User Perspectives of Photovoltaic Micro Utility Systems Installed in Rural Bangladesh

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Abstract- Photovoltaic micro utility (PV MU) systems are feasible both technically and financially in Bangladesh. This paper presents the user opinions towards photovoltaic micro utilities installed in the rural areas of Bangladesh as user acceptance could lead to the further expansion of these systems to meet electricity requirements at the rural areas. Five point Likert scale is employed to determine the user acceptance of the PV MU system. Impacts of PV MU on the social life of the users are also discussed to elucidate the changes in social life of the users after using these systems. Users were mostly pleased about the systems and were happy to obtain 700 lumens from PV lamps in place of 76 lumens of kerosene lamps. They were also satisfied about the reduction of kerosene consumption and reduced environmental impact, tenure of power supply, systems reliability and safety of the systems. The average kerosene saved by 40, 50, 60-65 and 80-85 W_p systems were around 15.20, 20.16, 22.48,32 liter/month respectively. They agreed that their access to the information, amount of sales and working opportunity increased after installing PV MU system. It also provided them very easy communication with their customers and suppliers, and increased their comfort.

Keywords: Rural electrification, PV micro utility, User perception, Bangladesh.

1. Introduction

Authors Solar photovoltaic technology is one of the most suitable among all renewable energy sources in Bangladesh to produce low carbon electricity as the potential of other renewable sources are not sufficient to produce electricity in large scale. Bangladesh is situated between 20^0 $34^/$–26^0 $38^/$ degrees north latitude and 88^0 $01^/$–92^0 $41^/$ degrees east, the daily average solar irradiation varies between 4 and 6.5 kWh/m^2 which is ideal for solar PV utilization [1]. Only47% people in Bangladesh have access to grid electricity [2]. As a result, rural communities suffer from an under-utilized economy and depressed business activities. Kerosene lamps called 'Cuppi' and 'Harricane' are the major appliances to meet the lighting needs of rural villages. Qualities of these lamps are very poor. Besides, these lamps have high risk of catching fire and negative impact on health. More than 1.4 million solar home systems (SHSs) have been installed by April 2012 in the country [3]. Solar program mainly targets those areas, which have no access to conventional electricity and have little chance of connecting to the grid within 5 to 10 years**.** The concept of solar home systems started in 1996-97, and the rate of installation was very low initially because of high initial cost. This increased significantly from 2004 to 2010 because of the soft credit through installment, reduction of price and the favorable policy of the government of Bangladesh. Though installment system for payment exists in Bangladesh, still at present solar home systems are not affordable for many poor villagers. This is one of the barriers to the scaling up of the solar program and the revitalization of the rural economy, through the use of solar PV technology. In order to help such consumers, Center of Mass Education and Science (CMES) and Grameen Shakti (GS) in coordination with Asian Institute of Technology, Thailand introduced the first PV micro utility (PV MU) in Bangladesh in October 1999.[4] Under this model, an entrepreneur installs the system at his own premise and shares the electricity generated with his neighbors. Electricity from PV panel goes to the battery for storage through a charge controller and all the loads are connected from the charge controller. Mostly DC (Direct Current) loads are used in the rural villages to minimize the cost of the system as there is no need of inverter. The owner of the system is responsible for making installment payments to GS and the users will pay monthly or daily rent to the owner. This micro-utility model has become very popular in the rural market places and more than 10,000 micro-utility systems are now in use the rural market places of Bangladesh [5], [6], [7]. It was found that the preferred micro utility is a 50 W_p system as this allows three to four fluorescent lamps (FL). Most of the shops in the rural villages do not need more than one or two lamps so that owner can use one lamp and can rent remaining one or two.

Markets of rural villages use diesel generators for lighting their shops. Though it provides better quality light, its quality of service is poor. Voltage fluctuations also shorten the life of the appliances connected [4]. The lack of energy and power reduces business hours and does not enable people to access modern technology and equipment which are required for development. Mobility of the people is also hampered after dusk due to security problems. PV MU program has addressed many of these issues in the rural market places by extending business hours and increasing business turnover. It was observed that users could work 1 to 2 hours more than before. New businesses, such as, mobile booth, mobile top up and mobile phone charging shops were started by the users after starting to use PV MU.

Though in the literature, almost all studies are about solar home systems in Bangladesh and very little information is available on PV micro utility and users' satisfaction. Moreover, an article regarding technical and economic analysis of micro utility has already been published by the authors as well [5]. So, to better understand about this technology an extended study was carried out to presents the user acceptance of solar PV micro utility installed in the rural areas of Bangladesh. Bangladesh government is also currently deeming about PV micro and mini grid in Bangladesh [6] and finding from this study will be helpful for further expansion and up scaling of such systems.

2. Methodology

A field visit had been conducted from December 2011 to February 2012 and January 2013 to December 2013 to get the user opinion of people using PV MU system at the rural market places in Bangladesh by an organized structured questionnaire. Forty to eighty five watt peak (40~85 W_p) systems are chosen for this study as these systems are mostly used in the rural users level. Mymensingh, Gazipur, Manikgong, Bhola, Chandpur and Rangamati were the six districts from where the data were collected to have the different geographical locations of the country as shown in Figure 1.The systems at Borokal in Rangamati District was in a hilly area, which is very difficult to access, while Bhola is a district island separated from the mainland of Bangladesh by a river.

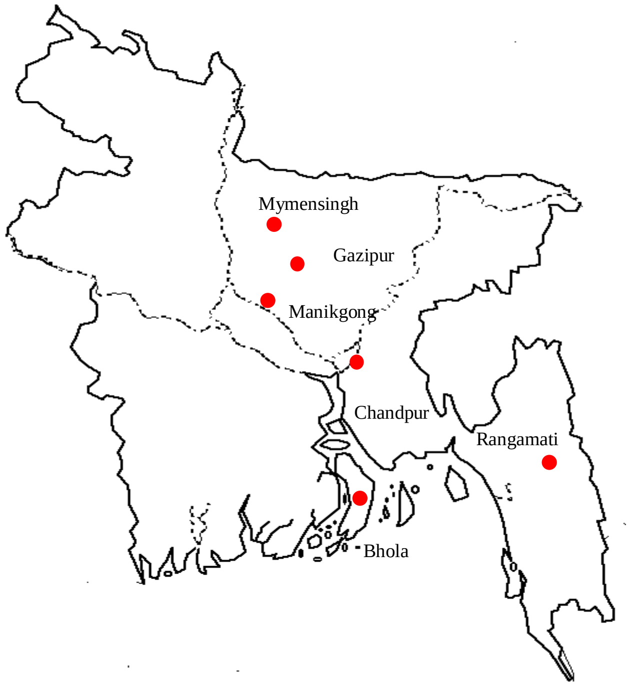

Fig. 1. Data collection at different places in Bangladesh

One hundred two (102) users' were chosen randomly from these locations to have the user perception about PV MU program in Bangladesh. Equal numbers of respondents were interviewed from each district while as these systems were chosen from rural market places and that is why most of the owners of these systems were male. Among the 102 users there were only two owners were female and remaining were the male. Among the users before using PV MU systems, 74 users were using different kind of kerosene lamps whereas remaining 28 users were lighting up there shops by renting electricity from generator owner. Normally at the rural market places one person buy diesel generator and the rent the electricity among the shop owners on a daily basis. The systems considered were not only from areas near the grid, but also from places up to 70 km away from grid.

Quantitative as well as qualitative study was done regarding the opinion. User acceptance is a successful tool to measure of a system's success. [13] To measure the user acceptance, five point Likert scale was employed in this study as this technique is commonly used to determine the users' satisfaction where satisfaction is ranked from 1 to 5. Score 5 is considered to have highest acceptance and 1 is the lowest [11], [13], [14].

3. User Perception

Among the users, systems age was within the 2 years for around 26% users, and the system age was within 2-4 years for 27% of the users. Besides, for 18% users' system age was within the range of 4-6 years. The remaining 30% users' systems age were between 6-8 years while the maximum system age was 08 years. User's opinion on various characteristics with their mean and standard deviation is listed in Table 1.

Table 1. User acceptance of PV MU systems in rural Bangladesh

Satisfaction Parameters	Level of acceptance					Mean	SD
	1	2	3	4	5		
Quality of light provided	0	0	0	8	94	4.92	0.27
Reduction of fuel consumption	0	0	0	2	100	4.98	0.14
Monthly expense for PV electricity	0	0	0	38	64	4.63	0.48
Service period	0	2	3	38	59	4.51	0.65
Reduction of health Hazard and environmental impact	0	0	0	24	78	4.76	0.42
Amount of power supply	2	5	17	48	30	3.97	0.91
Reliability	0	0	0	17	85	4.83	0.37
Safety	0	0	0	3	99	4.97	0.17
Maintenance service provided	0	4	8	12	78	4.61	0.79

It is found that users were mostly satisfied with the quality of light provided by the PV MU systems, reduction of fuel consumption, monthly expense for PV electricity, service period, reduction of health hazard and environmental impact, reliability and safety, and maintenance service provided by system installer. Some users showed reservation on the amount of power supply. They shared that during summer they need fan and some user near the grid also expressed that a refrigerator could increase their sales.

3.1. Quality of light provided by PV MU systems

Illumination produced by traditional lamps used by the rural villagers is very low. Illumination and efficiency of traditional wick lamps are 76 lumens and 0.35 lumens/W respectively [15]. Almost all the users reported that before using solar electricity they needed an extra torch light to see the goods though they had kerosene lamp in their shops. After using PV electricity, the users were receiving 700 lumens lamps that were good enough for their work. The efficacy of solar lamp was 100 lumens/watt as lamp circuit allows 7W to each lamp.

Users were highly satisfied about the quality of light provided by PV lamps. Satisfaction score for quality of light was 4.92 (SD=0.27). Traditional lighting equipments such as Kuppi, Harricane and Hazzak were the other options of lighting in the rural villages except PV systems. Light provided by those equipments were insufficient for the user, unhygienic and had risk of fire.[4] Only diesel generator was found to provide good quality of light but most of the users reported that they were not happy about its service as it was interrupted frequently. Around 92% users reported that light provided by PV MU was better than the other options available in the rural villages and sufficient for their work. For the remaining 8% users, the light provided by PV MU was better than Kuppi, Harricane and Hazzak, but not better than diesel generator. But, they were happy about the light provided by the PV system.

3.2 Reduction of fuel consumption

Traditional wick lamps (Kuppi and hurricane) used by the rural people of Bangladesh were tested at Bangladesh Council of Scientific and Industrial Research (BCSIR) to get the actual fuel consumption and the result show that the average fuel consumption per lamp was 0.042 lit/hour. Using this information, the amount of kerosene reduction was calculated by the number of working hours and fuel consumption per hour. The average amount of fuel reduction by the PV MU systems is shown in Figure 2. The average kerosene saved by 40, 50, 60-65 and 80-85 W_p systems were around 15.20, 20.16, 22.48,32 liter/month respectively. Most of the 80-85 W_p system owners used Hazzak (mantle lamp) that consumed around ½ liter of kerosene per day as they have multiple business in the market. Besides, they also rented two or three fluorescent lamp (FL). That is why the amount of kerosene saved by 80-85 W_p systems were significant. The average kerosene cutback by 80-85 W_p systems were around 34 liters/month.

By considering kerosene price of $0.85/litre [16], the money saved by the users is shown in Figure 3. It was found that saving was within the range of 0$-$3.85 per month for 15% users but for around 60% users, the saving was about $3.85-$3.77 per month. While, another 15%users used more than one traditional lamp (Harricane or kupi) before using solar electricity and saving was about $3.77-$11.54 per month. This saving was more than $11.54 for around 10% users as users in this category used Hazzak (mantle lamp) that consumed more than half a liter of kerosene per day. The survey showed that users were very much satisfied as they did not need to buy kerosene after using PV MU systems. It was found that user were happy in the reduction of fuel consumption with a score of 4.98 (SD=0.14). Around 92% users were happy in the reduction of kerosene use without any reservation. The reaming 8% were also very happy but they expressed that sometimes they needed to use kerosene as well when they opened shop for a longer period of time especially before any festivals.

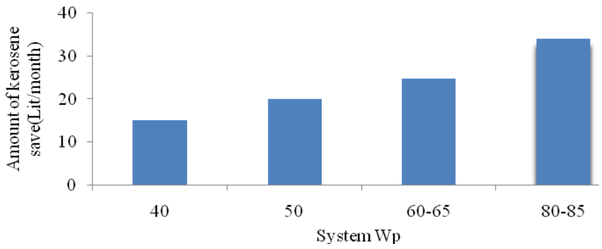

Fig. 2. Average kerosene reduction by the PV MU systems

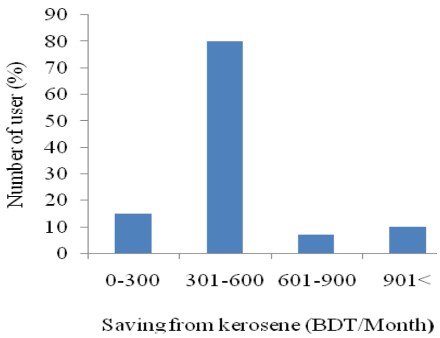

Fig. 3. Users' saving from kerosene

3.3. Monthly expense for PV electricity

The monthly expenses for the users of PV MU systems was divided into five groups and illustrated in Figure 4. Expenses varied between $1.92 per month to $4.68 per month. Expense was $1.92 to $2.56 for 42% users, $2.57 to$3.21 for 47% users, $3.22 to$3.85 for 3% users and $3.86 to $4.49 for 6% users. Only 2% users 'expenses were more than $4.5. Users were highly satisfied about their expenditure for PV MU as expense for PV MU was lower than the expense for kerosene, and users were getting quality light. There was no maintenance charge for the users for the first 03 years as these 03 years were covered by the warranty period by the systems installer except expenses required for water for the battery and fluorescent lamps. Project life 20 years were assumed based on the life of panel as panel life was considered usually 20 years. According to field visit, 03 batteries are required entire project life [5] and cost of each battery were around $128.20 (based on100 ah battery which required for 50 W_p system). Life of lamps was considered 02 years and cost of one lamp was around $1.54.

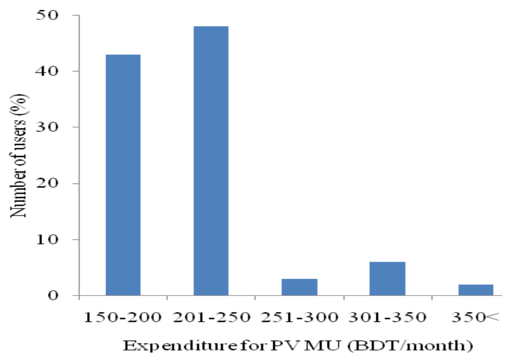

Fig. 4. Expenditure for the PV MU by the users

Besides these, except the initial one, one charge controller was needed to replace within the entire life which cost was around $12. By considering 20 years project life [4], [5], it is found that levelized electricity cost of these particular systems is around $0.85/kWh while simple payback period for the owners is found to be varied from 4.2 to 6.28 years [5]. The average satisfaction score for expenditure for PV MU was 4.63 (SD=0.48).

3.4. Service period (tenure of power supply/day)

Shops were open mostly for around 4 hours after sunset in the rural village markets in Bangladesh. Very few shops were also found to be open for 5 hours. Users of PV MU were satisfied about the service period with an average score of 4.51(SD=0.65). Around 58% users showed highest satisfaction about the service period without any reservation and another 37% users were also happy about the service period but they wanted more service period during festival periods. For example, some shop owners had to work till midnight (tailoring, haircutting) before festivals. Around 3% users showed moderate satisfaction about the service. Users of this category expressed that often they need to open shop for longer periods and PV MU could not supply. The remaining around 2% indicated low satisfaction about the service period. During data collection it was observed that user of this category had television and they wanted to enjoy it during day and night. But, no user showed total dissatisfaction about the service time as there were no other ways to get quality service of electricity.

3.5. Reduction of health hazard and environmental impact

Unhealthy smoke from kerosene is extremely hazardous to the users. Kerosene lamps produces CO_2, CO, NOx, SOx, VOCs, PM and HC emissions. These emissions not only create environmental problems, but also create unexpected health effects like lung infections, respiratory problems, and eye and throat infections. [17] IPCC guide line suggests that CO_2 emission from kerosene is 2.5 kg/liter. [18] According to a study in India, emission from kerosene lamp was 2.45 kg CO_2/liter. [19] But this value can vary with different types of lamps. The traditional lamps used by the rural people were tested at BCSIR. The average CO_2 emission from traditional lamps used by the rural people in Bangladesh was 2.41 kg CO_2/liter according to the test. The average CO_2 emission reduction from 40, 50, 60-65 and 80-85 systems were around 440, 583,716 and 985 kg /year [5]. However, a 50 W_p system can produce 253 Kg of CO_2 emission in its entire life of 20 years including CO_2 emission that produces during manufacturing its components (Panel, Battery, charge controller etc.), i.e., 12.6 kg/year only [20]. According to this, 10,000 PV MU systems in Bangladesh can mitigate 6.176 million ton CO_2 per year. Schare and Smith, 1999 reported that particulate emission from ordinary wick lamp was 535 ± 155 mg/hr and this value for glass wick lamp was 295 ± 120 mg/hr. [21] Fan and Zhang, 2001in another study found that the CO emission from simple kerosene lamp is 8.2 ±1.1 mg/hr. [22] It is observed that users were aware of the unhealthy smokes and others health hazards like lung infections, respiratory problems, and eye and throat infections produced by kerosene lamp. Users were satisfied about the reduction of health hazard and environmental impact with an average score of 4.76 (SD=0.42). Around 77% users showed highest satisfaction as they did not need to use kerosene lamp any more. They said that smoke of kerosene lamp was harmful for their health. Users of this group also reported that after touching kerosene lamp every time they needed to wash their hand with soap and they did not want to use kerosene lamp in future. The remaining 23% were also satisfied about the reduction of health hazard and environmental impact but users of that category were not too much concerned about this issue.

3.6. Amount of power supply

The average connected load for the system is shown for system W_p in Table 2. The average load used by the users of 40, 50, 60-65 and 80-85 W_p were 24, 26, 36 and 54 W respectively. Appliances used under the PV MU systems and their watt ranges are shown in Table 3.

Table 2. Average connected load of the PV MU system

System Wp	Connected load (W)
40	24
50	26
60-65	36
80-85	54

During the survey, it was found that almost all the users used FL for lighting and around 70% user of micro utility use solar electricity for mobile charging. Mobile charging was one of the main benefits of the users in the rural villages. Some users even traveled more than 2-3 km only to charge their mobiles before installing PV system.

Table 3. Description of appliances used under PV MU systems with number of user

Equipments	Number of user	Watt
FL	All users	7-10
Mobile charger	70%	3-9
Others (Black and White TV, Radio/Cassette player, DC Fan)	3%	12-20 (Fan and TV) and 3-9 (Radio/Cassette player)

On the other hand, only three percent users used television, radio, music player, and fan with lamps. The users of PV MU were satisfied with the amount of power supplied with a mean value of 3.97 (SD=0.91). Thirty percent users were fully satisfied with the amount of power supplied by the PV as they just needed light for 4 to 5 hour for their business.

Another 47% users were also happy as there were no other option of electricity sources and there were no possibility of grid electricity in the near future, 21% users indicated moderate and low satisfaction as they wanted fan and refrigerator for their shops. User of this kind reported that they felt hot and faced difficulty to work during summer and wanted to enjoy television all the day. Around 2% users were totally dissatisfied with the amount of power supply. The data collection team observed that these users, mostly lived near the grid and users of this kind were very unhappy and expected grid electricity as soon as possible as the power supplied by the PV MU were very low compare to grid electricity to run all the household appliances.

3.7. Reliability and Safety

Reliability is the key to success for any particular system. PV MU systems were designed to provide 4 to 5 hour continuous electricity service per day after sunset. Users were asked whether the system can provide the desired power supply everyday and whether the systems are safe. Users were very satisfied with an average score of 4.83 (SD=0.37). Around 83% users expressed highest satisfaction as the PV system maintained 03 days autonomy. Users reported that problem would come only if there was rain for more than three days in a row. Otherwise, users shortened their working period by one to two hours if there were any problem on any particular day. The remaining 17% users were also happy but reported that they needed to use candle some times during continuous rain and also expressed that during battery booster charge they did have no other option but to use candle. GS authority mentioned that they need 24 hour for battery booster charge. Battery booster charge was needed because of the over discharge battery due to problem in the charge controller or if any user used load directly from battery. Besides, all users were highly satisfied about the safety issue of the PV MU system as they never faced any problem. Only three user out of 102 users expressed that their clothes were damaged because of acid from the battery. Users were satisfied with a mean score of 4.97(SD=0.17) about the system safety. Battery was the only equipment where some accidents could happen. GS always installs the battery in dry and open places on a dry wooden structure.

3.8. Maintenance service provided by system installers

Problems regarding charge controller and battery were the common problem faced by the PV MU users. Users were happy about the maintenance service with an average score of 4.61 and 0.79 SD. Around 76.5% users showed highest satisfaction about the maintenance service and they had no complaints. Main installer of PV MU, Grameen Shakti, Bangladesh has 1181 branch offices, 158 regional offices and 14 divisional offices to provide after sell support to the users. They have also 46 Grameen Technology Centers (GTC) to accomplish major maintenance like battery booster charge (it is required if battery is over discharged due to the over used), charge controller repairs etc. Around 12% users were very happy but they wanted GTCs near their places because they had to send battery to GTCs by their own expenses if needed. Besides, around 8% users reported that they sometimes did not get the service in time and were moderately satisfied. A small fraction of around 4% users showed low satisfaction about the maintenance service as they complaint that sometimes they had to wait more than a week to get response from the technicians to repair the problems they faced. These users also expresses that they faced problem to find quality FL from local market during replacement

Table 4. Social impact of PV MU in the rural market places in Bangladesh

Social Impact	Percent Respondent (100%)				
	SA	A	N	D	SD
Increased information access	34	48	18	2	0
Working opportunity increased	62	34	4	0	0
Increase amount of sales	20	40	20	20	0
Provide easy communication with customer and supplier	93	7	0	0	0
Increase comfort of life	67	30	3	0	0
Increase recreational activities	56	28	9	7	0

SA= Strongly Agree; A=Agree; N=Neutral; D=Disagree; SD=Strongly Disagree

3.9. Impact of PV MU in the Rural Market Places of Bangladesh

This section shows the changes in social life of the users after using the PV MU system based on their change in daily life after receiving solar electricity like, access to information, income generation, comfort, recreational activities, etc. Two similar studies for solar home system in the rural villages of Bangladesh were carried out recent past. [23], [24] All the users of PV MU were business persons from rural market places as micro utility systems are popular in the rural market places in Bangladesh, while the earlier studies were on SHS and that is why the impact of PV MU was different than the previous studies done for SHS. Changes in social life by PV MU in the rural market places are shown in Table 4. Around 82% users agreed that their access to the information increased after using PV MU through TV, mobile phone and radio. It was found that almost all the market had common place to enjoy TV. One of the major and important benefits enjoyed by the users was the mobile phone. As mentioned in section 3.6, almost 70% users charged their mobile phones by using solar PV. It was also observed that remaining 30% users also used mobile but charged it from mobile charging shop or from their home. All the users agreed that after using PV MU system, their communication with supplier and customer became very easy.

The majority (around 96%) of the users expressed that their working opportunity had increased after using PV MU. It was observed that users could work 1 to 2 hours more than before. New business like mobile booth, mobile top up and mobile phone charging shops etc were found to be started by many users. During field visit, a mobile charging shop owner was charging 4 mobiles at a time. He started this extra business with his regular grocery business after using PV MU and reported that he could charge around 20 to 30 mobile per day and earned around $0.06/mobile. Sixty percent of the PV MU users reported that their amount of sales increased after using bright PV light. The remaining 40% users thought that their sale did not increase but remained the same. They reported that their business just shifted from day to night. While 97% users agreed that by using PV MU systems their comfort in life had increased.

They no longer needed to touch unhygienic kerosene lamp and could see their products very well under solar light. Many users reported that they could take long rest after lunch and could open the shop longer at night.

All the users thought that the smoke from the traditional lamp was harmful. They also reported that before using solar light they needed to use an extra torch light to find products from their shops at night. Besides, eighty four percent of the surveyed users thought that their recreational activities were increased by using TV, radio and mobile. It was seen that all market place had a common places to enjoy TV. They reported that they can enjoy gossiping under solar light with their friends especially in the tea stalls. Users also thought that their overall improvement of their market places was enhanced after installing PV MU systems. They reported that they feel more secured now. Comparison with previous study suggest that users of this kind showed more positive response about working opportunity increase, increased sales, easy communication and comfort after installing PV MU.

3.10. Recommendation for further expansion of PV micro utility

Government of Bangladesh has the vision to provide electricity to all its citizens by 2020. To fulfill this vision, the government has the plan to produce 500MW power from solar energy by 2015 [25]. But this plan will not be successful without proper policy and plan about PV micro and mini grid. Solar home systems are established technology in Bangladesh as its impact on social development is enormous [23, 24] and it is feasible in the country technically, financially and economically for the rural users [26, 27, 28] but it has been understood from field visit that it is very difficult to install and maintain PV MU systems without help from the government. There are so many risks involved such as possibility of grid electricity and users discontinuation after buying individual systems. There is no policy for solar micro and mini grid till now in Bangladesh though there is proper policy, evaluation and monitoring for SHSs. It has been found that appropriate policy towards PV micro utility, initiative to make available PV accessories locally within the country, proper monitoring and dedicated maintenance support can make PV micro utility program more successful in Bangladesh like SHSs. In Bangladesh, still there are many places like char (places within the river) and hilly areas where grid electricity will not be possible by next 15–20 years. So, the government should think of appropriate policies to implement PV micro and mini grid by private sector as like SHS under appropriate financing company like Infrastructure Development Company Limited (IDCOL) [6].

4. Conclusions

Users' satisfaction of PV micro utility program in Bangladesh is evaluated. The following conclusions can be drawn from the study:

i. The attitude of the users is mostly positive. Users were satisfied about the quality of light as quality of PV lights were much better than the others options of lighting. PV MU system provides 700 lumens compared to 76 lumens of kerosene lamps.

ii. They were happy as they no longer needed to use kerosene lamps. Their fuel consumption was reduced and a monthly expense for PV electricity was less than their expenditure for fuel (kerosene).

iii. Systems were safe and reliable according to them. The PV MU systems are free from emission where as their previously used kerosene lamp was very harmful for their health. The average CO_2 emission reduction from 40, 50, 60-65 and 80-85 systems were around 440, 583,716 and 985 kg /year respectively.

iv. Rural village markets were mostly open 4-5 hour after sunset and users were happy about the tenure of power supply by the PV MU. They reported that they faced problems only during continuous rain like two or three consecutive days. Users were mostly happy about the maintenance service provided by the installer.

v. Users expressed that after installing PV MU system, their access to information, working opportunity, sales, comfort of life and recreational activities had increased.

vi. Most importantly, PV MU provided them easy communication with customer and supplier that was a huge benefit for them.

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