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Comparative Analysis of Solar Photovoltaic Lighting Systems in India

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Abstract

This study is based on extensive survey of selected photovoltaic (PV) programs in India and presents a comparative analysis of four prevalent solar lighting technologies, namely Solar Home System, Solar Charging Station, Solar AC Mini Grid and Solar DC Micro Grid employed for rural electrification in India. The study is focused on technical, financial, and institutional aspects of these programs along with the social impact assessment of PV based electrification in rural households. The findings of this study revealed that private entrepreneurship based delivery model have shown better performance as compared to the subsidy based delivery model. It is also found that beneficiary ownership play a vital role in the performance and sustainability of PV programs. We suggest that financial support, local need based technical innovations, developing local technical expertise and sensitization and training of all stakeholders are key parameters to enhance the operational sustainability of the PV programs.

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*Keywords:*Photovoltaic, Photovoltaic lighting, Home lighting systems,Rural electrification, Energy access

1. Introduction

Access to electricity for rural areas in India has been a major concern with 43.2% of the rural population still deprived of electricity access [1]. Various past studies have highlighted the barriers existing in provision of electricity services to rural areas [2, 3]. Due to this hindrance, commercial acceptance of use of renewable sources of

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energy has not been very good. However, the rural electrification program by using renewable energy sources have been carried out by the Government of India and efforts made in the past three decades have been noteworthy [4,5]. While the centralized grid based electrification has been the most common approach, decentralized renewable energy options especially, solar photovoltaic (PV) systems have also been adopted and being increasingly considered as an cost effective mode of electrification, especially for areas where it is techno-economically not feasible to extend the electricity grid or in areas where electricity supply from the grid is inadequate to meet the demand. These off-grid communities often characterized by scattered settlements consist of small, low-income households. Hence, they are economically unattractive for electricity distribution companies to extend the grid. The state renewable energy development agencies, established in the different states by the state governments and working under the aegis of the Ministry of New and Renewable Energy (MNRE), Government of India has largely addressed this vacuum. In addition, NGOs have also implemented number of pilot projects by raising funding support from donor agencies and support received through funds from Corporate Social Responsibility (CSR) initiatives. Off late, private entrepreneurs have also ventured into the field foreseeing the business prospect of the sector.

Solar PV lighting programs have been implemented adopting various delivery models, such as leasing of energy products, consumer financing model and direct subsidy [6]. Institutional arrangement is also one of the important aspects in PV programs. Literatures have revealed the importance of an efficient institutional structure in the sustainability of PV programs [6, 7]. Dissemination of solar PV programs requires extensive financing from government and involved organizational supports as such projects are aimed at the low income sections of the nation. Alzola *et al.* (2009) depicted that the high cost of initial investment is the main barrier for the extensive use of solar PV and highlighted that direct contribution from the users, combined with financial tools such as subsidies and loans may be essential to support the project economically in the long run [8]. Solar PV electrification has also proven to have a positive impact on the lives of the rural population. Various studies have highlighted the contribution of PV electrification to improve the social-economic enhancement of the rural areas, clean energy supply and contribute to greenhouse gas (GHG) mitigation from use of kerosene for lighting [9-11]. Studies have also revealed how PV electrification has contributed towards enhancing the livelihood activities of rural households [12, 13]. Various studies have been carried out on individual PV lighting technology options and their performance and impacts [6, 7, 13-16].

This study presents a comparative analysis of the solar PV lighting options namely, Solar Home System (SHS), Solar Charging Station (SCS), Solar AC Mini Grid (SMG) and Solar DC Micro Grid (SDCMG) on their technical, social, institutional and financial aspects, to highlight the factors that are critical to the sustainability of PV based rural electrification programs and also presents an socio-economic impact of PV electrification in rural areas. 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. [15]. The charge controller which is an integral part of the SHS controls the energy inflow and outflow into and from the battery bank. A SCS on the other hand, comprises of solar PV modules in a specific voltage and current configuration to charge a number of solar lanterns or batteries. The charge controller is designed to ensure that all the lanterns and or batteries are adequately charged. SMGs are designed to generate electricity centrally and distribute it for various applications to households and small businesses spread within a particular area. They usually supply 220 V, 50Hz 3-phase or single phase AC electricity through a 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) low-tension power distribution network. SDCMG are a recent phenomenon in India and are designed to generate DC electricity using one or more solar panels and is distributed over a short distance from the battery banks to a cluster of households or shops. They usually supply at 12 or 24 V DC and provide minimum basic lighting services for 5-7 h using LED lamps and facility for mobile charging.

The paper starts by briefly introducing the experiences related to access of energy to the rural areas. Section II discusses the methodology followed for the research work. The paper then analyses the functionality, monitoring and maintenance of the systems, service delivery model, institutional structure and project impacts, especially impact on livelihood, in the Results and Discussion section. Finally, the Conclusion section summarizes the study from wide range of experiences and highlighted the linkage of various issues related to sustainability of the PV based electrification programs.

2. Methodology

A framework has been developed to carry out the study on comparative analysis of PV lighting systems. The framework consists of the technical, social, financial and institutional aspects. Each PV lighting systems have been analysed in terms of each of those aspects of the framework to understand the linkage between technology and associated business model that is best suited for the sustainability of the systems. The selection of states from each zone namely Northern, Eastern, North-Eastern, Western and Southern has been done after analysing the number of un-electrified villages in each state of the respective zones. Since Southern and Western zone have approximately cent percent electrification through grid extension, these zones are excluded from this study [17]. So the zones that have been covered under this study are Northern, Eastern, and North-eastern zone. The state has been selected from each zone which has a poor rate of household electrification. Also for the selection, it has been considered that the particular state must have at least two types of solar lighting systems employed for rural electrification which is scrutinized using the secondary data from various implementation agencies. Hence, based on the available data, Uttar Pradesh from North zone, Assam from North-Eastern zone, Odisha and West Bengal from the Eastern Zone has been selected for this study. The number of villages covered under this study is provided in the Table 1.

Table 1 Number of households covered under each PV lighting option

Solar PV lighting system	Number of households covered
Solar Home System (SHS)	65
Solar Charging Station (SCS)	65
Solar DC Micro Grid (SDCMG)	60
Solar AC Mini Grid (SMG)	10
Total	200

Table 2 Study area profile

State	Type of system/ technology	Name of the surveyed village	Current grid based electrification status
Assam	Solar Home System	Dakshin Narainpur, Sagalmoha, Bherveri Pather, Borpholong	Un-electrified
	Solar Charging Station	Jarauni Gaon, Lakhipur	Poorly Electrified
		Aliguri Bahumari, Dakshin Narainpur	Un-electrified
Odisha	Solar Home System	Ghaniaposi, Tilwadi, Porgarh, Kumudabadi	Poorly Electrified
	Solar Charging Station	Nangalsila, Baradisahi, Sundaroba	Poorly Electrified
		Antili B	Un-electrified
Uttar Pradesh	Solar Home System	Ataihia, Lakshminagar, Nurpur	Un-electrified
	Solar Charging Station	Hariawad, Atardhani	Poorly Electrified
		Salarikheda	Un-electrified
	DC Micro Grid	Tanda, Ruknapur, Bhur Bhawani Kheda, Atardhani	Poorly Electrified
West Bengal	Solar Home System	Bagdanga	Un-electrified
	Solar AC Mini Grid	Bagdanga	Un-electrified

Now in each state, the village clusters, both un-electrified and poorly electrified, are selected on the basis that there are at least two types of solar lighting systems disseminated by various agencies and institutions for electrification in the village. It is to be noted here that poorly electrified villages are selected as solar devices have been extensively implemented in many poorly electrified villages, where either many households have not taken grid connection or the electricity supply situation is very dismal. This selection has been done on the basis of secondary data on installation collected from agencies such as The Energy and Resource Institute (TERI), Odisha Renewable Energy Development Agency (OREDA), Assam Energy Development Agency (AEDA), Ministry of New and Renewable Energy (MNRE), rural banks such as Aryabhat Grameen Bank and private companies such as MINDA Nextgen Technologies. Two villages are selected from each cluster in a state on the account that at least 50 households have electrified through one of the two solar lighting technologies. This is selected on the basis of the secondary data collected from the agencies. Table 2 present the study area details. The actual households from a particular village are selected based on random sampling method.

3. Results and Discussion

A typical SHS was found to consist of a 37 Wp of solar panel, a 40Ah rechargeable deep cycle lead acid battery and two compact fluorescent lamps (CFL) of 9 W each. It is also found that LED based systems of 15Wp of solar module powering two 3W LED lamps are implemented in few households. SDCMG consisted of 140 - 240 Wp PV array for providing electricity to 20 - 40 households respectively. LED lamps of 1.5 to 3W are used in the households and mobile charging facilities are also provided. SCS were found to consist of five 50 Wp solar panel with five to six junction boxes, each having 10 ports to charge 10 lanterns. The SMG, covered under this study, was a 55 kW PV plant in Bagdanga village, in West Bengal, which is supplying electricity to 160 households consisting of 74 Wp PV module of appropriate numbers and a battery bank of 240 batteries, each of 2 V and 800 Ah capacity. Three inverters, each handling a load of 25 kW, and a charge controller of 25 kW have been used.

3.1. Functionality

The survey indicates that 49% of the households found the solar light quality very good, 35% of the households have reported that they are satisfied with the quality of light provided by the solar lighting systems (Fig. 1).In terms of SHS functionality, Assam projected a good functionality score followed by Uttar Pradesh and West Bengal. The systems implemented in Orissa are found to have a poor functionality rate. The reason for poor functionality of SHS program in Odisha is due to the fact that the authorized service personnel employed by OREDA are not performing any of the repairs reported by users. Also the systems are poorly maintained by the users and had no proper fixtures for keeping the panels. In terms of SCS functionality, out of eleven stations covered in Assam, Odisha and West Bengal, eight stations are found to be functional, two stations are functional with minor faults and one station was found to be non-functional. The non-functional station, found in Uttar Pradesh, was due to the non-provision of spares by the technology provider. One of the SCS in Assam was found operational with minor faults. The minor fault is due to the insincerity by the entrepreneur who was found to be less concerned about the basic routine maintenance required for operation of the SCS. SDCMGs' disseminated in Uttar Pradesh were found to function efficiently without any faults. These SDCMGs' were found to be operational for 5-7 hours per night depending on weather and daylight conditions. The plants were found to be efficiently maintained and operated by the respective entrepreneurs. The SMG implemented have been in operation for 5 years and is currently operational with minor faults. The plant was found suffering from faulty battery, inverter problems, charge controller issues and distribution cable faults. The system operation time was reported to have reduced form 5 hours to 2 hours.

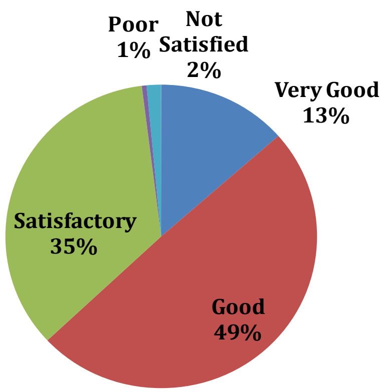

Fig.1. User satisfactions on PV lighting

3.2. Technical Knowhow

Among the SHS users, it was found that 98% users have good understanding about the importance of cleaning the solar panels, 58% knew about instrument connections and 34% users had idea about the faults in the systems. All the users were found well educated about refilling battery with distilled water and charge controller indications. Training initiatives have been undertaken by AEDA and OREDA in Assam and Odisha respectively. In Uttar Pradesh and West Bengal, the technician from Akshay Urja Shop has provided the required knowhow to the users. User's in Assam, Uttar Pradesh and West Bengal were also found to take proper care of the systems as instructed during the orientation program but in Odisha, the users were not following any instructions. SCS are operated by the entrepreneur, and it was found that out of 11 entrepreneurs interviewed, 9 had complete technical understanding of the system and thus is properly maintaining and operating the systems. The entrepreneurs were also found to have received extensive training in operation, maintenance and minor trouble shooting of the lanterns. Entrepreneurs in Odisha and Assam have good knowledge about simple troubleshooting but entrepreneurs in Uttar Pradesh did not perform any troubleshooting as they were not imparted training in troubleshooting by the partner NGO, who setup the stations for them. So the repairs of the lanterns got delayed. In Assam, it was found that one of the entrepreneurs was less concerned about the operation and maintenance of the system and was not performing any trouble shooting, leading to irregularity in operation of the station. The SDCMG's implemented in Uttar Pradesh were operated by the respective entrepreneurs. The entrepreneurs reported that they have received proper training on operation and maintenance from the respective Project Implementation Agency's (PIA) during installation and also are also getting efficient local technical support from the energy entrepreneurs, involved by the PIA. Since the SMG was being operated by an experienced operator, he was found to have good technical understanding and knowhow of the operation and maintenance of the plant.

3.3. Service delivery model

The SHS in Assam and Odisha were disseminated by AEDA and OREDA respectively under the subsidy scheme of Remote Village Electrification (RVE) initiative of the Government of India. The systems were provided with 90% subsidy by the Central Government and remaining 10% was borne by the State Government. In Assam, beneficiaries contributed 5% of the system cost, but in Odisha, the beneficiaries did not made any contribution. Under the RVE scheme, the systems are managed by the Village Energy Committee (VEC) setup by the beneficiaries. The technology provider under the RVE program was entrusted with the responsibility of setting up the service centres, provision of spare parts and training of local technicians. In Assam, AEDA has asked users in both Karimganj and Sonitpur districts, to deposit INR 70 per month to the VEC, which is to be saved as recurring deposit in a bank, so that the money can be used by them to replace the battery after 5 years of useful life. In this sum, INR 20 is technician's salary and INR 50 is deposited in the bank. In contrast, systems disseminated in the study villages of Odisha were found not following any such practices. In Uttar Pradesh, the SHS were disseminated under the NABARD consumer financing scheme by the rural banks such as Aryabhat Gramin Bank and Union Bank of India. The systems are provided with 40% subsidy (INR 100/Wp) by MNRE and the remaining 60% is borne by the users through EMI of INR 250/month for 5 years at an interest rate of 12%. Similarly, in West Bengal the systems have been provided under the NABARD scheme, with 40% subsidy by MNRE. These systems are self-managed by the beneficiary. After-sales service is provided by solar energy enterprises from where the systems were procured by the users.

TERI, under its Lighting a Billion Lives (LaBL) initiative, has been disseminating SCS in Assam, Odisha and Uttar Pradesh following the fee-for-service delivery model. While a major part of the capital cost for setting up the SCS in the study villages was found to have been raised by TERI from corporate donors and MNRE, there has been some equity contribution also by the entrepreneurs and the users. The SCS are owned and managed by the entrepreneurs and a partnering NGO in the respective areas. The operation and maintenance cost is borne by the entrepreneur from the tariff users pay, ranging INR 2-3 per lantern per night. In Sonitpur, Assam, the entrepreneurs were found to deposit INR 300 per month per SCS for maintenance and repairs to the NGO. Under this model, the battery replacement cost is borne by the users. However, in Karimganj, Assam, the entrepreneur is paying INR 1500 per month per SCS, under which battery replacement and all maintenance is to be taken care of by the NGO. In Odisha, the stations were found to be community managed. From the total collection in a month, the entrepreneurs keeps INR 300-500 as remuneration and deposits the balance amount as maintenance charge to the Village

Development Committee (VDC), who manages the stations. In Uttar Pradesh, no management body was involved and the entrepreneurs were found to manage the stations directly.

SDCMG commissioned by TERI in Uttar Pradesh is also operating using the fee-for-service delivery model. The system has been installed with a 2 years warranty. The SDCMG implemented by the private entity called Minda Nextgen Technology follow a more commercial form of fee-for-service delivery model in similar lines of other companies in Uttar Pradesh such as Mera Gao Power and Nature Tech Infra [6]. In this model, services such as lighting and mobile charging are provided without provision of other appliances. The systems are solely owned by the entrepreneurs, who contribute a major part of the cost as their equity for the plant. The SMG in Sunderban was disseminated under the RVE scheme of Government of India in which 50% of the systems cost was provided as subsidy. The SMG's was found to be commissioned by a technically competent contractor through WBREDA. The same contractor also works as Annual Maintenance Contractor (AMC) and is held responsible for operation and maintenance of the SMG. The plant is managed by a beneficiary committee under guidance from WBREDA.

3.4. Institutional structure

SHS systems, implemented under the RVE scheme, are managed by the VEC of the respective villages in Assam and Odisha. In Sonitpur, Assam, the management of VEC was found to be sincere towards their responsibility and thus the delivery model is found to be followed as per norms. However, in Gajapati (Odisha) and Karimganj (Assam), the local management lacked in their sincerity towards their role in the initiative and as a result the sustainability of the program has been at stake. In Mayurbhanj (Odisha), no NGO was involved with the SHS program. In Uttar Pradesh and West Bengal, the systems were personally managed by the owners with technical support from the energy enterprises. It was found in Uttar Pradesh that the SHS users are not aware about the institutional pattern that existed in the initiative. As a result they were notifying the bank in event of any replacement, and accordingly the bank notifies the system provider for providing the service.

SCS in Assam was managed by a partner NGO of the LaBL initiative. It was found in Sonitpur, that the management is dedicated and concerned about this initiative and has taken steps in providing the responsive service to the lantern users. The biggest issue being faced by SCS is the problem of taking and bringing the lanterns from/to charging station. The management has adopted a novel approach and is ensuring the service of door-step delivery with an extra fee of INR 1. Further, as a result of strict norms and good services provided by the management, the users are also sincere in their payment. In contrast, the management by the partner NGO in Karimganj district was found to be less involved in the initiative and insincere towards the role their responsibility. As a result, users reported of being unsatisfied with the service and the issue of irregular tariff payment was reported. Similarly, in Gajapati district, the management was found to be inefficient on their part. As a result of which the program was found not functioning efficiently and there is irregularity of tariff collection. In Mayurbhanj, on the other hand, the management is effective and dedicated towards the initiative and is reaping the benefits of this program in developing their village social status.

The SDCMG's in Uttar Pradesh was found to be solely managed by the entrepreneurs themselves. The entrepreneurs perform the daily management of the system and provide the timely report to the respective PIA's about system condition and problems. The SMG in Sunderban was being managed by the VEC, who are responsible for tariff collection and consumer grievance redressal along with playing a definitive role in operation and monitoring the agreed level and overuse of electricity. Though the management was found to be efficient in their roles, it was reported that they have been insincere in their role towards the issues of fault rectification and battery replacement since last two years.

3.5. Monitoring and maintenance

In Assam, AEDA has created a strong pool of technical staff for monitoring and maintenance. Two technicians for each village has been trained and deployed by AEDA who are paid by users for the repairs. In Sonitpur, this initiative was well followed but in Karimganj, it failed as users were not ready to pay the technicians as they have their repairs done at cheaper price from local shops, so technicians are less involved in the project. Sonitpur had an authorized service center but Karimganj still lacked in this as it was reported that BEL has shown less sincerity in setting up the centre. In Odisha, though OREDA has reportedly created a local technical pool for after sales services of the installations, but it was found that no such scenario existed in the study villages. Technicians were either not found in the villages or the designated service personnel were not interested in performing any repairs in the absence of any payment to them by OREDA. In Uttar Pradesh and West Bengal, the energy enterprises that sold the systems performed the required maintenance and monitoring services through its technicians.

TERI under its LaBL initiative has paid a lot of importance into training and capacity building. Entrepreneurs have been provided with proper training and TERI has involved local energy entrepreneurs for providing the spares and performing the required monitoring and maintenance aspects of the program. In Mayurbhanj, it has been found that the lack of local energy enterprise has affected the maintenance of some of the lanterns. SDCMG in Uttar Pradesh commissioned by TERI and Minda Nextgen Technology are constantly monitored by the local energy entrepreneur who provides the spares and technical support. The respective PIA's perform regular review to ensure proper operation. For the SMG in Sunderban, WBREDA has developed a strong technical resource at the local level for monitoring and maintenance. Ulsrud *et al.* [7] highlighted the initiatives of WBREDA, during the installation phase for training of local persons. These personnel took the responsibility for operation, daily maintenance and also in other cases trained personnel were involved from other places.

3.6. Project impacts

Figure 2 represents the kerosene consumption before and after PV lights installation in the houses. It is observed from the Figure 2 that before PV lighting installations in the villages, 61% of the household's kerosene consumption was 6 to 8 litres per month. However, after the PV light availability, this consumption has reduced to 2 litres per month. It is also can be observed form Fig. 3 that the expenditure on kerosene for lighting in most of the houses was in the range of INR 80-150 per month. However, after the PV light installation, this expenditure has come down to INR 30 in these houses. It means on an average INR 100 savings per month due to the less consumption of kerosene due to the PV lights availability in these households. It is also found from this study that 91% households have reported the issue of low illumination from kerosene based lamps which is an establish fact of kerosene based lighting and also reported the issue of erratic availability of kerosene from the local vendors [14]. Since the households are provided kerosene from government retail shops, the availability at the right time is always very erratic. It is also found that 24% of the households reported that the issue of far distance of kerosene based vendors and 77% of the households find kerosene is costly and extra addition to their expenses as the quantity doesn't suffice their need they get from government retail and as a result of which they purchase kerosene from private shops at higher rate.

It is further observed that the wide application of solar light primarily focused towards household work and study. About 40% of the women have reported reduction in the workload during day time. This is attributed to the fact that with the help of solar light they can now work at night as a result of which they don't have to complete all the work by day time. Due to reduction in work load, women have now more free time for themselves and are using such time for income generation activities like leaf plate making, mat making etc. creative activities like weaving, stitching, etc., extra household work and leisure time with family. With the solar light intervention, 85 % of the houses have reported that there is increase in monthly income in the range of INR 500 -1000 (Fig. 4).With the help of solar light, women also feel safe to travel at night as before it was not possible due to darkness.

It is found from the study that 80% of the women have reported health related issues faced earlier due to usage of kerosene lamps. The common issues faced are red eyes, headaches, watery eyes, blocked nostrils and cough (Fig 5). It is also observed that PV based lighting in comparison to kerosene based lighting is used for longer hours by children to study in the household (Fig 6). This is due to better illumination from PV light in comparison to kerosene base lamp; as a result the children don't strain their eyes during studying under solar light. Solar light has helped in eradicating such health related issues in the households.

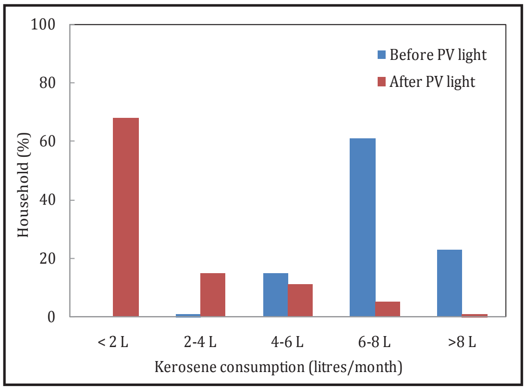

Fig.2. Kerosene consumption before and after PV light installations

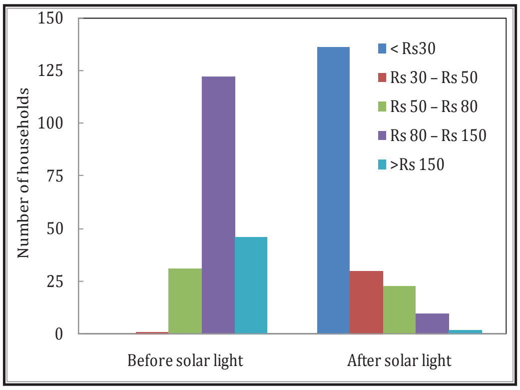

Fig.3. Monthly kerosene expenditurebefore and after PV light installations

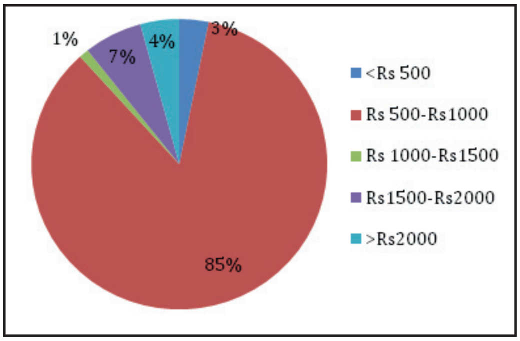

Fig.4. Impact of PV lighting on income generation

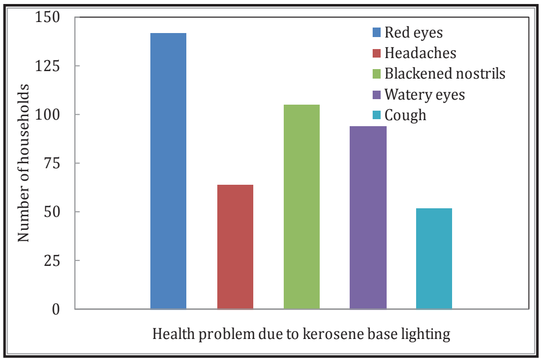

Fig.5. Effect on health due to kerosene base lighting

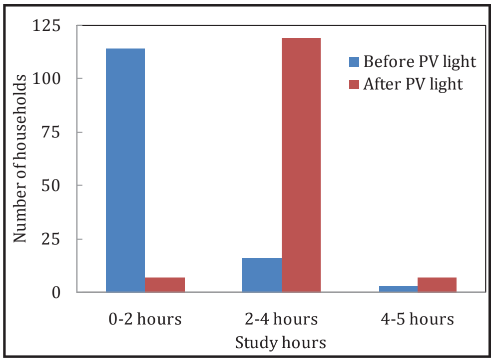

Fig.6. Impact on education due to PV light

4. Conclusions

One of the positive aspects of electrification is eradication of kerosene use for lighting. However, it was found that households having more than two rooms are still using kerosene to meet their lighting needs. For SHS, it was found that households still relied on kerosene for their lighting need because of the provision of two CFL's with the systems and provides backup of 4 hours for just two rooms. This did not suffice to the demands of the lighting needs of many of the households. This finding is also in line to the finding from a study conducted in Sunderban [16]. It is recommended that the SHS systems be replaced with high efficient LED lamps in the government driven initiatives. The reason for these recommendations is that two CFL bulbs require minimum of 18 watts (9W each). However, when replaced by LEDs, total of six LED lamps of 3W each can be supported by the same system capacity with a backup of 4-5 hours. In case a household require lesser number of light points, the price of the system will get reduced making it more affordable to the users and or lesser subsidy burden to the government. During this study, it was found that Solar PV programs with a strong management and monitoring mechanisms have shown better results in the operation of the systems. With a good management structure, the users were satisfied that there is responsive post-installation maintenance support for maintaining the systems. Good management structure also brings in transparency to the flow of information between the PIA and users leading to faster and efficient addressing of issues in a program. An institutional structure forms the main link between the PIA and the users and maintains the information flow in the hierarchy. This study has also found that various institutional innovations can actually be a boon in the sustainability aspects of PV programs. Innovative practices in delivery model will ensure consumer satisfaction and sustainability of the projects. Entrepreneurs related to the systems such as SCS and SDCMG, play a vital role in maintenance, operation and management of the systems. A dedicated and responsive entrepreneur happens to be the key factor in the sustainability of such projects. Efforts to provide best service should be the prime aspect of an entrepreneur. Entrepreneur selection should, thus, not be done on their capability to co-finance for setting up the system but also should take into account that they possess good attitude towards the importance of maintaining the user satisfaction and good health of the system to provide the best service to the users.

The study highlighted how the presence of strong technical assistance and proper training initiatives has been a key to the successful running of the PV programs. Capacity building should be the key emphasis in such projects. Findings have revealed that users with good understanding of the system have shown a positive attitude towards the systems and service provided to them. Also the level of sensitization in all stakeholders has shown benefits in the delivery model. Provision of after-sales technical support happens to be a major concern in maintenance of the systems. Programs with good technical support from the technology provider have immensely contributed to the system wellbeing. Most of the government funded projects lagged in the after sales service provision but in terms of the private and bank funded projects, it was found that the PIAs have involved local energy enterprises to provide the after sales service to the systems. Since the energy entrepreneurs are directly involved with the technology providers for supply of spares, this removes the involvement of PIA and leads to faster procurement of the spares and speedy rectification. Technology provider should provide the best of after sales service to their related projects. Insincerity on their part could lead to complete failure of the systems and the project. This not only makes the villages de-electrified but also renders these projects, usually set up with capital subsidy from the Government, as dead infrastructure.

Systems ownership related to SHS acquired under subsidy model or self-financed model have revealed different treatment by users towards the systems. Systems which are provided free to the users under the subsidy scheme without actually ascertaining the demand from users, users showed less sincerity in maintenance of the systems. Involvement of user's money, of an appropriate amount after subsidy, would give a sense of ownership and make them responsible to look after the system as the beneficiary knows the value of the money they have put in the system to acquire it. Lastly, for the sustainability of PV programs in India, strong technical, institutional and financial aspects are the key contributors. This paper based on comparative analysis highlighted how strong institutional aspects of a PV program, irrespective of the technology configuration, have been the main pillar for the viability of the programs. With the presence of a strong institutional structure, there is a need for transparency in communication among the stakeholders of each program. This study highlighted that the technology is not the only factor on which the viability of such programs 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 as revealed in this study.

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