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 performance of PV programs.

Keywords: Solar PV, Domestic lighting, PV lighting, Rural Electrification, Energy access

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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 energy has not been very good. However, the rural electrification programme 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 grid based electrification has been the pre-dominant mode for electrification, the use of solar PV for decentralized electricity provision in rural areas in India has also been highly promoted. Current statistics by Ministry of New and Renewable Energy (MNRE) shows a substantial growth in solar PV based rural electrification in the recent past [4].

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 performed 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 contributes to the sustainability of PV programs and also presents an impact of PV electrification in rural areas.

2. METHODOLOGY

A total of four states namely Assam, Odisha, West Bengal and Uttar Pradesh are selected for this study using a purposive random sampling technique considering the following points,
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1. Selection of zones in India, namely Northern, Eastern, North-Eastern, Western and Southern. Since Southern and Western zone have approximately cent percent electrification through grid extension, these zones are excluded from this study;
2. Selection of one state from each zone with at least two technologies implemented for electrification;
3. Selection of two clusters from each state having two technologies for electrification implemented by different agencies/organizations;
4. Selection of two villages from each cluster in one state, each village having minimum 50 households electrified by solar lighting systems;
5. Stratification and selection of households in each villages.

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 powering two 3W LED lamps are implemented in few households. SDCMG consisted of 140 - 240 Wp 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 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 plant in Bagdanga village, in West Bengal, which is supplying electricity to 160 households consisting of 74 Wp array 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

In terms of SHS functionality, Assam projected a good functionality score followed by Uttar Pradesh and West Bengal. Orissa had 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 did not perform any of the repairs reported by users. Also the systems were 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 were found to be functional, two stations were functional with minor faults and one station was 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 stations in Assam was operational with minor faults, which was due to the insincerity on behalf of the entrepreneur who was found to be less concerned about the basic routine maintenance needed to perform in the station. SDCMG’s disseminated in Uttar Pradesh were found to function efficiently without any faults. The SDCMG’s 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 from 5 hours to 2 hours.

3.2 Technical Knowhow

Among the SHS users, it was found that 98% users have good understanding about the importance of cleaning panels, 58% knew about instrument connection 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 a complete technical understanding of the system and are 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 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 respective entrepreneurs. The entrepreneurs have reported proper training on operation and maintenance provided by the respective Project Implementation Agency’s (PIA) during installation and efficient local technical support by 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 system cost for acquiring the system but in Odisha, the beneficiaries did not made any contribution. Under this 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, to deposit INR 70 per month to the VEC to be saved in recurring deposit in bank, so that the money can be used by them to replace the battery after 5 years of warranty. In this sum, INR 20 is technician’s salary and INR 50 is deposited in the bank. SHS management in Odisha followed no such practices. In Uttar Pradesh, the SHS were provided under the NABARD consumer financing scheme by the rural banks such as Aryabhat Gramin Bank and Union Bank. The systems are provided with 40% subsidy (INR 100/Wp) by MNRE and 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 are provided under the NABARD scheme with 40% subsidy by MNRE. The systems are self managed by the beneficiary. After-sales service is provided by the energy enterprises from where the systems are 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. The lanterns are rented out to users at a daily usage fee of INR 2-3. The capital cost is borne through equity contribution by the entrepreneur and the users and the viability is ensured by TERI through funds raised from government agencies, corporate donors, and bilateral /multilateral agencies. 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. In Sonitpur, Assam, the entrepreneurs were found to deposit INR 300 per month 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 paid INR 1500 per month under which battery replacement was free. In Odisha, the stations were community managed and from the total collection in a month, the entrepreneurs keeps INR 300-500 per month as remuneration and deposits the rest as maintenance charge to Village Development Committee (VDC) who manages the stations. In Uttar Pradesh, no management body was involved and the entrepreneur managed the stations themselves.

SDCMG commissioned by TERI in Uttar Pradesh is also run using the fee for service delivery model. The system is provided with 2 years warranty. The SDCMG implemented by a private entity called Minda Nextgen Technology follow a 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 are interested in equity contribution for the plant. The SMG in Sunderban was disseminated under the RVE scheme of Government in which 50% of the systems cost was provided as subsidy. The SMG’s are commissioned by technically competent contractor through WBREDA who also works as Annual Maintenance Contractor (AMC) and is held responsible for operation and maintenance. The plant is managed by the VEC. WBREDA is involved with technical support service and implementing improvements in the plant.

3.4 Institutional structure
SHS systems are managed by the VEC of the respective villages in Assam and Odisha under the RVE scheme. In Sonitpur, Assam the management of VEC and local partner NGO of LaBL was found to be sincere towards their contribution. This resulted the delivery model was followed as per norms. However, in Gajapati (Odisha) and Karimganj (Assam) the local management lacked in their sincerity towards their own role in the initiative and as a result the sustainability of the program was at stake. In Mayurbhanj (Odisha), no NGO was involved with the SHS programme like that of Assam. 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 were unknown of the institutional pattern that existed in the initiative as a result they were notifying the bank in event of a replacement which is then handled by the system provider.

SCS in Assam was managed by a partnering NGO. It was found in Sonitpur, that the management was dedicated and concerned about this initiative and has taken steps in providing the best service to the lantern users. The biggest issue faced by SCS is the problem of taking and bringing lanterns for charging from station. The management has ensured the service of door-step delivery with an extra fee of INR 1. As a result of strict norms and good service provided by the management the users are sincere in their tariff payment. In contrast, management in Karimganj was found to be less involved in the initiative and was insincere towards the role they have to perform for better management. As a result, users reported of being unsatisfied with the service and the issue of irregular tariff payment was reported. Similarly in Gajapati the management was found to be inefficient on their part as a result of which the program was not functioning efficiently and there was irregularity of tariff collection. In Mayurbhanj, this issue was not reported as the management was effective and dedicated towards this initiative and is reaping the benefits of this program in developing their village social status. In Uttar Pradesh, no such management exists. It is solely managed by the energy entrepreneurs. SDCMG’s in Uttar Pradesh are 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. SMG in Sunderban was managed by the VEC and involved with the tariff collection and consumer grievance redressal along with playing a definite role in operation and monitor the agreed level and type of electricity and overuse. Though the management was found to be efficient in their roles, it was reported that they have been insincere in their role towards 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 manpower 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 created a local technical pool but it was found that no such scenario existed. No technicians were found in the village and the designated service personnel were not interested in performing any repairs as they were not paid for the services. In Uttar Pradesh and
West Bengal, the energy enterprises that provided the systems performed the required maintenance and monitoring services though 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 was found that the lack of local energy enterprise has affected the maintenance of the lanterns. SDCMG in Uttar Pradesh commissioned by TERI and Minda are constantly monitored by the local energy entrepreneur who provides the spares and technical support. The respective PIA’s perform regular checking to ensure proper operation. For SMG in Sunderban, WBREDA has developed a strong technical resource 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 Impact on livelihood

The wide application of solar light primarily focused towards household work and study. Due to the availability of solar light, it is observed that the users have started using it working at night for various activities like agricultural work, work late at night in their shops and businesses like carpentry, mason, etc. It was also found that the women of the village are earning extra income by making leaf plates, mats etc. at night. Further, the survey indicates that 49% of the households found the solar light quality is 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). 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 options, 61% of the households, kerosene consumption was 6 to 8 liters per month. However, after the PV lighting availability, this consumption has reduced to 5%. It is also found from this study that 91% households have reported the issue of low illumination from kerosene based lamps which is a much known fact of kerosene based lighting and also reported the issue of erratic availability of kerosene from the local vendors. Since the households are provided kerosene from government retail shops, the availability at the correct time is always very skeptical. It is 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 have to purchase kerosene from private shops at higher rate. It was observed that 40% of the women have reported reduction in the workload. 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 indulgence in activities like income generation activities like leaf plate making, mat making etc., creative activities like weaving, stitching, etc. extra household work, leisure time with family. With the solar light intervention, 85% of the houses have reported that there is increase in come in the
range of INR 500 -1000 (Fig. 3). With the help of electrification by solar light, women now feel safe to travel at night as before it was not possible due to non availability of electricity. It is found from the study that 80% of the women have reported the health issues faced with the usage of kerosene lamps. Red eyes, watery eyes, blackened nostrils, cough and headache were some of the health issues faced with kerosene usage.
Solar light has helped in eradicating such health related issues in the households. It has been observed that the solar light is widely used for the various livelihood activities but the highest trend is observed in small additional income generating activities like leaf plate making, mat making, weaving, etc. This is because of the fact that such activities with the help of solar light can be carried out during the free hours in the night time. With the help of solar light people are able to spend more hours in the livelihood activities compared to use of kerosene lamps and this has lead to increase in earnings from the same activity in contrast to the days of kerosene usage. Also with the help of solar light, people now spend less on kerosene as the need for lighting is provided by the solar light leading to savings. It has been observed that the solar light in comparison to kerosene lamp is used for longer hours by children to study in the evening time. The reason is better illumination from solar light compared to kerosene lamp as a result the children don’t strain their eyes during studying under solar light. Also the inherent health issues of using kerosene lamp are eradicated by solar 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 the households. This finding is also in line to the finding from the study conducted in Sunderban [16]. The SHS systems need to be replaced with LED lamps. 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. During this study, it was found that Solar PV programs with a strong management and monitoring mechanisms have shown a positive indication in the operation of the systems. With a good management structure, the users were satisfied with the support provided to them in maintaining the systems. Good management structure would bring 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 entrepreneur happens to be a key factor in the sustainability of such projects. Efforts to provide best service should be the prime aspect of an entrepreneur. Entrepreneur selection should not be done on its capability to pay for setting up the system but also should 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 presences of strong technical assistance and proper training initiatives have 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 contributed to the system well being. 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 parts, this removes the involvement of PIA and leads to faster acquiring of 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.

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, users showed less sincerity in maintenance of the systems. Involvement of user’s money 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 have been the main pillar for the viability of the programs. With the presence of a strong institutional structure, there is a need of transparency in communication among the stakeholders of each program. This study highlighted that the technology is not the only factor on which the sustainability of such programs can be decided, but institutional and financial aspects are the important factors that contribute to the sustainability 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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REFERENCES

OASYS South Asia project

The Off-grid Access Systems for South Asia (or OASYS South Asia) is a research project funded by the Engineering and Physical Sciences Research Council of UK and the Department for International Development, UK. This research is investigating off-grid electrification in South Asia from a multi-dimensional perspective, considering techno-economic, governance, socio-political and environmental dimensions. A consortium of universities and research institutes led by De Montfort University (originally by University of Dundee until end of August 2012) is carrying out this research. The partner teams include Edinburgh Napier University, University of Manchester, the Energy and Resources Institute (TERI) and TERI University (India).

The project has carried out a detailed review of status of off-grid electrification in the region and around the world. It has also considered the financial challenges, participatory models and governance issues. Based on these, an edited book titled “Rural Electrification through Decentralised Off-grid Systems in Developing Countries” was published in 2013 (Springer-Verlag, UK). As opposed to individual systems for off-grid electrification, such as solar home systems, the research under this project is focusing on enabling income generating activities through electrification and accordingly, investing decentralised mini-grids as a solution. Various local level solutions for the region have been looked into, including husk-based power, micro-hydro, solar PV-based mini-grids and hybrid systems. The project is also carrying out demonstration projects using alternative business models (community-based, private led and local government led) and technologies to develop a better understanding of the challenges. It is also looking at replication and scale-up challenges and options and will provide policy recommendations based on the research.

More details about the project and its outputs can be obtained from www.oasyssouthasia.dmu.ac.uk or by contacting the principal investigator Prof. Subhes Bhattacharyya (subhesb@dmu.ac.uk).

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