₹ 400 (USD 6.42) per visit (Figure 11). These expenses are inclusive of consultation charges, medicine costs and transportation expenses incurred during the visit.

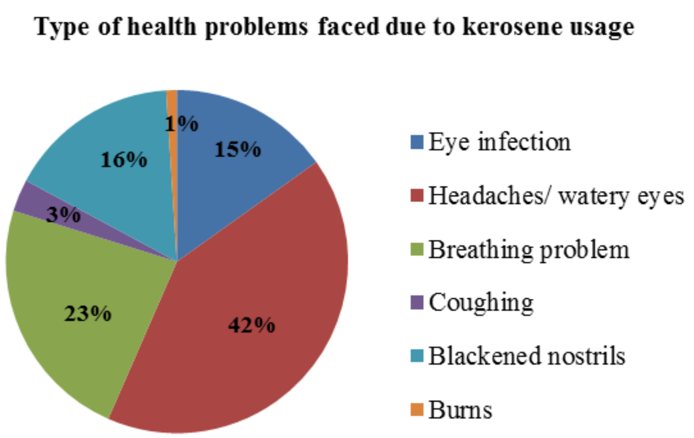

Figure 9. Type of health problems faced due to kerosene usage.

4.3.2. Impacts on business

4.3.2.1. Kerosene consumption and expenditure

In case of shops connected to pico-grid, six surveyed shops were using kerosene to meet their lighting requirements prior to pico-grid installation with a monthly average consumption of 3litres amounting to an average expenditure of ₹ 143 (USD 2.29) per month. However, post pico-grid installation, four out of the six shops continue to use kerosene- (around 2.9 litres/month), spending an average of ₹ 143 (USD 2.29).

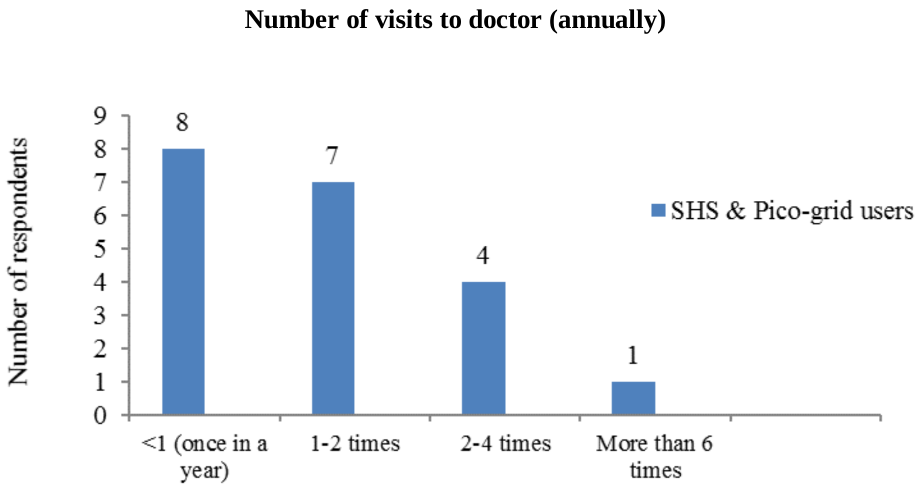

Figure 10. Number of annual visits to doctor.

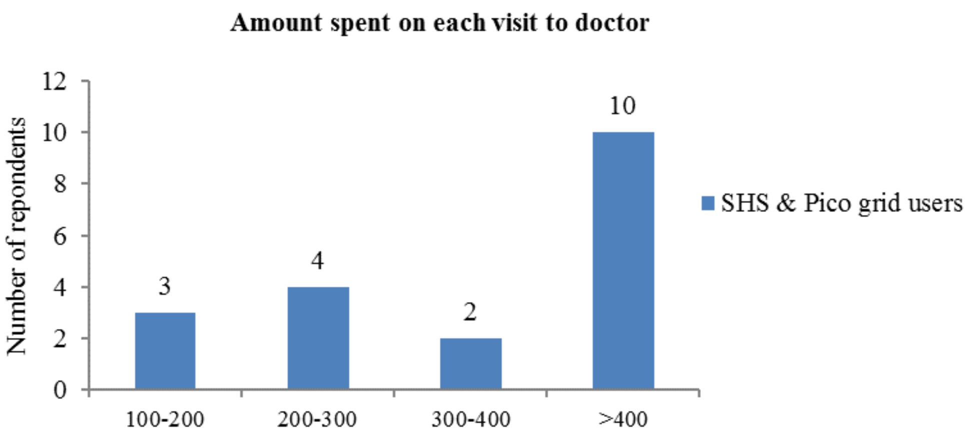

Figure 11. Amount spent on each visit to doctor (in INR).

Whereas, in case of shops connected with SHS, three surveyed shops were using kerosene with a monthly average consumption of 4 litres/month with a monthly average expenditure of ₹ 165 (USD 2.64). However, it was found during the survey that post solar system installation only two shops are using kerosene at a monthly average of 5litres in and expenditure of ₹ 216 (USD 3.46). This can be seen partly as an achievement of the solar PV systems as now lesser number of shops is dependent on kerosene, 2 out of 6 pico-grid connected shops and 1 out of the 3 SHS using shops have completely done away with kerosene use. At the same time it can be seen that the shops that are still using kerosene are spending more or less the same amount of money as they did in the past. This behavior can be attributed to the possible growing demand of their businesses, which create a requirement for more lighting beyond the hours of supply from solar interventions, which is being met by kerosene. Also, the rising prices of the fuel over the years may have also augmented the amount spent on each litre of the fuel.

4.3.2.2. Change in income

The shop owners were asked if they have seen any change in their profit since the time they got the new means of electricity. Out of the total shops surveyed, 67 percent of the SHS users and 60 percent of the pico-grid users have reported a change in profit. Out of the shops that reported change in income, 67 percent of the pico-grid shop users believe that the change in their monthly income is largely due to electricity access, while 26 percent of them do not attribute electricity to the change. In case of SHS shop users, 37.5 percent were of the opinion that the change in profit is largely due to electricity and the same percentage of users partly attributes electricity as the reason for their change in profit (Figure 12). The pico-grid beneficiary shop owners who believe that an increase in their profits is due to electricity are the ones having larger shops, offering a lot of services to their customers. Also amongst these pico-grid connected shop owners, 60 percent are those who are using ICT and entertainment appliances in their shops that require electricity to run. According to Mlinda Foundation, the shop owners approached them for these bigger systems so that they can expand their businesses and at the same time provide electricity connection to their neighbouring shops at a price. However, this is first validated by the field officers of the agency before handing the system over to the shop owners. On the other hand, most of the SHS shops are relatively smaller than the pico-grid ones and thus, do not require electricity that much.

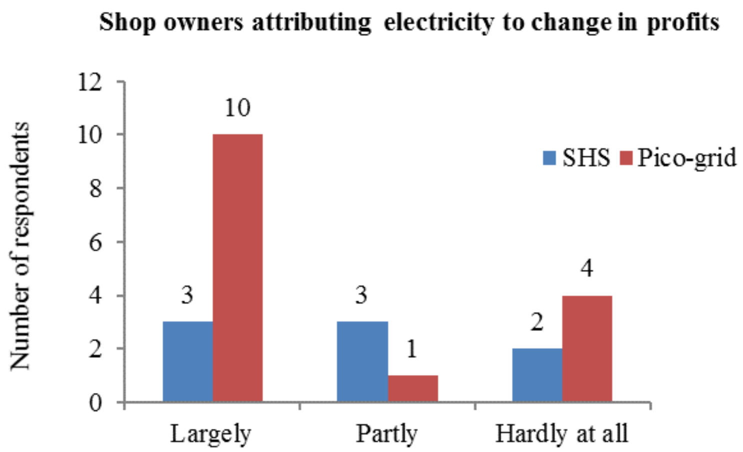

Figure 12. Shop owners attributing electricity to change in profits.

4.3.2.3 Future aspirations for appliances

The survey also attempted to understand the aspiration level of the users so as to know what type of appliances will probably be in use if higher amount of electricity supply is provided to them from solar PV systems or if grid reaches these villages. The survey results show that the pico-grid users aspire to purchase a wide variety of appliances (Figure 13), whereas SHS using shop owners are willing to purchase only some basic appliances (Figure 14). The pico-grids installed in the markets have sizes of 250 Wp, 500 Wp, 1 kWp, 1.5 kWp and 2 kWp, which are larger in size than most of the SHS. The aspiration levels of the pico-grid users are much higher than the SHS users, as most pico-grid users are already using appliances other than basic lighting like televisions, fans, computers, printers, fridge, lamination machine, etc. Thus, they have adapted themselves to the benefits and comforts of modern technology and have aspirations to own more appliances. The SHS users, on the other hand, are currently using basic appliances, owing to their smaller system capacity and their aspirations reflect a need for just a little more than what they already have.

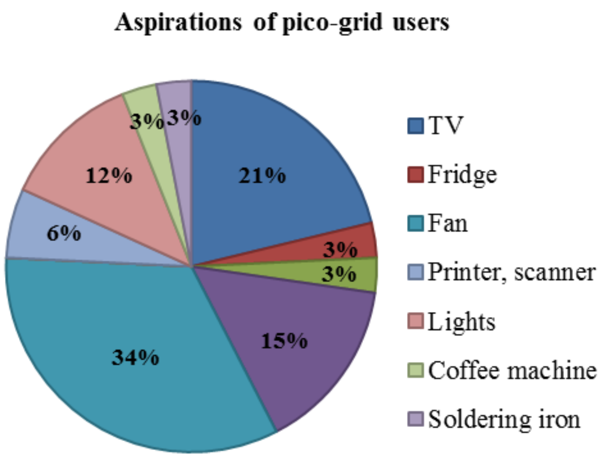

Figure 13. Aspirations of pico-grid users.

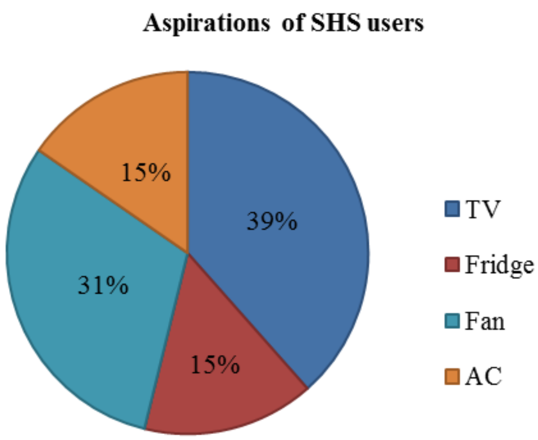

Figure 14. Aspirations of SHS users.

5. Discussion

The success of any techno-commercial model is not only dependent on its current workability but also on its ability to sustain itself in the future with minimum effort. The significance of off-grid models is greatly highlighted by the limited probability of the central grid reaching remote areas. Even though a few islands of Sundarbans region have been able to get grid connectivity, a great amount of difficulty persists in extending the central grid to all the islands. Similarly, the grid cannot be taken to the forest villages in India owing to prevalent regulations which do not allow extension of electricity lines through reserved forests in India [32]. The obstacles in extending the grid to all Islands are firstly being in the delta region number of rivers are flowing next to many of these islands, and secondly, the islands, though having a population of over 20,000 has very little productive load. Due to this, it is estimated that the grid would not reach many islands due to economic unviability. But, if in the future it does become feasible to extend the grid to these places, the mini-grid and pico-grids can still be integrated to it by replacing the inverters or can be used during blackouts thereby ruling out any redundancy.

The findings from the study elucidate that, in general, the impacts of the solar PV solutions used for electrification have been largely positive. The most important impact has been the reduction in kerosene consumption. But the quantities consumed by SHS users and pico-grid users show a stark difference, as the reduction is more significant in the case of pico-grid users. The reasons for this can be partly attributed to the economic stature of these two classes of users. The SHS users, being comparatively more financially sound, can afford to continue to spend on kerosene while using SHS, whereas, the pico-grid users have to cut back on kerosene as their poor economic conditions do not allow them to pay the monthly installment along with purchasing the same amount of kerosene as they did in the past. It will be worthwhile to mention here that kerosene, distributed through Public Distribution System (PDS) is heavily subsidized in India. However, researchers argues that kerosene subsidies are regressive and of minimal financial value to the poor rural households. This is because household quotas are based on cooking needs, whereas in all communities, kerosene is being significantly used for lighting purposes [31,33]. When the community is confronted with better lighting options, with affordable financing schemes, they are motivated to purchase them. However, they continue to buy kerosene through PDS to use it in case the solar lights do not function, like in case of bad weather conditions or if the systems become defective for some reasons. This also occurs in many grid-connected areas where households have arrangements for backup inverter or other lighting fuel (including kerosene), highlighting the need for planners of decentralized energy systems to communicate clearly the nature of faults and blackouts that users might encounter. Second, all households are currently availing kerosene under a government welfare benefit scheme and perceive a risk in opting out. Users are uncertain if opting out could lead to exclusion from the welfare benefits in the future.

It can be concluded that, in this particular case, financial constraints have involuntarily led the consumers to make an environmentally sound choice. However, the continued usage of kerosene lamps by many women in kitchen is a cause of concern, especially in terms of negative health impacts. What is worth noting is that the women are willingly sacrificing their convenience for the sake of other family members. This behavioral pattern amongst the womenfolk brings to the fore how social norms govern the choice and relevance of technology in the lives of consumers. The implementing agency for the pico-grids, Mlinda Foundation’s approach to electrification is not restricted to just plant installation and service delivery. It aims to bring a sense of ownership amongst the users. After repayment of the bank loan, the system’s ownership will get transferred to the consumers. By then, they will have been so well versed with the management of the system that they would not need external support. Even though the implementing agency assures its presence to address any technical or managerial issues, and also train the people to handle any problem that may arise; the decisions regarding the management of the system would be taken by the group members alone. It is expected that being solely responsible for the system and being in a position to take all major decisions will generate the need to preserve it and ensure its longevity, thereby leading to sustainability and self-sufficiency.

Many SHS users have opined that this system offers more freedom of operation than the pico-grid and that formed the basis of their decision to opt for this over the pico-grid connection. During the course of the surveys, it was found that even the pico-grid users preferred to own individual systems over the group arrangement, as it gave them autonomy of operation but due to financial constraints, they could not afford to purchase them, and thus, agreed to take group connections. But, it was seen that this unchecked freedom had a flip-side to it. Some users were operating their systems for extended hours without realizing the fact that the battery life will get reduced. In this aspect, the restriction on the hours of operation in the household model of pico-grids helped curb reckless usage by the operators. However, in the market model, the systems were owned by individuals, so such a restriction could not be imposed and the shop owners are using their systems as per their requirement.

It was observed that a lot of SHS users are facing problems due to lack of proper maintenance of their systems. Also, there is a dearth of trained technicians in the area. It was even reported in some cases that the agents, after selling the system, could not be traced again for after-sales services. In such a scenario, utilizing the skills of the technicians trained by the implementing agency of the pico-grids can turn out to be a boon for these users. The staff of the Mlinda Foundation is of the opinion that they are willing to provide maintenance services to the SHS users, who are not their clients, provided they are ready to pay for these services. Another interesting observation was that the users have tried to plug in different appliances like fans and televisions into the sockets provided for mobile charging, thereby damaging the system. If these sockets are replaced with various charger pins, it would, to some extent, deter the users from trying to run appliances other than the ones permitted.

The solar mini-grid at Indrapur has been not been in operation for a while now. Apart from technical problems, a lot of managerial problems surfaced while it was operational. WBREDA shares a view which is similar to the approach adopted by Mlinda Foundation. It opined that proper management can be ensured if there is a sense of ownership amongst the consumers, for which models have to be redesigned to make the consumers the owners of the system. They have to be made aware of the basic working of the system and they should be able to check for minor problems so that they can specify these complaints to the maintenance technicians and the problem can be resolved in the shortest possible time. Even these technicians have to come from within the village instead of being outsourced to increase the efficiency and sustainability of the model. WBREDA can act as a facilitator to augment the local engineering manpower of these Panchayati institutions. Currently, WBREDA is working on to revive the plant.

One issue that was not anticipated was the problem regarding the Indrapur market committee. The committee has imposed restriction on all shopkeepers to use the electricity from the diesel generator and is not allowing shopkeepers to take electricity connection from the pico-grid connected shops. On enquiry, it was found that the market committee procured a diesel generator set with the consent of all shopkeepers of the market way before the concept of solar pico-grids was introduced. The committee now feels if all shopkeepers switch to pico-grids then their investment in the generator bring a huge loss to them. The other reason given by the committee is that solar electricity is limited and intermittent. During rains and cloudy weather, the shopkeepers will need an alternative source of power, for which they will inevitably turn to the diesel generator set. This enforcement of a compulsory diesel generator connection on the shop owners by the market committee of Indrapur is a cause of concern. As a measure to pacify the concerns of both the shop owners as well as that of the market committee, WBREDA can transfer some part of the Indrapur power plant to the market committee for operation and management so that they can recover the cost of the generator set through the tariffs earned by giving out paid connections to the shop owners.

With an increase in electricity access, a growth in the demand for more aspirational loads is also inevitable. While the present pico-grids are not equipped to handle loads higher than what they were designed for, solar being a truly modular technology, it is possible to increase the capacity of the system. But, increasing the capacity would increase the system cost, which may make it less affordable to the people. The Foundation feels this would require either subsidies greater than 50 percent of the project cost or long term low interest loans from banks and financial institutions as opposed to the current short-term loans. As it seems difficult for the conventional grid to be extended to these remote villages in the near future, environmentally sustainable alternatives have to be explored to meet the growing demands of the people.

The aspiration to own better and more advanced appliances, as seen in the survey results, not only throws light on the willingness of the people to spend money but also reflects the level of awareness possessed by them with regards to the progress of the world outside their territorial limits. Despite living in geographically remote regions, the people have shown an acumen and keenness to be at par with the fast pace of development around them. This can also be corroborated by the observation that most children are being educated by their parents. However, it was also found that students seeking college education had to go to other places as the facilities were lacking in their own islands. Expanding the educational infrastructure can be done by the concerned authorities keeping in mind the success of solar PV based interventions in the area. Also it was found that presently only a miniscule percentage of the people are making use of solar light for generating additional income. Their success stories should be treated as case studies for other beneficiaries to draw lessons from, which can be done by the various NGO's operating for the empowerment of people, with a special focus on women. Further, with appropriate policy intervention, new and upcoming enterprises and industries can be made to use solar or other renewable technologies as a part of their power source, All these call for in-depth planning and gauging of the specific needs of the different sections of these communities, so that appropriate measures can be taken to provide them not just basic lighting services but also fulfill their aspirational requirements. This becomes even more important if holistic development of the remote community, especially the un-electrified households mentioned as category (a) and (b) in the Introduction section, is identified as a priority by all the stakeholders- right from the governments concerned to private organizations working in this field. Literature also indicates that, apart from solar lighting solutions, other appliances such as motors, photocopier machine, grinding machine, water purifiers have been used with solar power in India to meet the growing demand and higher aspirations of the community or for creating income generation activities [18,19,22,34]. In fact, when the option of installing hybrid renewable energy models was discussed with the implementing agency of the pico-grids, it was found that they are in the process of designing such a model to meet the aspirational demand of the users. WBREDA also agreed to the possibility of developing such systems, which will incorporate other forms of renewable energy along with solar PV technology. While it feels that a combination of wind and solar energies are feasible in some parts of the Sundarbans and have been tried in some cases but observes that using a biomass gasifier in one of the islands of Sundarbans has not been able to yield the required output. The main reason for this is the limited availability of good quality biomass feedstock, since trees of the Sundarbans forests are not permitted to be cut down and the available biomass is high in moisture content. This leads to a decrease in the plant efficiency. Owing to the shortage of feedstock, the people use diesel to fuel the gasifier, thereby defeating the very purpose of using a renewable energy based technology. This highlights the need for research in the field of hybrid technologies in order to augment their technical viability and commercial robustness in the competitive energy market.

6. Conclusion and recommendations

The study clearly shows that both pico-grid as well as SHS has tangible benefits accruing to the local community in terms of improved quality of light, reduction in kerosene consumption and a sense of associating with improved standard of living. However, a significant difference is observed between pico-grid and SHS in terms of their service delivery and financial structure but rural community is definitely exploring these options and learning to make a comparison between different options available to them.

Further, in order to address the complaints of the users and to strengthen the communication between the implementing agency, technicians and users, frequent meetings between the stakeholders are required. Lack of regular maintenance has emerged as one of the major reasons for the poor performance of SHS. It was seen that consumers are simply getting the battery water refilled as a maintenance activity rather than getting the entire system inspected properly. On the other hand, the pico-grids are being regularly inspected and maintained by the installing agency. It is recommended that efforts should be made to extend the benefits of regular maintenance to individual system users as well. The existing network of trained local technicians of the Mlinda Foundation should be encouraged to enlarge their client base as it will contribute to additional income for them also. In addition to this, developing necessary infrastructure and technical capacity at the local level for developing the last mile distribution channel and providing after-sales services will ensure self-sustenance of the systems.

Since it has been found that in some cases the women themselves are not taking a light connection in the kitchen, it is clear that they are putting the comforts of their family ahead of their own needs, even in cases where they know that their health is being compromised with. This cannot be totally justified. As a solution it is recommended that the installation agencies take responsibility and offer no choice wherever kitchen lighting is concerned or can install the bulb in such a way that both kitchen and study area is illuminated. This enforcement will mitigate a lot of kerosene related health problems and accidents in the long run.

It was seen that school going children are spending more study hours in the evenings at tuition centers and not at home. Not all of these tuition centers have lighting facilities available and are still dependent on kerosene to meet their lighting requirements. Thus, the motive behind having a light dedicated to studying children has become redundant. In order to tackle this situation, it is recommended that the group concept or individual ownership model be followed for the tuition centres as well. This will improve both the quality and quantity of study hours and also serve to control the negative health impacts of studying under kerosene light.

The usage of SHS and pico-grid services by the people to meet basic lighting requirements has created a demand for more power supply. This in turn has led to a demand for metered connections as the JLG members wanted to pay only for the amount of power they are consuming. The concept of pre-paid meters with automatic tripping mechanism can act as a solution if it is found to be technically compatible and economically feasible with respect to the current system.

A key conclusion from the study is that strong local institutions, such as Mlinda Foundation, can play a big role in facilitating access in energy starved areas. Thus technology is not the only factor on which the viability of a program can be decided but institutional and financial aspects are the important factors that contribute to the success of the programs. Developing a strong framework and institutional policies is the need of the hour for achieving higher success rates in PV programs.

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Conflict of Interest

All authors declare no conflicts of interest in this paper.

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