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Performance and impact evaluation of solar home lighting systems on the rural livelihood in Assam, India

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ABSTRACT

This study was carried out in four districts of Assam to assess the technical functionality of the solar home lighting systems (SHLS), service delivery model, institutional mechanism, maintenance and monitoring, user's awareness and its impacts on rural livelihood. The study found that only 28.9% of the systems are functional, 62.3% are found working with minor faults and 8.8% are either non-functional or having major faults. The average working durations per day for winter, summer and monsoon seasons are 2.2 h, 3.5 h and 2.3 h respectively. The study observes noticeable benefits due to adoption of SHLS such as reduction in kerosene consumption, increase in children's study hours, extended working hours of small businesses and income generation through mobile phone charging. One of the key reasons for unsatisfactory technical performance of SHLS is because of poor service delivery model and inefficiency in existing institutional structure such as passive village energy committee and non-availability of service centres or local technicians for post-installation maintenance. The study observes that user perceptions on the system are positive. However, cost considerations seem to be the main obstacle for system adoption. This study concludes that availability of local technicians, effective village energy committees, demand driven system design and appropriate social awareness towards livelihood improvement options will improve the sustainability and economic viability of the SHLS.

Introduction

In India even as village after village is electrified under different schemes of the Central or State Government, still 18,500 villages had no access to electricity (As on March 2015). Central Electricity Authority indicates that the central grid has reached 97% of the villages but yet, policies and institutions that contributed to this achievement still could not bring electricity to approximately 300 million people in India. There is also a huge urban–rural disparity. While the rural household electrification rate is only 67% (CEA, 2015), the urban electrification rate is 94% (Census of India, 2011). The rural households which are yet to have electricity access usually fall into three categories (i) households in remote inaccessible villages where extending the grid is technically not feasible or economically daunting, (ii) households in unconnected hamlets of grid connected villages and (iii) un-electrified households in grid connected villages (Palit, 2015). In the last case, the issue appears to be less of opportunity to get connected to the grid, but more of inability of the households to take electricity connection due to their financial constraints or the perception that electricity services (quantity and quality) will be inadequate (Palit and Chaurey, 2011). In addition, high poverty level, lack of effective developmental programmes and policies, resource constraints and weak institutional arrangements have also contributed to the low energy access level in rural India (Balachandra, 2011; Palit and Chaurey, 2011). The consequence is that the kerosene continues to be the major source of lighting for the un-electrified households as well as households with intermittent access to electricity in rural areas of India. Kerosene based lamps are inefficient so replacing them with energy efficient lamps not only reduces the health issues associated with it but also reduces the primary energy consumption (Mahapatra et al., 2009; Urpelainen and Yoon, 2015).

While the centralized grid-based electrification has been the most common approach in India, decentralized renewable energy options, especially solar photovoltaic (PV) based systems, have also been adopted and being increasingly considered as a cost-effective mode for providing electricity access (Palit and Bandyopadhyay, 2015). There were more than one million households in India in 2011 using solar PV power as their primary source of lighting (Census of India, 2011). With an average household size of five, this means five million people in India rely on solar power for their lighting needs (Census of India, 2011; Urpelainen and Yoon, 2015). Of the various distributed

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generation systems implemented in off-grid areas, solar home lighting systems (SHLS), centralized charging of solar lanterns as well as solar mini-grids (both AC and DC), has proven to have a positive impact on the lives of the rural population. Various studies have highlighted the contribution of solar PV to improve the socio-economic enhancement of the rural areas, access to clean energy and contribute to mitigation of CO_2 emission from kerosene base systems for lighting (Chakrabarti and Chakrabarti, 2002; Nouni et al., 2006; Mahapatra et al., 2009; Urpelainen, 2016). Studies have also revealed how PV systems have contributed towards enhancing the livelihood activities of rural households (Borah et al., 2014; Palit, 2013; Harish et al., 2013; Mondal, 2010; Halder and Parvez, 2015; Wijayatunga and Attalage, 2005). The SHLS have been promoted as one of the better options for off-grid electricity supply among all the solar programs in the developing countries (Holtorf et al., 2015).

Urpelainen (2016) critically examined the perceptions of solar power in marginalized communities in Uttar Pradesh, India. This study found that users are not satisfied with the kerosene based lighting and solar entrepreneurs needs to deliver quality service and products. Harish et al. (2013) observe based on an empirical study in Karnataka that even the grid-connected households do not hesitate to adopt SHLS without any subsidy as the users found grid is not a reliable source for lighting due to its frequent brown-outs and black-outs. Urmee and Harries (2011) investigated the determinants towards the success of SHLS in Bangladesh. This study found that the primary reasons for the program's success is due to strong focus on meeting household needs and ability to make the systems as affordable as possible to the users. This study also observed that SHLS has resulted in improvements in the quality of life, create opportunities for new income generation activities like mobile phone charging shops, operating social TV halls, ability to work at night and enjoy the superior quality light. An interesting observation is that SHLS is not only used for lighting in the households but also found uses in the small shops as it relates with extra income generation activities which indicate better economic viability of the systems (Mondal, 2010; Halder and Parvez, 2015). Komatsu et al. (2011) found that the household income, ownership of rechargeable batteries, kerosene consumption, and the number of mobile phones are the key determinants of the adoption of the SHLSs. The capacity of the SHLSs chosen by households is related to the amount of kerosene consumption, number of children and demand for electricity for lighting in the household in addition to extra household income generation. This study concluded that kerosene consumption is the significant factor on both the adoption of SHLSs and the selection of the system size.

Solar lighting programs have been implemented by adopting various delivery models, such as leasing of energy products, consumer financing model and direct subsidy (Palit, 2013). Institutional arrangement is also one of the important aspects in these kinds of programs. Wong (2012) analysed the obstacles towards the effective solar lighting interventions in South Asia. This study identified the major obstacles like financial exclusion, weak governance, passive NGO and customer participation that constrained poor people to implement the solar lighting systems. This study suggested that poverty sensitive cost management; better governance and robust technical support are the key solutions to make the solar lighting projects more effective, inclusive and pro-poor. Brooks and Urmee (2014) observed that lack of adequate technical training and appropriate social understanding resulted in the failure of most of the solar project in Philippines. The poor installation and maintenance, lack of understanding by the system owner, non-availability of local technician are the primary reasons of non-functioning of the systems. Adequate user and local technician training are an important attributes towards successfully implementation of solar power systems. Nathan (2014) observes that the primary reasons for the failure of solar PV systems is due to the location in rural and remote areas, where households cannot afford to pay much and also lack of supply chain and skilled manpower for maintaining the systems. Thus, availability of skilled local technician, user's awareness and proper collaboration among the concern stakeholders are to be the key determinant for successful implementation of any solar projects (Karakaya and Sriwannawit, 2015; Holtorf et al., 2015).

In India, SHLS implementation has been supported under the Ministry of New and Renewable Energy (MNRE) subsidy programme since the early 1990's to provide access to clean energy specially meeting the lighting loads of rural households which are not connected to the central grid. A typical SHLS, supported under the government programme consisted of a 37Wp module, a 12 V 40AH tubular plate battery, luminary of two 9 W CFL, a charge controller and module mounting structure. A large number of SHLS have been installed by various agencies in rural households of Assam. Hence, it is important to understand the impacts, success, limitations or failures of these installed systems based on a comprehensive field survey analysis. While there are some literature on ex-post evaluation of systems in India in general and Assam in particular (Palit and Hazarika, 2002; Buragohain, 2012; Borah et al., 2014 and others), there is absence of recent scholarly work on ex-post evaluation of decentralized solar PV system for the state of Assam and North-eastern region of India. This paper thus attempted to undertake the evaluation and presents the analysis of the technical performance and functionality of the installed systems based on field study conducted in Assam, as the state has installed 40,035 SHLS under the remote village electrification programme[1] of the Government of India (AEDA, 2015). This constitutes one of the largest dissemination of decentralized solar PV systems in India. So to look forward the future scope of PV projects in this region, the general and scholar's curiosity here is to know about the present performance of these already installed SHLSs. This study thus critically examined the performance of the installed SHLSs in terms of service delivery model used in implementation of the systems, financial scheme and institutional structures, user's technological know-how capability about the systems, benefits and improvements in the livelihood of these households and suggests recommendations for strengthening the implementation and functioning of the SHLS.

Study area

The study area is the state of Assam, India is located at the longitude of 89.42° E to 96.0° E and the latitude of 24.8° N to 28.2° N. Assam has a peak shortage of power supply of 189 MW as on March 2016 (APDCL, 2016). The per capita electricity consumption in Assam is as low as 314 kWh, whereas national average is 1010 kWh (CEA, 2015). The number of un-electrified villages in Assam is 803, out of the total 25,372 villages (as on March, 2015). This also includes the number of villages, which are not complying with the definition of village electrification and number of villages where no electrification infrastructure is available (CEA, 2015). While, little more than 93% villages in the state are officially electrified, however, only 34.22% of the rural households have access to electricity[2] (as on May 31, 2016). The situation is little better in the urban areas. Of the total number of 6,367,295 households in Assam, 37% depends on electricity for lighting and 62% depends on kerosene for lighting (Census of India, 2011). The villages which were not covered under the erstwhile grid electrification programmes such as Rajiv Gandhi Grameen Vidyuktikaran Yojana (RGGVY) were covered under the Remote Village Electrification programme (RVEP). Mostly PV based lighting systems were installed in these villages to meet the basic

[1] The Remote Village Electrification Programme (RVEP) was initiated in 2001 for provision of basic lighting facilities in un-electrified census villages whether or not these villages were likely to receive grid connectivity. As part of the programme, central financial assistance of up to 90% of the project cost is provided as a grant with specific benchmarks as applicable in respect of the technologies adopted for electrification, with the balance of project costs being met by the beneficiaries and/or the state governments (Palit et al., 2014).

[2] http://www.garv.gov.in/assets/uploads/reports/statesnaps/Assam.pdf, Accessed on 15th October, 2016.

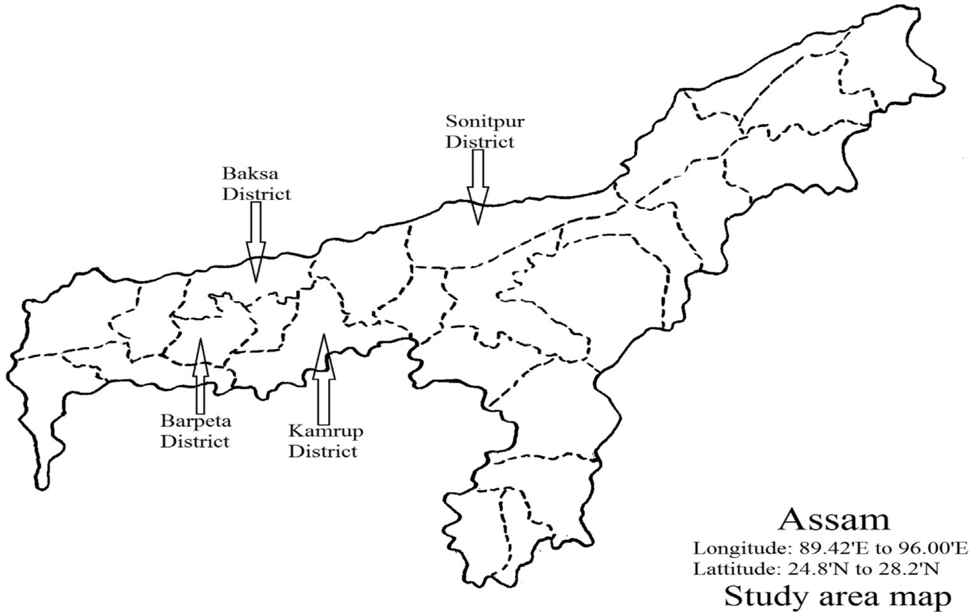

Fig. 1. Selected study areas in the state.

minimum energy needs of the households, as the other energy sources were found not feasible. It is worthwhile to mention that at the national level also a vast majority, more than 90%, of the villages taken up for electrification under RVEP are provided with solar home system or solar power plants (Palit, 2013). The state Assam was selected for the study as a large number of SHLS have been installed in the state to provide access to electricity to the rural households. The Assam Energy Development Agency (AEDA) has been the nodal agency for implementation of renewable sources of energy for the state and has installed 40,035 SHLS, spread across 776 villages in different districts of the state in association with different NGOs during the period from March 2006 to March 2014 (AEDA, 2015). It is also important to mention that most of these villages are remotely located with less numbers of households and or still does not have complete access to the central grid.

Methodology

The villages with the large number of installed SHLSs were identified from the data provided by AEDA (AEDA, 2015) in the selected districts. The criteria followed for selection of the sample households is as follows:

a. Four representative districts from different regions of Assam (i.e. North/Upper Assam, Lower Assam, Central Assam and a tribal populated district) where significant numbers of SHLS are installed, and considering that they represent different socio-economic geographies in the state were first selected;
b. Villages with SHLS were then selected from these four short-listed districts on a random basis;
c. Finally households with SHLS were selected from the short-listed villages randomly. Further, households were such selected that the SHLS have been installed at least two years before the survey period to ensure that the system are old enough to assess the real field performance.

The villages of four different districts of the state namely Sonitpur, Kamrup, Barpeta and Baksa were selected based on the criteria stated above. Questionnaire based door-to-door household survey was then conducted in the selected villages of each district. The study areas are described in Fig. 1. Table 1 presents the village details and number of households surveyed in each district.

A comprehensive questionnaire was prepared to collect information related to socio-economic conditions, education, income, technical functionality of the system, institutional mechanism, user's technical know-how on the system and the possible changes in the livelihood of the beneficiaries due to the adoption of the solar system. The specific survey questions and the research design were used to understand how the SHLS are performing with the existing operating conditions; how it has changed the life and the living condition of the beneficiaries and how the beneficiaries perceive them. Considering, a confidence level of 95% and confidence interval of less than 4, the sample size[3] for the survey (Bartlett et al., 2001) was determined and carried out in 544 households spread over the four districts. The survey was conducted during the period of December 2013 to May 2014 and a single set of data was collected. The respondents were mostly the head of the households or the spouse of the head of the households. The seasonal data was gathered based on the information provided by the respondents. The battery and module voltage was measured using a Multimeter for each system.

Socio-economic analysis of the villages

Fig. 2 presents the share of various energy sources used for lighting in all these 544 households surveyed in the different villages of four districts of Assam. It can be observed that kerosene and solar are predominantly used as energy sources for lighting. Conventional grid is also used in 13.6% of total households along with kerosene and solar systems. Kerosene and/or solar is used as backup energy sources as the availability of electricity from grid is not reliable. The socio-economic status of the households in the selected villages were analysed based on the primary data collected during the survey. Household income,

[3] Sample size (ss) is 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

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

Table 1
Village wise study area details.

District	Latitude and Longitude	Village name	Number of households	Total population	Literacy rate (%)	Grid Electrification status during survey	Number of household surveyed
Sonitpur	26.63° N and 92.80° E	Uriam Guri Gaon	533	2747	60.72	Electrified	183
		Amola Pam Gaon	464	2352	63.60	Electrified	
		Jahajduba Gaon	248	1220	19.10	Un-electrified	
		No 3 Siruani	404	2293	41.56	Un-electrified	
		Karaini Nepali Gaon	540	2880	46.94	Electrified	
		Parmai Gauli Gaon	296	1523	52.92	Electrified	
		Bherveri Pathar	64	447	63.53	Un-electrified	
		Barphalong	72	463	62.42	Electrified	
Kamrup	26.33° N and 91.25° E	Kalardia	122	674	31.22	Un-electrified	153
		Maghuabilar Pathar	21	110	12.73	Un-electrified	
		Sitalmari	25	118	21.19	Un-electrified	
		Koltulipathar	117	642	9.20	Un-electrified	
		Khatrapara	116	942	12.53	Un-electrified	
		Ujan Duramari	98	516	11.05	Un-electrified	
		Deori Doba	110	624	11.38	Un-electrified	
		Nowapara	106	674	17.80	Un-electrified	
		Choudhuripara	10	42	2.38	Un-electrified	
Barpeta	26.53° N and 91.00° E	Belortari	394	1594	50.88	Electrified	125
Baksa	26.68° N and 91.17° E	Mainamata Pathar	187	1007	69.81	Electrified	83

education of the household heads is used as the key determinants, as they determine how the households perceived the solar home systems. These are also key determinants in the growth rate of solar market in the rural area (Urpelainen and Yoon, 2015; Urpelainen, 2016).

The Census of India, 2011 data clearly indicate that the literacy rate in the surveyed villages is very poor (Table 1). Some of the villages' literacy rate is in the range of only 10–20%. The major income activities found in the surveyed households are agriculture (52.4%) followed by daily wage labour (12%) and contractual jobs (8.11%) in nearby places (Table 2). The other activities are business such as vegetables and fish vending in nearby markets and activities related to agriculture based services.

The household size and the number of children in the households are the key determinant of the energy requirement in the household. It is found from the analysis of the survey data that 77.6% of the households have more than 5 family members. The number of children is more than three in 26.48% of the surveyed households. Thus, it appears that the basic energy requirement in these households cannot be met by a single solar home lighting system.

Results and discussion

The field survey analysis to assess the technical performance of SHLS, service delivery mechanism, institutional arrangements, users understanding of the systems and the various benefits towards improvement in the livelihood in the four survey districts are presented in this section. All the 544 surveyed SHLS were installed under various schemes implemented by the Assam Energy Development Agency (AEDA). The analysis of the results are presented on three aspects (i) technical features, system performance, maintenance requirements and user's know-how (ii) service delivery model and institutional structure and (iii) benefits, user's satisfaction and perception towards the performance of the SHLS and its impact on the rural livelihood. It is found that the socio-economic status of all the surveyed households is almost similar in nature (Table 1), except in the Baksa district, where literacy is relatively high. The responses on the performance of the systems are more or less similar, except Baksa district. Since the performance and impact was found to be almost similar, so district-wise distinction was not performed in the paper.

Technical features and system functionality

Technical features of the system

A typical SHLS disseminated by AEDA includes a PV module (37Wp), module mounting structure associated with a short pipe of 0.6 m long, battery (12 V, 40 AH), charge controller (5 A), and luminary (2×9 W CFL). The modules consist of 36 polycrystalline solar cells and module dimension is $612 \times 669 \times 35$ mm which varies slightly depends on the manufacturer. The system specification is prescribed by the Ministry of New and Renewable Energy (MNRE), Government of India. MNRE has prescribed this system specification to fulfil the basic minimum energy needs (like energy for lighting) for the duration of minimum 4 h per day with 2 days battery autonomy (i.e. total 8 h run time) in an average family size households (average rural family size as per

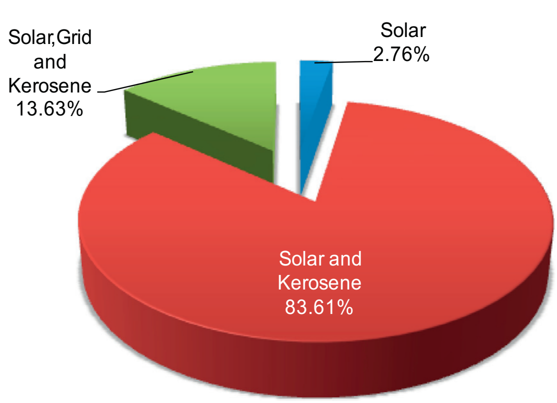

Fig. 2. Share of energy sources for lighting in the households.

Table 2
Income activities in the surveyed households.

Different income activities	Household (%)
Agriculture	52.40
Daily labour	12.00
Job	8.11
Business	6.49
Agriculture and animal farm	6.09
Agriculture and job	5.53
Self employed	3.14
Agriculture and daily labour	3.13
Agriculture and business	1.66
Agriculture, job and business	0.62
Business and daily labour	0.32
Agriculture, job and self employed	0.18
Agriculture and self employed	0.18
Self employed and job	0.15

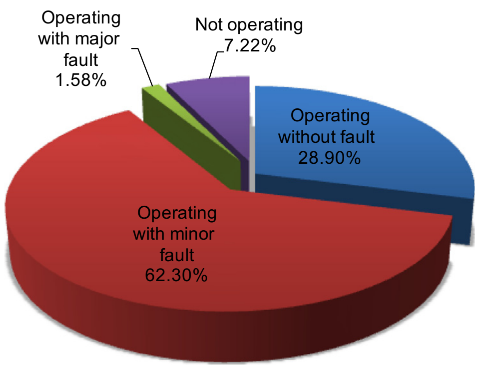

Fig. 3. Operational status of the systems.

Census of India is 5.1) and considering the social lifestyle of the beneficiary population. As per the MNRE's scheme, this type of system was provided to the households at a subsidized price. The idea was to provide illumination to two rooms in households where most of the activities like study of the children, cooking etc. could be done in a better quality of light.

System performance

The field survey analysis found that only 28.9% of the surveyed systems are operating without any fault (Fig. 3). The rest of the systems are found to have various types of faults. Table 3 presents the various types of faults related to different component of the systems as experienced by the users. The analysis observed that overall 62.3% of the SHLS are operating with minor faults related to lamp, charge controller and battery, 1.58% of the total systems are operating with major faults like damage of charge controller,[4] partial battery fail etc., and approximately 7.22% of SHLS are found to be non-functional due to complete damage of the battery.

The batteries were found damaged mainly due to overloading by the users. Sometimes due to low sunshine hour in a day, battery did not get charged sufficiently to provide energy to both the luminaries in the night time. In such situation users thought the system is not working due to the fault of the charge controller and the system is directly connected with the load by removing the charge controller. Charge controller is cut off from the circuit and the power is directly supplied to the luminary from the battery, and in long run the battery got damaged due to the overload in less sunshine hour of the day. Further various kinds of module mounting structures (pole) were found to be used for the system mounting. It is also found that the module orientation and shading due to the neighbouring trees and house also reduces the power output from the module even on sunny days. This aspect is discussed in the Module orientation and shading section.

During the survey the open circuit voltage was found to be in the range of 11.1 V to 19.75 V and average open circuit voltage of the modules was found to be 17.54 V. The average voltage of the batteries during the survey was 11.97 V. The survey also indicates that the majority of the systems are under loaded i.e. load is less than 18 W (two lamps of 9 W each) (Fig. 4). The average load on the system is 14 W (lamp and mobile charging). Overloading was found to occur in 9.3% of the systems mainly due to mobile charging by the users, which was not considered during the system design specification. The loading of the SHLSs are addressed here based on the instantaneous load found connected to the SHLSs. Once the load, especially luminaries has any problem, the system operates with only one lamp. It is worthwhile to mention that provision of rectification of the problems is absent in most of the cases due to non-availability of any service centres and/or technicians. The implementing agency had included training as one of the tasks for the vendors. However, it appears that the training imparted by the vendors was not enough to make the users fully aware about the day-to-day maintenance of the system.

Table 3
Types of fault experienced by the users in the systems.

Different faults	Households (%)
CFL blow off	24.32
Charge controller faults and CFL blow off	24.12
Battery fault and CFL blow off	12.48
Battery fault	6.00
Charge controller fault	5.76
CFL blackening	5.03
Charge controller fault and CFL blackening	4.80
Battery fault and charge controller fault	3.83
Battery fault, charge controller fault and CFL blow off	3.60
CFL blow off and holder circuit fault	2.40
Battery fault and CFL blackening	1.43
Charge controller fault and holder circuit fault	1.31
CFL blackening and holder circuit fault	1.21
CFL blackening and CFL blow off	1.05
CFL blackening, charge controller fault and holder circuit fault	0.84
Charge controller fault, CFL blackening and CFL blow off	0.58
CFL blow off, charge controller fault and holder circuit fault	0.34
CFL blow off, CFL blackening and holder circuit fault	0.28
Module breakdown	0.24
Battery fault, CFL blackening and CFL blow off	0.20
Battery fault, CFL blow off and holder circuit fault	0.18

Fig. 5 presents the working duration of the SHLS in different seasons in the year. The working duration of the systems in all the seasons were collected through a questionnaire based survey by interviewing the respondents. Fig. 5 data is based on the information provided by the respondents of each household during the interviews. Since the solar radiation intensity is higher during the summer season as compared to winter and monsoon, so the working duration was found to be higher in the summer season as compared to the winter and monsoon. During winter season, 64.5% of the systems and during monsoon season, 57.4% of the systems were found to work for only 2 h or even less. On the other hand, in summer season, 34.7% of the systems were found to operate in the range of 2 to 3 h, and 14.8% of the SHLS were found to operate for more than 4 h per day. The average working duration per day for winter, summer and monsoon seasons are found to be 2.2 h, 3.5 h and 2.3 h respectively. It is imperative to mention that as per system design specification, the system should work for 4 h per day with two days autonomy. (i. e. total 8 h working). Thus, from the analysis, it can be inferred that even in summer, the system operation hours are less than its design value. This may be due to over use of the battery, and use of extra load such as mobile phone charging. Further, the module orientation was found not proper in many cases or there is shading on the module due

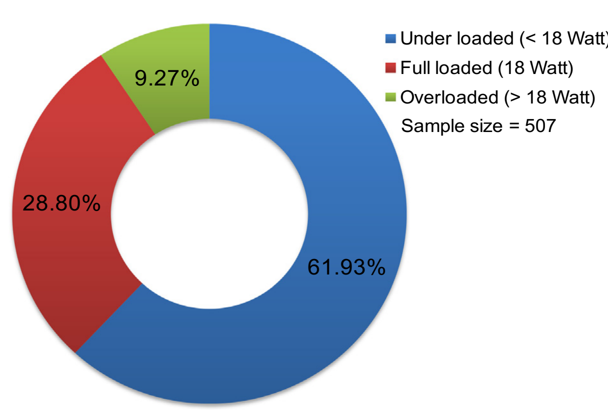

Fig. 4. Loadings of the SHLSs.

[4] The SHS are operating using direct connection from module to battery to lamps.

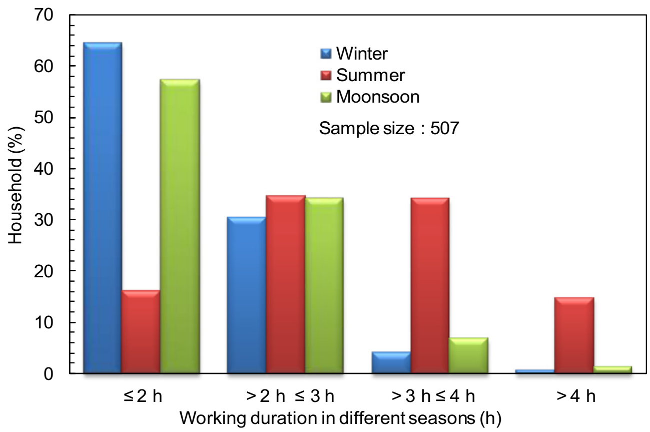

Fig. 5. Working duration of the systems in different seasons.

to presence of trees. This aspect is discussed in details in the Module orientation and shading section.

Module orientation and shading

Proper orientation and inclination angle of the module is the foremost requirement to get the design power output of any solar PV systems. Hence, the module needs to be fixed permanently on the roof of the building or in a pole with its optimum inclination angle and facing south (in case of Northern hemisphere and vice versa) to get the optimum solar radiation in all seasons of the year. The field study analysis found that module mounting pole was not provided to the users as all the users are not likely to install the panel on the pole with some may prefer the rooftop as well. So the pole was not considered as an essential part of the system in the scheme. It was also done to reduce the cost burden to the users by reduced cost of the pole and to promote use of some locally available material like bamboo. A short pipe of 0.6 m long to maintain the inclination angle with a module mounting structure associated with it to hold the panel was provided to the users in the scheme. So in majority of the surveyed households modules are fixed in the rooftop, or by using a bamboo pole, by inserting the short pipe holding the module mounting structure. A significant numbers of modules (40%) are installed on bamboo poles and useful life of the bamboo post is usually not long. The mechanical strength of the bamboo pole does not last long, as it strength reduces due to constant force from wind acting on it or due to rainfall, which resulted in the inclination angle of the module changed with time. As a result, installation became movable with time and the modules get deviated from its original inclination angle and orientation. This became a major cause for improper orientation of the module. The analysis shows that only 2.7% of the total systems, modules are installed on a strong iron pole (Fig. 6). Temporary arrangement was also found in 8.6% of the total systems. It was also reported in a surveyed village of Sonitpur district that two modules have been stolen during night time; so households started to keep the module inside during night time and take out the modules in the day time and place on the floor or rooftop for charging the battery.

The analysis reveals that 76.9% of the total systems, modules are in south facing and rest of the modules are facing towards other directions (Fig. 7). It is found that only 56.4% of the total south facing modules are tilted with proper inclination angle. It was also reported during this survey that after the implementation of the systems, no technical inspection has been carried out by any institution in last two years in all these villages. While the technology provider was supposed to conduct user awareness as part of the schemes, there was no meeting or awareness programme conducted by any institution in all these villages. Consequently most of the users do not have the basic knowledge about the importance of orientation or inclination angle of the module on power output. Irrespective of the fact whatever is the mechanical strength of the pole provided to the modules, the weak pole is the main cause of these results.

The field study analysis reveals that only 66.3% of the total modules are found where there is no shading effect, 29.8% of the total modules are affected due to partial shading and rest 3.9% module are completely shaded due to nearby trees (Fig. 8). The shading on the module reduces the power output and consequently the operation hour of the load reduces from its design value of 4 h. In case of Sonitpur districts, 9.5% of the total modules are found completely shaded. For instance, in Jahajduba village, the systems were disseminated to the households by the village energy committee and installation was carried out by the users themselves. As there was no technical person engaged by the technology provider, and villagers didn't have had any prior knowledge of installation of solar systems, systems were installed in places where module does not receive the solar radiation.

Fig. 9 shows the district wise shading effect on the modules of the systems. In the case of Baksa district, modules were found to be installed at proper location, where it is not shaded. The technician who installed the systems at Baksa districts has created required awareness among the users about the shading effect on the module power output. The awareness has a good impact on the villagers and successfully able to motivate the users to look after the shading issues of the modules. The analysis also brought out the positive result compared to other three districts, where no such awareness activities have been carried out by the technician or the technology provider. In Baska district 92.8% of the modules do not have any shading and no module is found under the complete shading. However, in case of Sonitpur district, most of the modules are partially or completely shaded due to non-availability of prior information of installation procedure to the villagers.

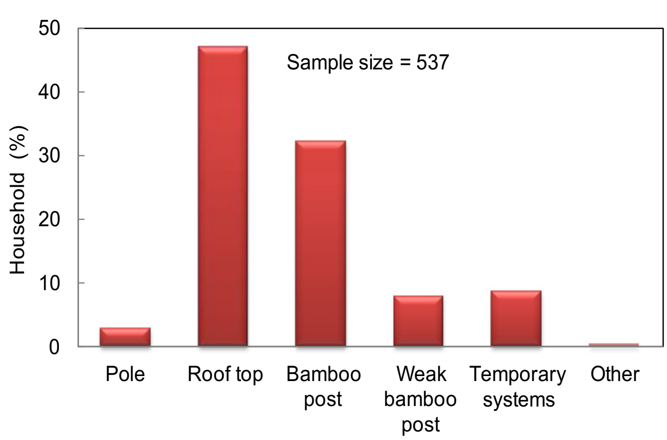

Fig. 6. Module support systems.

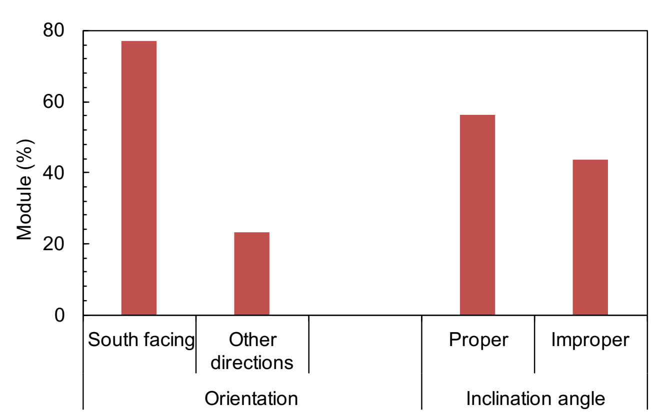

Fig. 7. Orientation and Inclination angles of the modules.

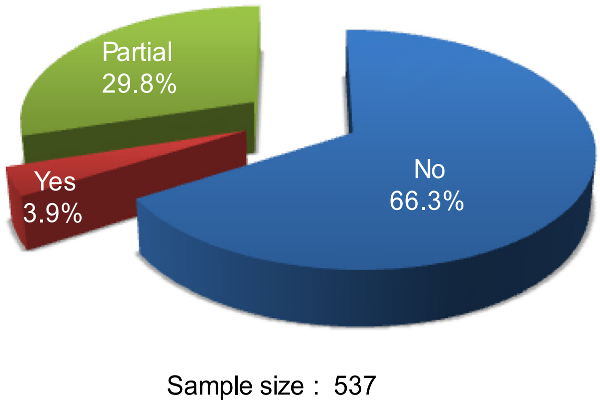

Fig. 8. Shading effect on the modules.

Service delivery model

Affordability is one of the main determinants towards adoption of the solar home lighting systems in the remote villages. This is where the pro-poor service delivery model, inclusive and pro-poor financial scheme plays a vital role in the success of any photovoltaic project (Wong, 2012). We observe that in all the studied villages, systems were installed under the RVE programme of MNRE. While as per programme design, 90% of the system cost was provided by the Government of India, the balance 10% was equally shared by the State Government and the beneficiaries. The systems are supposed to be managed by Village Energy Committee (VEC) formed by the beneficiaries in each of these villages. The technology provider under the RVE program was entrusted with the responsibility of setting up the service centres, make provision for spare parts; create awareness among the users on the system operation and training of local technicians for after-sales maintenance. However, the study found that no such service centre or skilled local technicians are available in any of the study villages. It is worthwhile to mention that AEDA made the guidelines for the system maintenance, where the beneficiary need to deposit an amount to the VEC, which is to be saved as recurring deposit in a bank, so that the deposit amount can be used to replace the battery after its useful life and service fees can be paid to the technician. However, no such VEC was found to exist in the surveyed villages and users are also not depositing any amount towards the maintenance of the systems. While each village had formed the VEC during the system installation and its function modalities are also documented. However, with time, these VEC stopped functioning due to various reasons. The members of the VECs were found financially underprivileged and they were found to devote most of their time in earning their livelihood. The nodal agency approved the project completion just after one month of the system installation when the VEC had just formed in the villages but after a few months the institutional structure was found collapses. As the state nodal agency did not have any field level officer nor there was adequate fund sanctioned for project monitoring by the government for regular monitoring of the post-installation activities, such activities were not carried out by the nodal agency, highlighting its institutional weakness. Wong's (2012) study also reveals similar kinds of experiences like passive or non-performing VEC, poor customer participation and consequently failed to make the solar lighting system performance in its desired level in South Asia.

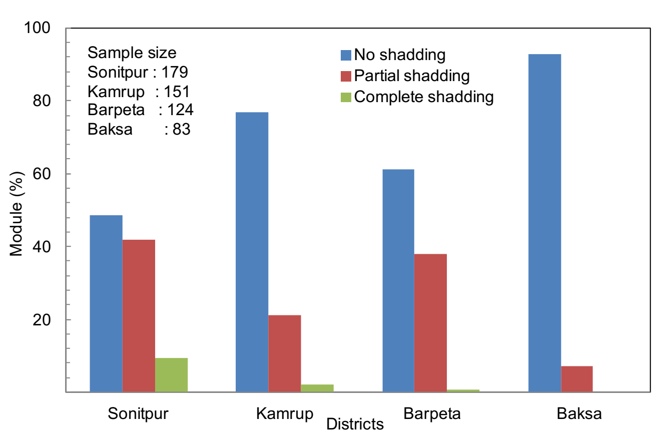

Fig. 9. District wise shading effect on the modules of SHLSs.

Institutional structure

All stakeholders in an institutional structure play an important role in the successful penetration and effective management of the systems. The SHLS are implemented in remote areas, where users do not have much technical understanding and spare parts are not easily available. Hence, effective institutional structure for proper local management is very important to ensure that the technology is useful to the beneficiaries. The institutional structure for the project under study was such designed that SHLS are managed and maintained by the technology provider, partner non-governmental agency and the village energy committees (VEC). The VECs in almost all the surveyed villages were formed by the beneficiaries during the commissioning of the systems. The partner NGO was to be involved with the VEC for the system maintenance and management and also act as the link between beneficiaries and AEDA. The technology provider was responsible for setting up service centre and deployment of trained technician and make provision for necessary spare parts during the warranty period (5 years) for responsive repair and maintenance. The role of the service centre was to provide the required spare parts whenever it is required to rectify any SHLS. The project implementing agency (AEDA) made an arrangement, where each of the household need to deposit an amount of INR 70 per month to the VEC. Out of this amount, local technician would receive an amount of INR 20 per month per household and the balance amount of INR 50 per month was required to be deposited in a recurring deposit in any rural banks for battery replacement after 5 years. This model was set by AEDA with a view that the savings accrued in the bank could be used for battery replacement after the warranty period so that user will be free from the future burden to meet the cost of the battery. The local technician will also get some small amount as monetary incentives for regular maintenance of the systems. However, it was found during the field survey that none of the stakeholders of the institutional structure is performing their role as designed. The users even do not know that such kind of institutional structure even exists. The VEC or the partner NGO also made no attempts to aware the users to deposit the monthly amount. It is also important to mention that the most of the users are financially very poor including the VEC members. As a result the VEC members are also unable to invest their time and effort towards the functioning of the institutional mechanisms. As the users are financially weak to deposit the monthly amount for local technician and battery replacement, so the intuitional structure is not working nor it is present in these villages. It is also found that no training or awareness programmes were held among the beneficiaries in any of the districts in the last two years. Sometimes the users repair their systems at their own cost even if the system is under warranty period. It is found that even if simple fault occurs, it remains in non-working condition due to lack of awareness among the users or unavailability of local technician or authorized service centre nearby. In this regard, Bhattacharyya and Palit (2016) observe that off-grid electrification projects also require an organized delivery approach through some sort of standardization and utility-like management for successful outcomes.

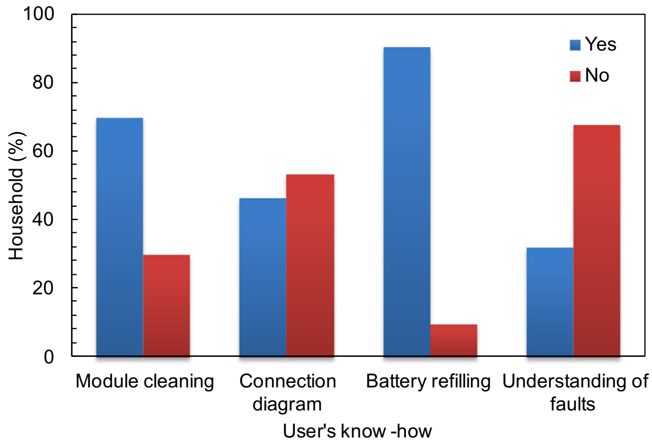

Fig. 10. User's know-how on system maintenance.

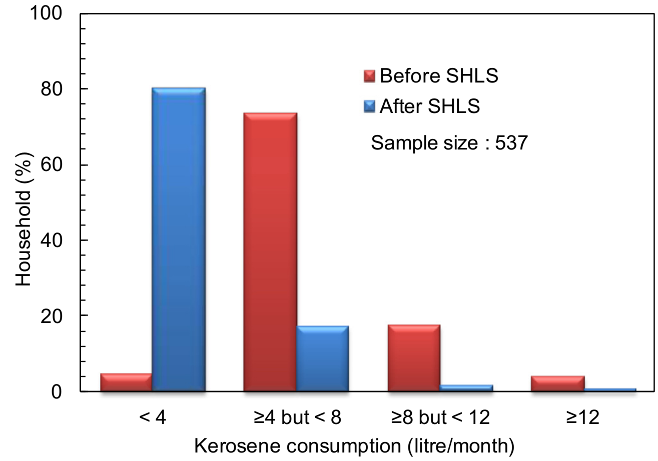

Fig. 11. Monthly kerosene requirements for lighting.

User's know-how on operation and maintenance

The SHLS is simple energy systems, which consists of module, battery, charge controller and the performance of the system depends on regular monitoring and maintenance. In this regard, the technical know-how of the users to operate and maintain the technology is the key determinant to assess the performance of the systems. It is found from the analysis that the user's know-how is primarily limited to module cleaning and battery refilling with distilled water (Fig. 10). However, majority of the users is found to have no knowledge about the different faults occurred and the rectification required for the systems. In many cases, it is found that the charge controller has been removed from the system, when both the lamps are not working. Such issue arises due to the wrong orientation and shading on the module, which consequently reduces the module power output. It was reported during survey that there have been some training initiatives in some places on the basic operation and maintenance of the systems by AEDA and technology provider during the installation of the systems. However, it is found that such training was not effective, focused and sufficient, to enhance the technical know-how capability of the users. The systems are supposed to be managed and maintained by the VEC, technology provider and partner NGOs. It was reported during survey that in some areas of the Sonitpur district, the model was initially well followed by the users, but after six month the users stopped giving the monthly amount to the VEC. The reason was the unavailability of spare parts in the service centres. The technology provider was repeatedly unable to supply the spare parts to the service centre, so the local technician could not repair the faulty systems on time. Hence, there was negative impact among the users about the service centre, local technician and VEC and thus the users started refusing to follow the model.

Benefits due to adoption of solar home lighting system

Inspite of the limited technical performance of the systems, the analysis reveals that the installed systems provide many direct and indirect benefits to the users of the systems. Increase in the study duration of the children of the households and the decrease in the monthly kerosene consumption per households are the most noticeable among them. As the burning of kerosene for lighting in traditional lamps produces indoor air pollutants with adverse effect on the human health and the living environment, adoption of SHS helped in mitigating the indoor air pollution to a large extent. It is also observed that higher amount of energy (one SHLSs system is not sufficient) is required in the households as 78% of the total households has family members with more than five. This can be corroborated from the fact that 83.6% of the respondents are still using kerosene in addition to solar systems and 13.6% of the respondents are using grid in addition to kerosene and solar systems for lighting. Only, around 2.8% of the respondents are solely relying on solar systems for lighting and not using kerosene at all (Fig. 2). The systems are also used for mobile charging, running television or radio in few households.

Kerosene saving

Kerosene is the primary energy source for lighting in all the households of these villages. The study found that 73.6% of the total household's are using kerosene for lighting and it is in the range of 4 to 8 l per month per households before adaptation of the SHLS (Fig. 11). The average kerosene consumption per month per household was 6.28 liters. After the adaptation of SHLS, kerosene consumption has decreased significantly to 2.78 l per month per household. It is clear that due to adoption of SHLS, kerosene consumption has reduced by an average of 3.5 l per month per household. Hence, it can be concluded that the villagers are saving a significant amount of money, spent for kerosene by a household, after adopting SHLS. The cost of the kerosene based on public distribution service is approximately INR 20/l. Hence, the saving due to reduction in kerosene consumption translates to an amount of INR 75 per month per household. Most of the study reported by various other researchers also found that reduction in kerosene consumptions is one of the noticeable change occur in the villages due to adoption of solar home lighting systems (Harish et al., 2013; Wijayatunga and Attalage, 2005). The solar system provides better living conditions especially for women and children. In the same time, solar systems provide better quality of lighting compared to kerosene based lighting systems (Mahapatra et al., 2009). Burning of kerosene for lighting produces air borne pollutants and CO_2 which are very

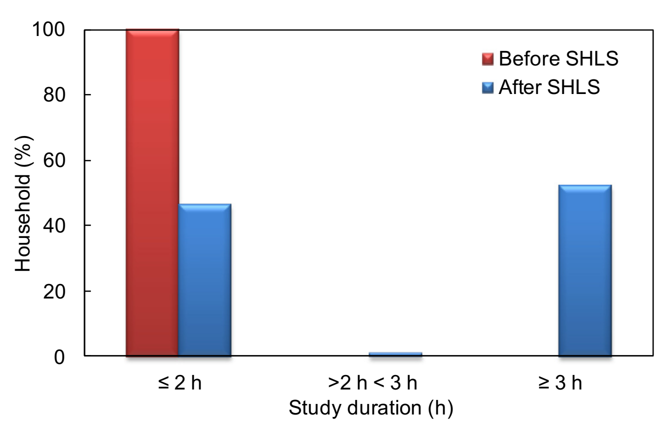

Fig. 12. Study duration of the children.

harmful for the living environment. In this study also, 56% of the users reported that there is an improvement in the health of woman due to the use of solar systems. Health related problems like cough, headache and eye problems have reduces among the users due to the use of systems compare to earlier days when kerosene based lighting systems were used.

Improvement in education of the children

Fig. 12 presents the increase in the daily study duration of the children before and after the adaptation of solar home lighting systems. It is found from the analysis that that there is an improvement in the daily study duration of the children in 96.3% of the total household due to the use of solar home lighting systems. The study duration of the children of these households was closely 2 h per day, by using kerosene base lighting. However, after the adoption of solar home lighting systems, 52.4% of the total household's children studies for more than 3 h per day.

The daily average study duration of the children in all the surveyed areas before the use of solar system was 1 h and that increases to more than double, 2.6 h after the use of solar systems. This is primarily due to better quality light or illumination from solar home lighting systems compared to kerosene based lighting system. The children feel less strain in their eyes in studying and their concentration had also increased in studying under the better light of solar systems as compared to kerosene based lamps. However, as the family members are on average more than five, one single solar home lighting systems with two lamps, always does not allow using the lamps for study purpose. In the same time, it has been reported in earlier sections, due to bad management of the systems, the operation hours of the systems also reduces to 2.2 h, 3.5 h and 2.3 h in winter, summer and monsoon seasons respectively from its design operation hours of 4 h per day. The annual average working duration considering the seasonal variation and the study duration of the children comes to be 2.6 h per day. Hence, better effective management of the system will improve the daily study duration of the children from more than 2.6 h (at present) to atleast 4 h per day.

Contribution to livelihood improvement

Adoption of solar home lighting systems not only improves the children study duration hours or reduction in kerosene consumption, but also it improves the daily needs like mobile charging or households extra income due to certain activities which are performed in the night time. It is found from Fig. 13 that 26.3% of the total households reported that there is an improvement in the livelihood in the households due to mobile charging or extra income generation. It is observed that all total in 98 households, users used to charge their mobile on a daily basis by using the solar systems. Earlier the villagers need to travel far away distance to charge the mobile phones and need to pay an amount of INR 10 for onetime charging. The rapid acquisitions of the mobile phones actually motivate the people to adopt the solar systems. However, it is important to mention that the present solar systems which are disseminated in these villages are designed only for two 9 W lamps, not for any mobile charging. Hence, villagers compromise their lighting needs by diverting the load from lamps to mobile charging. The priority analysis reveals that mobile charging is the first priority compare to lighting needs in these villages.

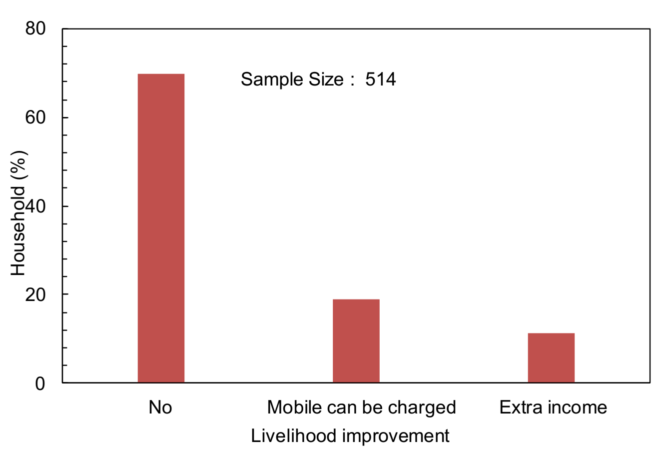

Fig. 13. Livelihood improvement due to adoption of solar systems.

It is observed that in Sonitpur district, two households are using the solar systems for entertainment activities like watching television and listening radio. So it is evident that the solar systems are also contributed in the connecting the users with the latest information. It is also found that 38 households especially in Sonitpur and Kamrup districts extra income generated due to the adoption of systems. The extra income generated from the activities like business during evening time or working in the late evening related to processing of agricultural products, which all resulted in improving the household's daily income. The peoples who are doing business such as selling of vegetables, fish or grocery shop using traditional kerosene based lamps are switched to SHLS. This has improved in the business due to the better quality of lights makes more customer presence compare to the other shops. In some households, women are found engaged in homemade food business like pickle making by extending their working hours in the evening and night by using the solar lighting system. This also resulted economically empowerment of the poor women in these households. The analysis observed that the households who do not have the solar systems at present are also motivated to adopt the systems in Kamrup and Barpeta districts. However, due to their weak financial position, users are looking for subsidy base scheme from the government towards adoption of the system.

User's satisfaction and perception

It is the most important indicator to evaluate the performance of any technology/systems at the field level. The analysis reveals that 41.4% of the total households preferred the SHLS over the conventional grid. The reason cited by the users are portability, reliability, flexibility and expenses towards lighting after the subsidy received under RVE programme. With most of the surveyed places being remote and flood prone, the users move to a safer place during flood. So portability of the lighting source becomes a key factor to choose a source of lighting. At the same time, solar systems are also simple, light-weight. Reliability is another important factor to choose the solar systems over the conventional grid. The frequent power cut during evening hours makes the grid electricity completely unreliable in these villages. In case of solar systems, users have flexibility to use the power from their own individual system whenever they need it.

Most of the household are economically weak in these surveyed areas. So they prefer the source of lighting which is most economical. In conventional grid, initial investment for the electricity connection and monthly electricity bill makes the system costly as compared to solar systems. It is also important to mention that on average users spends INR 125 per month for kerosene. In case of solar system, users only paid 5% of the total system cost. However, it is also found that 58.6% of the households prefer conventional grid supply over solar systems. This is mainly due to the weather dependence of the solar systems and energy requirement in the households is not sufficiently met by a single solar home lighting system. In bad weather conditions especially in monsoon and winter seasons of the years, the sunshine hours in a day reduce up to a significant level, so the energy generated from solar systems are less but the demand is almost the same. However, in case of conventional grid the users have the flexibility to use the energy as per their requirement in a particular time, so they prefer conventional grid over SHLS. The households with better economic strength and more numbers of family members preferred the conventional grid supply over SHLS. Most of these users wanted to have appliances like

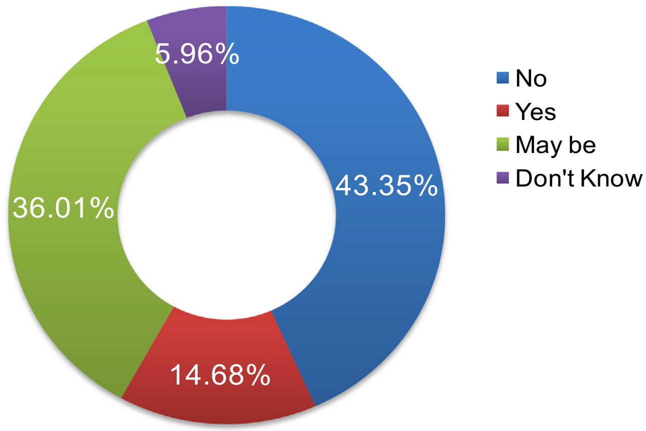

Fig. 14. Ability of the systems to meet user's demand.

mobile charging, television, fan etc. and also more than two light points. Almost all the households are reported to acquire at least one more lamp than what they have currently got in the solar home lighting system.

Fig. 14 presents the ability of the present solar systems (two light points) to meet the user's immediate demand. It is found that only 14.7% of the total users reported that the present system has been able to meet their electricity demand. However, 43.4% of the total users expressed that the present system is unable to provide the amount of energy they required. It is also found in the user's feedback that the system have the ability to meet their immediate electricity demand if it functions properly. It is also reported by 36% of the total users that if the existing SHLSs are technically maintain with proper institutional mechanism, these systems would be able to meet their immediate electricity demand.

Conclusions

The solar home lighting systems are reliable, simple and portable renewable energy technology which can meet the basic energy demand (lighting) of a household in the remote rural areas. This study clearly shows that acquiring SHLS has certain clear and definite benefits like increased in the study duration, reduction in kerosene consumption and a sense of associating with improved standard of living with higher quality of light. Further, in order to address the complaints of the users the institutional structure and communication between different stakeholders needs to be strengthened, availability of local technician and spare parts in the service centre and frequent meetings between the implementing agency, technicians and users are required. Though the SHLS are simple, but this study reinforces the need for their regular maintenance to operate efficiently and effectively. This is where the basic technological know-how of the systems plays an important role. It is found that users are simply getting the battery water refilled as a maintenance activity rather than getting the entire system inspected properly. The study found that there was no effective awareness program conducted by any of the institutions in all the four districts. So, users do not have the sufficient opportunity to learn about the basic operational practice to be followed to make the system in operation.

Adoption of the systems has translated saving of kerosene on average of 3.5 l per month per household which is the most noticeable benefit. However, kerosene consumption has not been eliminated completely as the current design of the SHLS are not being able to meet the complete lighting demand of all household, especially the household with larger family size. This calls for demand-driven system design instead of dissemination of same type of system for all household. While the government support may be kept same for equity consideration, beneficiaries who are willing to take higher capacity system on payment should be provided such systems. Rapid acquisition of mobile phones motivates the people to adopt the solar system; otherwise users need to travel far away for charging the mobile phone. This study further observed that overall 98 households are charging the mobile phones on a daily basis by using the systems. The SHLS were also found to extend the working duration in the evening and especially women are found engaged in weaving and homemade food businesses such as pickle preparation. The study also found that 38 households are earning extra income through activities like mobile phone charging, extend the business hours in the evening. Thus, adoption of SHLS has lead to an improvement of rural livelihood to a certain extent. The study also observes that user perceptions on the system are positive. With off-grid systems, especially solar home systems, being increasingly considered to expand energy access in many countries in addition to the central grid extension, the lessons and conclusion from the study will be important for cross-learning. The study concludes that availability of local technicians or service centres, effective village energy committees, users need-base system capacity, appropriate social awareness towards livelihood improvement options based on solar lighting systems will improves its sustainability and economic viability.

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