Sustainable Use of Solar PV Systems in Rural Ghana: Barriers, Barrier Removal Measures and Priority Factors

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Abstract

This study examined two major public solar photovoltaic (PV) projects that operated on fee-for-service in rural Ghana. The purpose was to identify and analyse barriers to the sustainable use of solar PV systems and priority factors for increasing its future use in off-grid rural communities. The study was based on a cross-sectional survey conducted in rural solar-electrified households and enterprises. Using Pareto's analysis, the study ranked the barriers facing rural households as: unavailability of PV parts on the local market; high price of PV parts; limited government support; and lack of end-user financing. At the enterprise level aging/defective batteries and power fluctuation due to low sunshine hours during rainy seasons prevented extension of working hours after sunset. Measures to remove the barriers such as local capacity development to reduce system failure, charging the poor fees up to US$3/month as well as the priority factors for increasing the use of PV systems are discussed.

Keywords: Solar photovoltaic; barriers; priority factors; sustainable use; Ghana.

1. Introduction

1.1 Background

The policy of the government of Ghana is to achieve universal access to electricity by the year 2020. However, access to electricity is unevenly distributed and highly skewed in favour of the urban population. Out of about 3.7 million households in Ghana, access to grid-electricity was about 54% in 2005 [1] and 60.5% in 2009 [2], and about 72% in 2012 [3] with rural access being relatively low. In most developing regions, grid extension to remote rural areas is found to be expensive because of low population density, lower consumption and lower revenue per km [4]. In line with government's energy policy, solar photovoltaic (PV) systems are being promoted in rural Ghana to increase electricity access for socio-economic development. Although solar PV systems are cost-effective alternatives, there are several barriers to its sustainable use.

In this paper, we define sustainable use of solar PV systems as the ability to use PV systems to meet the electricity needs of the present without compromising the ability to meet future needs. Barriers are also defined as structures and systems that prevent or discourage actions and benefits [5]. The generic barriers to renewable energy in developing countries often cited in the literature include high initial system costs, lack of national markets, lack of information, lack of finance and low investment [6, 7, 8, 9].

Pegels [10] identified cost and risk structures as major barriers to renewable energy in South Africa. In the specific context of solar home systems, Ketlogetswe and Mothudi [11] cited low income status of rural inhabitants and migration of house-owners from village status to lands, or cattle posts as major barriers causing low use of solar home systems by rural communities in Botswana. Assessment of GEF-supported solar PV projects in several African countries including Kenya, Ethiopia, Mozambique, Zambia and Uganda indicated high investment costs, low awareness, lack of technical skills and low capacity as the major barriers [12]. Nevertheless, these barriers are universal and lack ranking for attention and key barrier removal measures.

Given the fact that barriers are often quite situation-specific in any given region or country, there is the need to examine important few barriers specific to the Ghanaian context for policy and planning decisions, bearing in mind budgetary constraints and limited resource allocations. Despite considerable deployment of solar PV systems in Ghana, there is relatively little research on the specific challenges facing rural consumers. Furthermore, there are uncertainties with regard to the specific barriers to the sustainable use of rural PV systems at the household and enterprise levels.

Results available indicate that the use of solar PV in off-grid rural communities is plagued with barriers, which must be carefully researched. At the same time, there are priority areas of concern, which must also be researched to provide the direction to sustain off-grid PV systems. Without a clear analysis of the barriers and the priority factors for sustainable use, potential users may not accept PV technology as an appropriate alternative. Therefore, two major public solar PV rural electrification projects in Ghana were studied for analysis: (1) Spanish/Ministry of Energy Solar PV Electrification Project; and (2) UNDP-GEF Renewable Energy Service Project (RESPRO). These projects were implemented between 1998 and 2002 in off-grid rural and peri-urban communities in Ghana using fee-for-sevice approach.

1.2 Research Questions and Objectives

To help analyse the barriers and priority factors for sustainable use of off-grid PV systems, the following research questions were posed to guide the study: What specific barriers affect the sustainable use of solar PV systems in off-grid rural communities? What measures can contribute to remove or mitigate the barriers? How do solar-electrified households perceive the future use of PV systems? What factors can contribute to increase the future use and maintenance of solar PV systems in rural communities? What policies can contribute to ensure the sustainability of public solar PV rural electrification projects? The objectives of this paper were three fold: First, to identify and analyse the barriers to the sustainable use of solar PV in rural households and micro-enterprises in Ghana; second, to suggest measures to remove the barriers; and third, to determine priority factors and make recommendations for the sustainability of public solar PV electrification projects.

2. Methodology

To determine the barriers to the sustainable use of solar PV in rural households and micro-enterprises, cross-sectional surveys of 96 solar-electrified households and 22

2.1 Study Areas and Research Methods

solar-electrified enterprises (N=118) were conducted in sixteen communities of five regions in Ghana. The study areas were the following off-grid rural communities:

Kpentang, Kpenbung, Kambatiak, Bamong, Kintango, Chintilung, Tojing, Gbetmanpaak, Jimbali, Najong No.1 and Pagnatik in Bunkpurungu Yunyoo district (Northern region); Kpalbe in East Gonja district (Northern region); Tengzuk in Talensi-Nabdam district (Upper East region); Wechiau in Wa-West district (Upper West region); Kpassa in Nkwanta district (Volta region); and Apollonia in Tema district (Greater Accra region). Pre-testing of the questionnaires was carried out in the Nkoranza district of Brong-Ahafo region.

In each of the communities research assistants who speak the local language were engaged in the administration of the questionnaires. The household and enterprise-level questionnaires contained 192 and 91 variables respectively. In view of the homogeneity of the end-uses of the PV systems - mainly for lighting, radio and television - the selected sample size (n=118) with 5% margin of error is statistically adequate for analysis. Several authors consider sample sizes ($N \geq 30$) as statistically large samples [13, 14]. However, most social researchers would probably recommend a sample size of at least 100 as adequate for statistical data analysis [15].

Separate lists of beneficiaries were used to select the households and enterprises in a systematic sampling. In each sampling, the first case was randomly selected by drawing slips of paper with numbers from the first cases based on calculated sampling fraction (actual sample size divided by total sample population). Subsequent cases were systematically selected using the sampling fraction to determine the interval of selection. From the lists of the beneficiaries, PV systems (50Wp and 100Wp) that have been operational for over three years were selected. This criterion was based on the assumption that over a three-year period, PV systems and components (car battery, regulator and fluorescent lamp etc.) would have gone through a cycle of operation and maintenance (O&M) and beneficiaries would have learned lessons worth studying. The purpose of the questionnaire was to gather ex-post information regarding the factors affecting the sustainable use of solar PV systems in off-grid rural Ghana.

2.2 Underlying Assumptions

The underlying assumptions that govern the interpretation of the study results were that since the solar-electrified households and enterprises did not pay for the costs of the installed PV systems, initial investment costs were not considered in the analysis. At the household and enterprise levels monthly household expenditure and enterprise purchases were used as proxies for incomes. The underlying reason was to find out whether low income adversely affect sustainable use of solar PV in rural Ghana as reported by Ketlogetswe and Mothudi [11].

2.3 Statistical Analysis

Pareto analysis and barrier ranking were used to identify and analyse the barriers associated with the use of solar PV at the household and enterprise levels. Statistical significance was computed at $p<0.05$. In order to analyse the data, SPSS 16.0 for Windows was used. The data were cleaned by visually cross-checking the data base with the individual questionnaires to find out wrong entries; and by using box-plot to identify extreme values and outliers.

3. Results

3.1 Characteristics of the Surveyed Households and Enterprises

In the surveyed households the mean age of the respondents was 45 years. About 92% of the respondents were married, 4% single; 2% separated; 1 % divorced and another 1% widowed. The mean household sizes were about 8.3 members. An average of 5 children per household was recorded. Majority of the respondents were farmers (59%), teachers (20%) and traders (9%). The household heads had no education (29%), primary (15%), secondary (12 %) and tertiary (22%). A fairly equal proportion of modern (concrete and aluminium roof) and traditional buildings (mud/earth materials and thatch roofs) were observed.

The enterprises surveyed were generally small-scale employing less than 6 people. They were mainly shops engaged in the sale of groceries (village supermarket), chemicals (drugs), tailoring, drinking bars, spare parts, electronic repair and video show business. However, grocery shops, chemical shops, drinking bar and tailoring were the predominant enterprises in all the communities. Enterprise owners were predominantly males (91%). Their ages ranged between 20 and 49 years. They have been engaged in their businesses for 4-15 years. Their monthly estimated earnings varied by size, type, season and geographical location. Their earnings ranged from about US$ 108 per month in tailoring business to over US$ 490 per month in spare parts business. A summary data on the characteristics of the surveyed households and enterprises are provided in Tables 1 and 2 below.

3.1.1 Satisfaction with PV Services

The results of the study indicated that in general, the project beneficiaries were satisfied (81%) with the basic electricity services provided by their solar PV system. Lighting, radio listening and television viewing emerged as the most significant outputs of solar PV in the study areas. The main reasons provided by those not satisfied (19%) were: defective battery and lamps (59%); inadequate power supply during the rainy season (18%); PV system could not run devices such as electric fans (12%); poor maintenance services (11%); and light not sufficient for lighting entire place (6%).

3.2 Analysis of Barriers

Table 3 displays the count (frequency) of responses by type of barrier to the use of solar PV. Pearson chi-square test of the responses by each type of barrier shows significant values of 0.000 ($p<0.05$) indicating differences in responses to each type of barrier. Since all the respondents were users of solar PV, the observed difference in the responses are likely to be real and not due to chance.

Table 1. Household characteristics and socio-economic data

	Solar-electrified Household
Average HH size	8.3
Average no. of children (≤ 14 yrs)	5
Average Age of Household head	45
Occupation of HH head (%)	
Farming	59.4
Trading	9.4
Artisan	2.1
Teaching	19.8
Public Service	5.2
Others	4.2
Level of Education of HH (%)	
No Education	29.2
Primary	14.6
Middle	10.4
JSS	4.2
Secondary	11.5
Tertiary	21.9
Others	8.3
Estimated Monthly Income	
% up to US$ 1 per day	17%
% between US$1 and US$ 2 per day	42%
% above US$ 2 per day	41%
Monthly fee-for-service	
50 Wp PV system	US$ 1.63
100 Wp PV system	US$ 2.72
Average maintenance cost	US$ 3.00
Dwelling type	Modern/Traditional
Average monthly household expenditure on kerosene	US$3.13
Average monthly expenditure on dry-cell batteries	US$ 2.70

Table 2. Summary data on surveyed enterprises

		Grocery	Chemical Selling	Tailoring	Drinking bar	Spare parts	Electronic repair	Video centre	Total
Solar-electrified Enterprises	Ent. size	2	3	5.5	2	2.5	3	-	
	Age of owner.	30-39	30-39	30-39	40-49	20-29	30-39	-	
	Male Female	12 -	2 1	2 -	1 1	2 -	1 -	- -	20(91%) 2 (9%)
	% Sampled	12(54.5%)	3(13.6%)	2(9.0%)	2(9.0%)	2(9.0%)	1(4.5%)	-	22 (100%)
	Monthly purchases	US$ 217	US$ 163	US$ 109	US$ 217	US$ 490	US$ 163	- -	

Table 3. Barriers to the use of solar pv by household

	Barriers to the Sustainable Use of Solar PV						
	Most severe	**More severe**	**Severe**	**Somewhat severe**	**Less severe**	**Not Ranked***	**Total**
Lack of end-user financing	11	12	11	28	13	21	96
Limited government support	22	7	19	13	13	22	96
High price of components/ parts	12	21	25	17	11	10	96
High monthly service fees	14	10	8	9	14	41	96
Unavailability of solar components on the market	32	28	14	12	7	3	96
Lack of trained technicians	5	11	10	13	16	40	96
Lack of information	3	4	6	4	22	57	96

*Not ranked = response was not ranked among 1-5 rankings

3.2.1 Weighted Mean Score

To provide a clear picture to reflect the rankings of the barriers, the results in Table 3 were further analysed by using a barrier ranking of 1-5, with 1 being less severe; 2 being somewhat severe; 3 being severe; 4 being more severe and 5 being most severe. Adding the individual weighted responses and dividing by the sum of the weights, the mean severity scores were obtained as shown in Table 4. The mean severity scores were calculated as follows: For example considering the response: Unavailability of solar components on the market**,** the weighted responses are (32x5) + (28x4) + (14x3) + (12x2) + (7x1) = 345. The sum of the weighting factors equals 5+4+3+2+1 = 15. The mean severity score was calculated by dividing the 345 by 15 to obtain a score of 23.0. The calculations of the severity scores of the other barriers follow the same steps.

Table 4. Barriers to the use of solar pv by weighted mean scores

Barriers	**Mean Severity Scores**
1. Unavailability of solar components on the local market	23.0
2. High price of solar PV components	17.6
3. Limited government support	15.6
4. Lack of end-user financing	13.7
5. High monthly service fees	11.1
6. Lack of trained technicians in the community	9.4
7. Lack of user information on costs and benefits	5.3

3.2.2 Pareto's Analysis

Using Pareto's analysis, Figure 1 demonstrates the barriers identified by the study. The length of a bar stands for (or is proportional to) the mean severity score. More severe barriers (longest bars) are positioned to the left of less severe barriers.

The Pareto chart revealed that by far the important few barriers accounting for most of the problems are ranked in the following order:

(1) Unavailabilty of solar components on the local market
(2) High price of solar parts/components
(3) Limited government support
(4) Lack of end-user financing

Unavailability of Solar PV Parts on the Market

Figure 2 indicates that all the communities responded that solar components were not available with the exception of Kpassa, where 14% of the solar-electrified households reported of local availability, while 11% responded that solar PV components were not locally available.

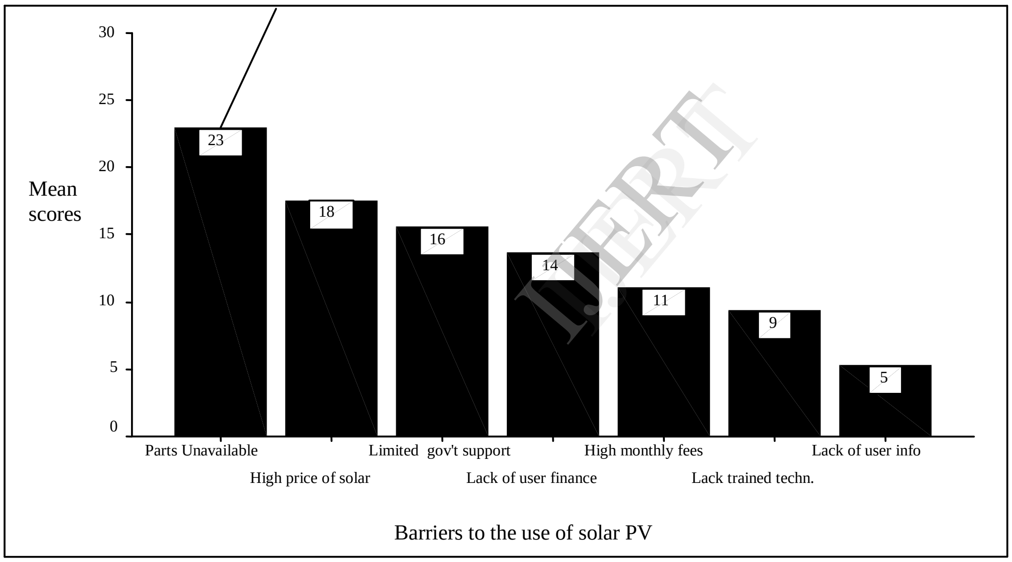

Figure 1: Pareto chart: barriers to the use of solar pv in surveyed households

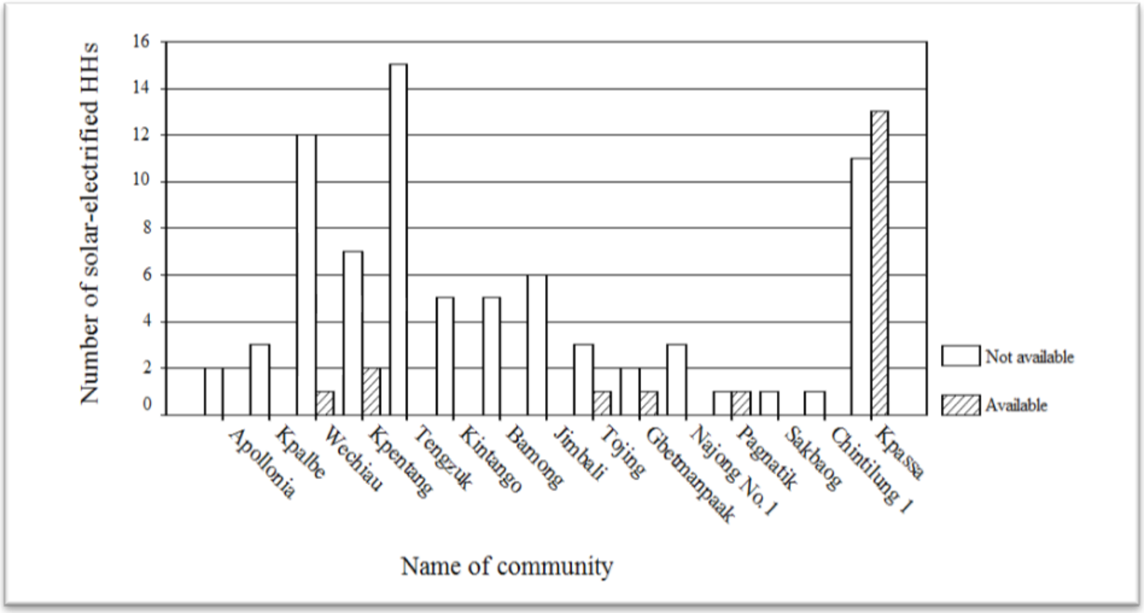

Figure 2. Availability of solar components on the local market by community

High Price of Solar Components

Evidence from the study revealed that high price of solar components on the local market was a barrier to the use of solar PV. The selling price of car batteries used in Solar PV was about US$60-150 and compact fluorescent lamp (CFL) was being sold at US$5- 13. Compared to the price of incandescent bulbs used in grid-electrified households, solar PV lamps were expensive. Figure 3 depicts the prices of 5-10 watts solar dc lamps sold at US$ 4.4-13 and 20-100 watts incandescent bulbs sold at US$0.33-2.72.

Limited Government Support

With a mean severity score of 15.6, limited government support was ranked as the third severe barrier to the use of solar PV in the surveyed communities. The results presented in Table 4 indicated that about 50% of the solar-electrified households reported it was severe to most severe (23% said most severe; 7% said more severe; and 20% said severe). About 14% considered this a less severe barrier, while 22% did not rank it as a barrier.

Lack of End-User Financing

From the weighted mean scores presented in Table 4, lack of end user financing scored 13.7 and was ranked the fourth barrier. From the results in Table 3, about 35% said lack of end-user financing spans from severe to most severe; 21% said it was somewhat severe; while about 14% said it was less severe. Of the 96 households with solar PV, only 21 (22%) did not rank end-user financing as a barrier (Table 3).

Faulty Component Parts at the Enterprise-level

Frequent occurrence of faulty system components can affect the sustained interest of end-users to use solar PV systems to enhance their income generation opportunity after dark. When asked about problems affecting the use of solar PV in the enterprises, the responses revealed that the PV system components causing most problems to the solar-electrified enterprises were batteries and regulators. Overall 86% of the reported problems were on batteries and regulators as shown in Figure 4.

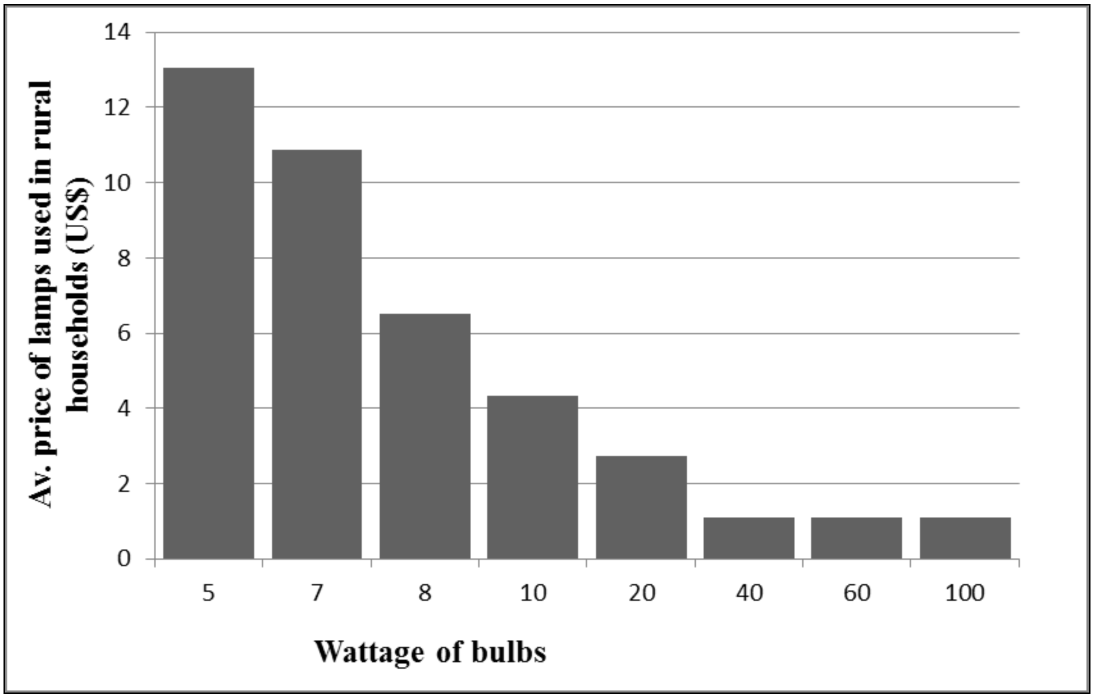

Figure 3. Prices of 12v dc solar lamps (5-10w) compared to 230v, ac lamps (20-100 w).

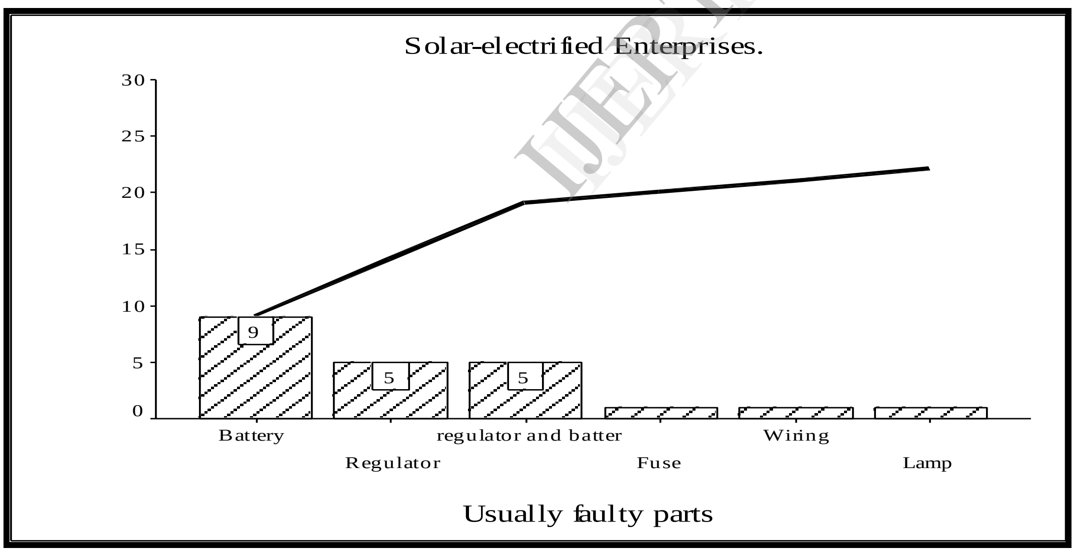

Figure 4. Faulty parts of solar pv at the enterprise level.

Factors Limiting the Extension of Working Hours by Rural Enterprises

Using Pareto's analysis, the factors that limited the enterprises from extending their working hours and hence the possibility of gaining additional income are analysed. The results in Figure 5 revealed that the principal factor that prevented the solar-electrified enterprises from extending their working hours was power fluctuation in the evening during the rainy seasons in June-August. This is indicated by the response: lamp off during low sunshine hours.

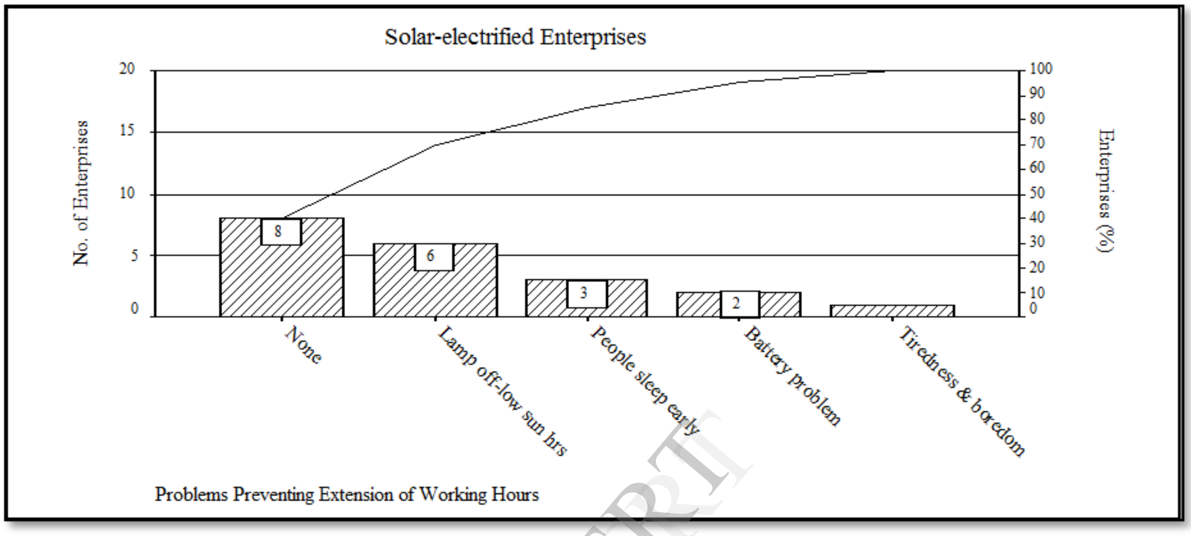

Figure 5. Problems preventing the enterprises from extending working hours

3.3 Priority Areas for Increased Use of PV

When asked whether the present use of household solar PV system would increase or decrease, the results in Table 5 revealed a declining use of solar PV in almost all the surveyed communities with the exception of the Kpassa community. Overall about 63 % of the solar-electrified households felt the present use of solar PV was likely to decrease, while 37% was optimistic that it will increase. However, on the future need for household solar PV systems almost all the surveyed communities were optimistic, reporting of more percentage increase than decrease, with the exception of the Wechiau community. Overall, about 62% of the solar-electrified households were hopeful that the future need for solar PV would increase.

3.3.1 Factors Contributing to Increased Use and Maintenance

Examining the factors that could contribute to increased future use and maintenance of solar home systems, the responses of 96 solar-electrified households are presented in a Pareto's chart in Figure 6. The chart showed seven bars of differing heights. The bars revealed consistent decrease in the height of the first four bars with a break point after the fourth bar (labeled end-user financing). This indicated the relative importance of the first four bars as the priority factors that can increase the future use and maintenance of solar home systems: (1) low pricing of parts; (2) availability of parts on the local market; (3) low monthly fees; and (4) access to end-user financing.

Table 5. Present and future need for household pv systems

Present use of household solar PV systems.	**Study Location**						**Total**
	Kpalbe	**Wechiau**	**Bunkp Area*.**	**Tengzuk**	**Kpassa**	**Apollonia**	
Increase	3.1%	2.1%	6.3%	4.2%	20.8%	1%	37.5%
Decrease	0	11.5%	34.3%	11.5%	4.2%	1%	62.5%
Total	3.1%	13.6%	40.6%	15.7%	25%	2%	100%
No. of Households	3	13	39	15	24	2	96
Future need for household solar PV systems.							
Increase	3.2%	3.2%	23.1%	10.5%	20%	2.1%	62.1%
Decrease	0	10.5%	17.9%	5.3%	4.2%	0	37.9%
Total	3.2%	13.7%	41%	15.8%	24.2%	2.1%	100%
No. of Households	3	13	40	15	23	2	96

* Bunkpurungu area comprises: Kpentang; Kpenbung; Kambatiak; Bamong; Kintango; Chintilung; Tojing; Jimbali; Gbetmanpaak; Najong No.1; Pagnatik.

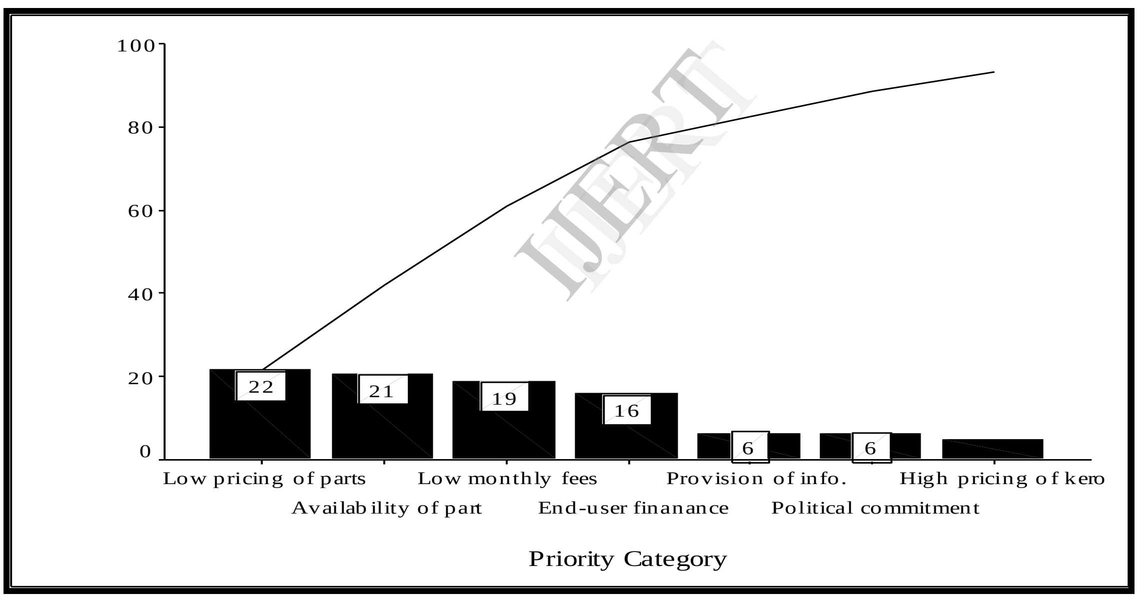

Figure 6. Priority factors for increased future use of Solar home systems

4. Discussion

4.1 Barriers

It is worth bearing in mind that some specific impediments can prevent the development of new markets for the widespread use of solar PV. Such impediments are considered as barriers that can prevent the effective use of solar PV for quality of life and productive improvements of the rural poor. In examining the responses to the question on barriers, the initial results did not provide a clear picture to reflect the rankings of the barriers. There was therefore the need to further analyse the barriers using weighted mean scores and Pareto's chart. Using Pareto's analysis vital few important barriers could be separated from the trivial many [17, 18, 19].

From the results, the Pareto chart revealed four specific barriers. These barriers were ranked in the following order: unavailability of solar components on the local market; high price of solar PV components; limited government support; and lack of end-user financing. Bearing in mind budgetary constraints and limited resource allocations in most developing countires, ranking the specific barriers to the use of solar PV in rural Ghana is major contribution to knowledge. This study has clearly filtered from the variety of barriers to the expansion of renewable energy that are reported in earlier studies on developing countries [7, 8, 9, 16].

Basic solar PV components such as batteries, lamps, and regulators were scarce in the surveyed communities. Reasons may be due to lack of established markets and limited sales outlet [20, 21]. The local trading in solar PV components has not been very encouraging because of low patronage. Therefore component parts were not readily available on the local market. Unavailability of solar components is therefore the first barrier to tackle. Overcoming this barrier will yield the highest benefit to prospective users of solar PV in off-grid rural communities.

High per unit price of solar PV electricity is also reported as a barrier to sustainable use and expansion [22, 23, 24]. This barrier was overcome as a result of the fee-for-service approach. However, the study revealed that high price of solar components on the local market was a severe barrier to the use of solar PV. Due to the higher prices of (60-70Ah) car batteries, which were sold at about US$ 54-150 and a typical CFL lamp sold at US$ 5 with some as high as US$13, it is likely that some of the low income consumers switched back to kerosene lanterns as they could not afford the replacement costs of about US$3 per month. Compared to the price of incandescent bulbs US$ 0.33-2.72 used in grid-electrified households, the solar dc lamps were costly.

The study results revealed that about 17 % of the solar-electrified household heads earned up to US$1.08 per day (about US$30 per month). Comparing this income level to the maintenance cost of approximately US$3 per month, one could infer the financial pressure on the poor if they have to allocate a substantial part of their agricultural-based income to the maintenance of PV systems. It is recommended that in order to overcome enegy poverty, poor households should not spend more than one tenth of their income to meet elementary individual energy requirements [23]. As the price of the components rises, low income and less enthusiastic consumers are likely to fall out of the market, leaving the high income earners or more enthusiastic users [25].

In analysing the study results, though 17 % of the households income hovered around US$1 per day, low income status was not identified among the major barriers to sustainable use of solar PV in rural Ghana. On the basis of the scoring method in Table 4, high price of solar components on the market is the second barrier to remove. The removal of this barrier will produce bigger benefits to off-grid rural communities and other stakeholders.

In general, rural people see most community projects as government intervention to provide goods and services for socio-economic development. Consequently, a change in incentive enjoyed within a project is interpreted as a withdrawal of government's support services. In the surveyed communities, the solar-electrifed households felt deceived by the project implementers (known as government officials), because they could not sustain their support services: monitoring visits and replacement of component parts, particularly the batteries. This situation was interpreted as a withdrawal of government's support services. In this context, lack of such support services can be misinterpreted as a denial of basic electricity services from government.

Again, the study revealed that over half (56 %) of the solar-electrified households reported of the lack of end-user financing as a barrier. Other studies have reported of lack of financing as a barrier to the expansion of renewables [7, 8, 9]. Inadequate financing of solar PV projects is among the main constraints inhibiting its widespread use in poor rural communities. This issue is more pronounced in the rural communities because of the low income levels of end-users who are mostly peasant farmers. In the surveyed communities, about 60 % of the beneficiaries were farmers who earned an average income of about US$1.32/day. This average income is close to the absolute poverty line of US$1 per day [26, 27, 28]. Lack of end-user financing is therefore the fourth barrier to tackle. Overcoming this barrier will yield some benefits to the rural poor to improve their quality of life.

At the enterprise level, about 86 % of the reported problems were on batteries and regulators. Therefore priority attention must be focused on these components to improve system reliability and sustainability. The factors that limited the enterprises from extending their working hours and hence the possibility of gaining additional income were also analysed. From the results the principal factor that prevented the solar-electrified enterprises from extending their working hours were: aging batteries and power fluctuation in the evening, particularly during the rainy seasons of June-August. The consequence is that majority of the solar-electrified enterprises combined solar PV and kerosene lantern. The data suggest that system efficiency and continuous supply of power are prerequisite for extension of working hours and additional income generation after sunset.

4.2 Measures to Remove Barriers

From the perspective of this study, the following measures can contribute to remove or mitigate the barriers to the sustainable use of rural PV systems:

- Financial and fiscal incentives (e.g micro credits, soft loans) to motivate the private sector to open retail outlets at the local market. The establishment of sales outlets through enhanced public-private partnership in rural communities can increase the prospects of access to scarce replacement parts (e.g. dc lamps, regulators,lamp fittings, wet batteries).
- Periodic visits by local government representatives (District Assemblies) for firsthand information on utilisation so as to allocate financial resources towards system management and sustainability.
- Temporary short-term subsidy, particularly for the replacement of batteries and repair of regulators, targeting poor households.
- Consistent technical and entrepreneurship-related training of skilled adults in the communities.
- Subsidised monthly fees (up to US$3 per month) covering consumption

and maintenance, particularly for the rural poor who earn up to US$1 per day.

4.3 Priority Factors and Policy Implications

On one hand, there was a fairly high proportion of the solar-electrified households who felt that if the present conditions, namely faulty parts, poor management services among others are not improved the use of rural solar PV systems would decrease. On the other hand, an equally high proportion of the respondents were optimistic that if the present challenges are effectively addressed more rural households are hopeful of using solar PV in the future. The priority factors that can increase the future use of rural solar PV systems were in the following order: (1) low pricing of parts, (2) availability of parts on the local market, (3) low monthly fees, and (4) access to end-user financing. Knowledge of the ranked priority factors is likely to inspire hope for future policy and planning decision making.

To ensure the sustainability of solar PV rural electrification projects, there is the need for institutional support by the District Assemblies in the management of rural PV systems at the community level. A sufficient requirement for sustainable use of PV systems should include a joint action of household members backed by institutional structures to facilitate access to information on good operating practices, maintenance costs and responsibilities. Good operating practices minimize recurring costs and can enhance battery life.

A focus on an effective approach to sustainability should also include strategies that would respond to the differing ability to maintenance. In this regard, low income households should be assisted with cost reduction instruments e.g. capital grant to defray PV system costs and affordable monthly fee-for-service (up to US$3 per month). On the contrary, rural enterprises are likely to afford maintenance costs, but would also require access to micro-credits and better quality batteries and lamps to enhance the opportunity for additional income generation. The lack of substantial uses likely to enhance income generation may create less possibility for the sustainable use of solar PV systems.

Though lack of technicians was not among the 'vital few' barriers, it was however, ranked as the sixth barrier to the sustainable use of solar PV systems. The data suggest that human resource development is an essential component for sustainability. Capacity building aimed at human resource development should include the retraining of technicians on quick response to faults and quality service delivery. Furthermore, rural technicians should be provided with financial incentives to diversify their income sources in order to commit themselves to the maintenance of PV systems. The creation of a community-based organizational framework (e.g. Local Energy Development Agency) by the Ministry of Energy in collaboration with the Energy Commission and the District Assemblies will clarify the question of who should be responsible for monthly user-fee collection, routine maintenance, and end-user education and the form they should take. A concerted effort on these actions would yield the benefits expected from the sustainable use of public solar PV systems.

5. Conclusion and Recommendations

This study established and ranked the major barriers to the sustainable use of solar PV in rural Ghanaian households in the following order: unavailability of solar components on the local market, high price of solar PV components, limited government support, and lack of end-user financing. At the enterprise level the principal factor that limited enterpreneurs from extending their working hours with the possibility of gaining additional income after sunset were aging/defective batteries and power fluctuation in the evening during the rainy seasons. This made majority of the solar-electrified enterprises to combine the use of solar PV and kerosene lantern.

Measures to remove the barriers include among others the establishment of sales outlets through enhanced public-private sector support services, periodic visitations by local autorities for first hand information on utilisation so as to allocate financial resources towards system management, temporary subsidies for maintenance and repair, capacity building and affordable monthly fees. To support income generation in rural enterprises there is the need to put in place mechanisms to ensure system efficiency and continuous supply of power to achieve extended working hours after sunset and additional income generation.

For future deployment of rural solar PV systems, a sufficient requirement for sustainable use, particularly at the household level should include a joint action of household members backed by institutional structures to facilitate the provision of information on good operating practices, maintenance costs and responsibilities. A focus on an effective approach to sustainability should also include strategies that would respond to the differing ability to maintenance and repairs, which vary between enterprises and households. Low income households, in particular, should be assisted with cost reduction measures to encourage uptake and widening of access. The priority factors that can increase the future use of rural solar PV systems are low pricing of parts, availability of parts on the local market, low monthly fees, and access to end-user financing. This study lays down the direction for sustaining off-grid rural PV systems.

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