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Impacts of public solar PV electrification on rural micro-enterprises: The case of Ghana

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ABSTRACT

Micro-enterprises are a key component in rural enterprise creation and income generation. In rural areas far removed from grid-electricity, public solar photovoltaic (PV) electrification projects have served useful purposes by contributing to improve the economic activities of micro-enterprises beyond daylight hours. Through fee-for-service approach some rural micro-enterprises in Ghana were provided with access to solar PV systems to enhance their output. It is expected that the effect of solar PV electrification on enterprise output would be of research interest. However, the relationship is under-researched. Hence, there is lack of data particularly quantitative ones to show the benefits that can be derived from the sustainable use of solar PV to electrifiy rural micro-enterprises. Using systematic sampling and developing a set of enterprise-level indicators, micro-enterprises with and without solar PV were surveyed in eight rural communities in five regions of Ghana. The results revealed that the cost avoided by using solar PV in the enterprises instead of kerosene lanterns was US$1–5/month. The results established a statistically significant association between solar PV lighting and additional income after sunset of US$ 5–12/day in grocery (merchandise) enterprises. Without the external lighting of solar-electrified enterprises, the businesses of about two night vendors were affected. Further to the impacts on income and cost savings the study discussed affordability, factors preventing the extension of working hours after sunset and sustainability issues.

Introduction

This paper presents the impacts of solar photovoltaic (PV) electrification on micro-enterprises located in off-grid rural areas of Ghana. According to the definition of the National Board for Small Scale Industries (NBSSI) in Ghana, micro-enterprises are the very small businesses that employ less than six people (Osei et al., 1993; Dalitso and Quartey, 2000). In recent years, micro-enterprise and enterprise development have become key components in rural enterprise development and income generation into rural economies. Rural areas in particular face more economic obstacles due to geographic isolation, changing economies, lack of resources and environmental degradation (Dabson and Woodroofe, 2008). As incomes increase, rural populations are better able to afford greater levels of services including energy to support the growth of local economies (Martinot et al., 2002). To foster economic growth as well as improve quality of life of families, the Government of Ghana (GoG) recognises the need to diversify the national energy mix to take account of renewables such as hydro, wind, solar PV (Daily Graphic, 2004, NDPC, 2005; Ministry of Energy, 2006; NDPC, 2008).

Solar PV electricity can support rural micro-enterprises to generate additional income by extending their working hours after dusk (Grameen Communications, 1999; Allderdice and Rogers, 2000; DFID 2002). However, effective usage of renewable energy for rural economic development are among the under-researched areas in Ghana. Hence, there is lack of both qualitative and quantitative data to show the benefits that can be derived from the sustainable use of solar PV to make living and working in rural Ghana more attractive. Any system that rewards rural entrepreneurs to effectively use energy services needs to be pursued.

In light of this, the study is guided by the following specific objectives. First, to identify and select indicators that can be used to measure the association between solar PV electrification and rural enterprise output. Second, to analyse the impacts of solar PV electrification on micro-enterprises located in off-grid rural Ghana and make recommendations for sustainable use.

Study areas and methodology

Study areas and methods

First, a set of enterprise-level indicators for measuring economic outputs were developed through expert consultation, reconnaissance survey and extensive literature review. The use of the indicators enabled

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a more complete description of the change between the project group (*micro-enterprises with solar PV*) and control group (*micro-enterprises without solar PV*). Second, a generic interviewer-administered questionnaire based on the indicators was designed for rural micro-enterprise surveys during the months of November 2005 to February 2006. The 50 enterprises surveyed in this study were part of a survey of about 308 households, enterprises and community level projects with and without solar PV in rural and peri-urban Ghana. The enterprise-level questionnaires were administered in eight communities (Wechiau, Kintango, Kpassa, Apollonia, Najong, Kpalbe, Binde, Asekye/Tom) located in six districts in five regions of Ghana, namely Northern, Upper West, Volta, Brong Ahafo and Greater Accra regions. Fig. 1 is the map of Ghana showing the regions.

A list of project beneficiaries (solar-electrified enterprises) and incoming/potential beneficiaries (non-electrified enterprises) obtained from the solar cooperatives in the communities was used to select the enterprises using systematic random sampling technique. However, electronic repair and spare parts enterprises were purposively sampled due to their meagre number in all of the rural areas. At the time of the study, several PV systems were damaged by wind, some were stolen, and others had relocated to unspecified locations. Therefore, based on the selection criteria, about 37 solar-electrified enterprises and 39 non-electrified enterprises in the study areas qualified for the impact study.

Research assistants from the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana who speak the local languages of the respondents (owners or managers) were engaged in the administration of the questionnaires. The purpose of the questionnaires was to gather ex-post information on how solar PV electrification contributes to the productive improvements of off-grid micro-enterprises. The questionnaires contained 91 variables including indicators on: demographic data, technology functionality, energy sources used and economic impacts. They were administered to 50 micro-enterprises (25 solar-electrified enterprises and 25 non-electrified enterprises). This sample size is sufficient for data analysis due to (1) the low proportion of micro-enterprises in rural Ghana, particularly solar-electrified ones and (2) their relative economic importance to rural development. Several authors consider sample sizes ($N \geq 30$) as statistically large samples (McClave and Benson, 1988; Spiegel and Stephens, 1999).

Fig. 1. Map of Ghana showing the study regions.

Selection criteria

The rural communities selected for the study were off-grid communities that were not covered under the Self Help Electrification Project (SHEP) because of their locations. They were selected for the fieldwork because the two major public sector solar PV electrification projects (MOE/Spanish Funded Solar PV Electrification Project and UNDP-GEF/RESPRO) in Ghana were implemented in their regions from 1998 to year 2003. Hence they were suitable locations for the impact study. From different lists of the beneficiaries of solar PV electrification projects in rural Ghana, the following criteria were adopted: (i) projects that have been operational in the rural terrain for over three years; and (ii) those that had not been earmarked by the Ministry of Energy for relocation were selected. These criteria were based on the assumption that over a three-year period, PV system components such as car battery (lasts for about 2–3 years), fluorescent lamp (lasts up to 1.5 years[1]) etc. would have gone through a cycle of operation and maintenance (O&M).

Underlying assumptions and statistics

The underlying assumptions that govern the interpretation of the study results were that since the solar-electrified enterprises did not pay for the costs of the installed PV systems, initial investment costs were not considered in the analysis. Secondly, in the absence of the interventions, enterprises 'with' solar PV systems would have experienced a similar energy use situation as those 'without'. Exposure to solar PV electrification might have contributed to a change in the indicators being examined between the two groups. In order to analyse the data, SPSS 11.0 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. To provide understanding of the relationship, descriptive statistics was used for data analysis. Pareto analysis was used to identify the most important problems associated with the use of solar PV at the enterprise level. Statistical significant difference was computed at $p<0.05$.

Results

Characteristics of surveyed enterprises

The enterprises surveyed were generally small-scale employing less than six 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 (74%). Their ages ranged between 20 and 49 years. They have been engaged in their businesses for 3–15 years. Their monthly estimated earnings varied by size, type, season and geographical location. Their earnings ranged from about ¢1,000,000 (US$ 108) per month in tailoring business to over ¢4,500,000 (US$ 490) per month in spare parts business.

The worth of goods purchased per month is used as a proxy for monthly earnings, since some of the owners were not prepared to respond to questions relating to their monthly earnings for fear of taxation etc. It is assumed that the money used for purchases were not loans, but proceeds from their sales. Five enterprise owners declined to provide information on the average worth of goods they could purchase per month. A summary data on the characteristics of the surveyed enterprises is provided in Table 1.

[1] From field data, quality fluorescent lamps imported from Europe (Denmark, Germany) could last up to 1.5 years.

Table 1
Summary data on surveyed enterprises.

		Grocery	Chemical selling	Tailoring	Drinking bar	Spare parts	Electronic repair	Video centre	Total
SEE	Enterprise 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	13	3	2	1	2	1	–	22(91%)
	Female	–	1	–	2	–	–	–	3(9%)
	% Sampled	13(52%)	4(16%)	2(8%)	3(12%)	2(8%)	1(4%)	–	25(100%)
	Monthly purchases	¢2,000,000	¢l,500,000	¢1,000,000	¢2,000,000	¢4,500,000	¢l,500,000	–	
		US$217	US$163	US$109	US$217	US$490	US$163		
NEE	Enterprise size	2	2	5	1	–	–	3	
	Age of owner	20–29	30–39	30–39	40.49	–	–	60+	
	Male	8	2	3	1	–	–	1	15(60%)
	Female	7	–	1	2	–	–	–	10(40%)
	% Sampled	15(60%)	2(8%)	4(16%)	3(12%)	–	–	1(4%)	25(100%)
	Monthly purchases	¢l,250,000	¢l,250,000	¢500,000	¢l,500,000	–	–	–	
		US$ 132	US$ 132	US$ 54	US$ 163				

SEE — so1ar-electrified enterprise NEE — non-electrified enterprise.
US$ 1 = ¢9200 (Ghanaian cedis) in 2006.

Enterprise-level indicators

To measure the difference in economic output that is associated with the type of energy services available to a micro-enterprise, a number of key enterprise-level indicators were developed. The indicators sought to measure the change in output associated with the electrification status of the enterprises. Table 2 shows the indicators and assumptions that were used to measure the impacts on the micro-enterprises.

Energy sources used and savings on kerosene in surveyed communities

The pie charts in Fig. 2 showed the following: in the non-electrified enterprises, those using kerosene lantern and dry-cell batteries (about 50%), kerosene lantern and candles (20%), car battery and drycells (8%), while those who used generator to run their video business (16%). In the solar-electrified enterprises, those who used only solar PV (40%), solar PV and kerosene lanterns (36%), while those who used solar PV and dry-cell batteries (24%).

In the surveyed communities, kerosene lantern was the main source of lighting in the evening for both domestic and business purposes. Money not spent on kerosene and therefore 'saved' by enterprise owners is a principal benefit and has an impact on enterprise business. In Table 3, cost savings from using solar PV for lighting instead of kerosene lantern ranged from ¢12,000 (US$ 1.3) in Najong to ¢48,000 (US$ 5.2) per month in Apollonia. Comparing the statistics across the communities revealed differences in estimated cost savings, depending on the type of enterprise. Out of 22 solar-electrified enterprises, 18 (82%) reported cost savings on kerosene fuel. A level of significance of 0.000 ($p<0.05$) of the F-statistics indicates statistically significant difference in response between the two groups of enterprises.

Type of energy system and cost saving on kerosene and dry-cell batteries

Solar PV can replace and reduce the recurrent costs associated with the use of kerosene lanterns and dry-cell batteries. The results in Table 4 revealed that 100 Wp solar-electrified enterprises are likely to save an average of ¢30,700[2](US$ 3.34) per month on kerosene and dry cell, while 50 Wp electrified enterprises are likely to save ¢27,250 (US$ 2.96) per month. The standard deviation values of the data indicate that cost savings on kerosene consumption is more variable for the 50 Wp solar-electrified enterprises than those with 100 Wp system. The measure of association (Eta squared = 0.509), indicates an association between the use of solar PV in enterprises and monthly savings on kerosene.

Enterprise electrification status and extended working hours

The availability of quality lighting after sunset can increase the likelihood of off-grid rural enterprises to extend their working hours and generate additional income. The results in Table 5 showed that though there were slight variations in daily extended hours among the surveyed enterprises, both solar-electrified and non-electrified enterprises extended their working hours beyond daylight hours (after 6:00–6:30 pm) by 1–5 h per day. Assuming equal variance on the basis of the Levene's test significance value of 0.883 ($p>0.05$), the t-test significance value of 0.421 ($p>0.05$) indicates no significant difference in the average extended working hours per day between the two groups of enterprises.

Test of hypothesis: electrification status and additional income after sunset

The purpose of the hypothesis test is to examine whether there exists an association between enterprise electrification status and additional income after sunset. Enterprise owners are certainly interested to know how much additional income they can generate by extending their working hours beyond daylight hours. It is recognized that impact predictions can rarely be precisely quantified (Pearce, 2002; Paris et al., 2002). Therefore, to have a plausible estimate of the extra income after sunset, the study used different questions to work out the estimated monies

Table 2
Enterprise-level indicators.

Indicators	Assumptions
1. Type of energy sources used in enterprise	1. Reliable energy sources conthbute to output
2. Estimated monthly cost savings on energy services	2. Savings on energy services can be reinvested
3. Extended working hours due to lighting services	3. More hours may result in extra income
4. Increased income associated with lighting services after sunset	4. Increased income improves business and wellbeing
5. Number of night vendors likely to benefit from enterprise external lighting	5. More micro-enterprises improve local economy
6. Frequent faulty parts and affordability	6. Justification for sustainability efforts
7. Percent reporting of problems preventing extension of working hours	7 Rationale for planning and evaluation review

[2] The currency of Ghana is cedis (¢). And ¢24,000–30,000 (US$ 2.60–3.33) was the average selling price of 1 gallon of kerosene (4.5 liters) during the enterprise-level survey in February 2006.

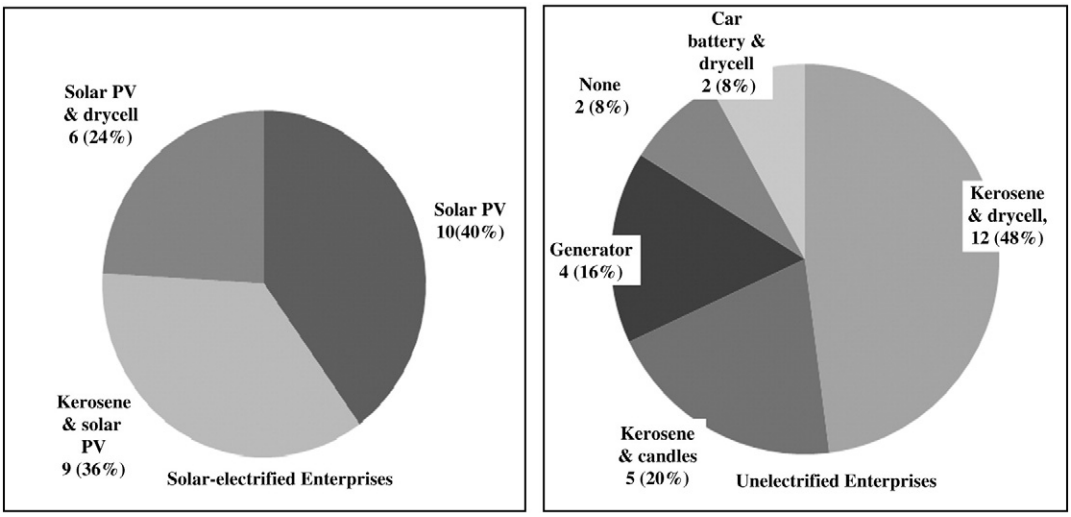

Fig. 2. Type of energy sources used in surveyed enterprises.

added to daily income as a result of availability and use of enterprise lighting after sunset.

To make any inference as to whether enterprise electrification status has an association with additional income generation after sunset, a hypothesis test is carried out. The hypothesis testing was done on the premise of a null hypothesis (H_o) that there is no relationship between enterprise electrification status and increased mean daily income after sunset against the alternative hypothesis (H_a) that solar-electrified enterprises are likely to increase mean daily income after sunset.

In Table 6 the results of the relationship between mean daily income after sunset, type of enterprise and electrification status are shown. In this analysis, equal variance is not assumed because of the Levene's statistics significance value of 0.005 ($p<0.05$). The mean incomes after sunset were: solar-electrified enterprises (mean $\bar{x}_1 = ¢74{,}764.82$) and non-electrified enterprises (mean $\bar{x}_2 = ¢41{,}047.71$). A two-tailed significant value of 0.015 ($p<0.05$), indicates statistically significant difference in mean income after sunset between the two groups of enterprises. The results in Table 6 revealed that by overall average the solar-electrified enterprises generated more income after sunset than the non-electrified enterprises ($\bar{x}_1 > \bar{x}_2$). The observed value of the t-test $t = 2.617$ exceeded the critical value (tabulated value) $t_{0.05} = 1.708$, hence the difference in mean income after sunset is significant at 0.05 (95% confidence).

Introducing type of enterprise as a layer variable, Table 7 revealed the particular type(s) of solar-electrified enterprises that positively associated with mean daily income after sunset. The results showed differing mean incomes across type of enterprise and community. In the cases of the tailoring and chemical sellers, data were insufficient to compare two separate communities.

Overall grocery enterprises revealed consistent differences in mean extra incomes earned by both solar-electrified and non-electrified enterprises in two separate communities where data were available for comparison. For example, the mean daily incomes of grocery enterprises in Nkwanta [solar-electrified — ¢114,000 (US$ 12.4); non-electrified — ¢47,000 (US$ 5)] can be compared to Bunkpurungu [solar-electrified — ¢50,000 (US$5.4); non-electrified — ¢21,000 (US$ 2.3)]. A significant value of 0.20 ($p>0.05$), indicates no significant difference in mean income values between the groups.

Enterprise lighting services and night vendors

The availability of quality source of external lighting in off-grid rural communities can provide an opportunity for night vendors to spend less on kerosene lantern for lighting. In the surveyed communities, night vendors[3] especially women usually sold items such as bread and beverage, fruits, porridge, groundnuts etc. in front of or near a micro-enterprise as a way of benefitting from the external lighting. Without the external lighting of some enterprises the business activities of some night vendors were affected after sunset. This information was triangulated by asking the night vendors. Table 8 revealed that 2 night vendors would be affected without the external lighting of solar-electrified enterprises, while only 1 would be affected without the external lighting of non-electrified enterprises. In all the communities, relatively more vendors would be affected without the external lighting of solar-electrified enterprises. A significant value of 0.021 ($p<0.05$), indicates that the observed difference is statistically significant. However, the amount of variation in the number of vendors who would be affected that is explained by electrification status is relatively small (Eta squared = 0.112).

Sustainability issues: faulty parts and affordability

Faulty component parts. 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 in Fig. 3 revealed that the PV system components causing most problems to the solar-electrified enterprises were batteries and regulators. Overall 19 (87%) of the reported problems were on batteries and regulators. Therefore priority attention must be focused on these components to improve system reliability and sustainability.

Affordability of component parts. The ability to repair or replace faulty components is influenced by the income generation opportunities derived from the use of an energy delivery system in rural enterprises. When asked whether the owners could afford to buy the component parts when their energy delivery systems were faulty, the results in Table 9 indicated that 80% of the solar-electrified or the non-electrified enterprises expressed that they could manage to pay for the cost. A high significance Pearson chi-square value of 0.874 ($p>0.05$), indicates no significant difference in the response between the two groups of enterprises.

[3] In this study night vendors refer to table-top sellers of foods, beverages, fruits etc. who site their tables near an enterprise (retail store, drinking bar etc.) mainly to benefit from their external lighting after sunset or daylight hours.

Table 3
Monthly savings on kerosene by electrification status and community.

How much savings on kerosene in a month can you estimate?							
Enterprise electrification status	Name of village	Mean (cedis)	Median (cedis)	Minimum (cedis)	Maximum (cedis)	Std. Deviation (cedis)	N
Solar-electrified enterprise	Kpassa	38,143	40,000	16,000	60,000	14,404	7
	Apollonia	48,000	48,000	48,000	48,000		2
	Kpalbe	20,000	20,000	10,000	30,000	14,142	2
	Wechiau	34,000	30,000	24,000	48,000	12,490	3
	Najong	12,000	12,000	9,000	15,000	4243	2
	Binde	14,667	15,000	14,000	15,000	577	3
	Asekye/Tom	20,000	20,000	10,000	30,000	14,142	3
	Total	29,167	29,000	9000	60,000	15,629	22
Non-electrified enterprise	Kpassa	0	0	None	None	0	12
	Apollonia	0	0	None	None	0	2
	Wechiau	0	0	None	None	0	3
	Najong	0	0	None	None	0	3
	Kintango	0	0	None	None	0	1
	Total	0	0	None	None	0	21

F- value = 73.467, df. = 1, Sig. = 0.000.

Factors limiting the extension of working hours

Using Pareto's analysis, in the context of electrification, the factors that limited the enterprises from extending their working hours and hence the possibility of gaining additional income are analysed.

The results in Fig. 4(a) revealed that the principal factors that prevented the solar-electrified enterprises from extending their working hours beyond daylight hours were: (1) power fluctuation due to insufficient sunlight in the evening during the rainy seasons of June–August when the sky is often covered with clouds; (2) people sleep early; and (3) battery problem. In the non-electrified enterprises as indicated in Fig. 4(b), the main factors causing most problems were: (1) poor lighting (brightness) of kerosene lantern; and (2) cost and scarcity of kerosene in the communities.

Discussion

Energy sources used in surveyed enterprises

The enterprises covered in this survey relied on various sources of energy to meet their daily electricity needs. The study results revealed that the non-electrified enterprises relied on a number of energy sources, namely kerosene lanterns, dry-cell battery, generator, car battery and candles. However, kerosene lanterns, dry-cell batteries and generators were the predominant energy sources. In the case of the solar-electrified enterprises, two out of every five enterprises relied solely on solar PV systems. Majority of the solar-electrified micro-enterprises combined solar PV and kerosene lanterns to extend their working hours throughout the year as a result of: power fluctuation due to low sunshine hours during the rainy seasons, aging batteries, long system downtime, and difficulty in obtaining replacement parts.

It is understood that without a reliable source of light, there is the likelihood for enterprise owners to switch back and forth between kerosene lanterns and solar PV to fill in when PV power supply fails (Obeng, 2008). And this could affect the extension of the activities of rural micro-enterprises after sunset. Lighting emerged as the most significant output interacting to achieve impact. Several authors have noted that lighting is a productive application of renewable energy in off-grid rural areas (Fishbein, 2003; Kapadia, 2004; Martinot, 2001). Productive use of energy is simply defined as any use of electricity that helps generate income for the end-user (Kittelson, 1998; Ministry of Energy, 2003; Energy Commission, 2005). It involves the utilization of energy (electric and non-electric) in the forms of heat, or mechanical energy for activities that enhance income and welfare (Kapadia, 2004), for which local people are required to make an investment (UNDP, 2003).

Table 4
Size of lighting system and cost savings on kerosene and dry-cell batteries.

Enterprise electrification status	Size of system	Mean (cedis)	Median (cedis)	Std. deviation (cedis)	Minimum (cedis)	Maximum (cedis)
Solar-electrified enterprise	100 Wp solar PV	30,700	31,500	14,353	9000	50,000
	50 Wp solar PV	27,250	20,000	17,910	10,000	60,000
	Total	29,166	29,000	15,623	9000	60,000
Non-electrified enterprise	None	0			None	None
	1 lantern	0	0	0	None	None
	2 lanterns	0	0	0	None	None
	3 lanterns	0	0	0	None	None
	Total	0	0	0		

F = 41.404, Sig. = 0.000, Eta = 0.713, Eta squared = 0.509.

Estimated cost savings on kerosene

The amount of money avoided by using solar PV in the rural enterprises instead of kerosene lantern ranged from US$ 1.3 per month in Najong to US$ 5.2 per month in Apollonia (Table 3). The variation in estimated savings results from several factors including type, size, location of enterprise, PV system capacity among others. The enterprise in Apollonia, which consists of a drinking bar and a merchandise goods store, appears to have saved relatively more on kerosene consumption than all others. Using a 100 Wp PV system, two kerosene lanterns that were previously used for lighting the stores were replaced and this resulted in a relatively high monthly savings on kerosene. This is a significant benefit to the enterprise because in the rural areas the expenditure on kerosene is a major concern.

The data revealed that on average, rural enterprises using a 100 Wp capacity solar PV system are likely to save about US$ 3.34 per month on kerosene consumption, and those using 50 Wp PV system about US$ 2.96 per month (Table 4). Both estimated monthly savings exceed the monthly fee-for-service[4] repayments by US$ 0.63 and US$ 1.33 respectively. All things being equal, excess of savings of US$ 0.63 when saved for 4.5 months can settle up one month fee-for-service of a 100 Wp system. Similarly, excess of savings of US$ 1.33 when saved for 1.5 months can defray one month fee-for-service of a 50 Wp system. These micro-level data provide some insights and understanding

[4] Monthly fee-for-service was ¢25,000 (US$ 2.71) for a 100 Wp system and ¢15,000 (US$ 1.63) for a 50 Wp system in the year 2006.

Table 5
Extended daily working hours by enterprise electrification status.

Enterprise electrification Status	Type of enterprise	Energy sources used for the enterprise	Extended hours (mean)	Extended hours (median)	Std. deviation	N
Solar-electrified enterprise	Grocery trading	Solar PV	2.0	2.0	0.8	4
		Kerosene and solar PV	3.2	3.0	1.3	6
		Solar PV and dry-cell	4.3	5.0	3.1	3
	Chemical selling	Solar PV	1.0	1.0		1
		Kerosene and solar PV	2.5	2.5	3.5	3
	Tailoring	Solar PV	5.0	5.0		1
		Solar PV and dry-cell	4.0	4.0		1
	Drinking bar	Solar PV	3.0	3.0		1
		Solar PV & dry-cell	2.0	2.0		2
	Spare parts	Solar PV	3.0	3.0		1
		Kerosene and solar PV	0.0	0.0		1
	Electronic Repairing	Solar PV	2.0	2.0		1
		Total	2.8	2.5	1.8	25
Non-electrified enterprise	Grocery trading	None	0.0	0.0		1
		Kerosene	3.0	2.0	1.7	3
		Dry-cell battery	4.0	4.0		1
		Generator	3.0	4.0	2.6	3
		Kerosene and dry-cell	3.8	3.5	0.9	6
		Kerosene and candles	4.0	4.0		1
	Chemical selling	Kerosene	5.0	5.0		1
		Car battery	5.0	5.0		1
	Tailoring	None	0.0	0.0		1
		Kerosene and dry-cell	3.3	4.4	1.2	3
	Drinking bar	Kerosene and dry-cell	4.0	4.0	1.0	3
	Video centre	Generator	0.0	0.0		1
		Total	3.2	4.0	1.73877	25

Equal variance assumed. Levene's test Sig. = 0.883 t = 0.813 Sig. (2-tailed) = 0.421.

of the benefits and impacts that can be derived by sustaining the use of solar PV for rural enterprise development and growth.

Enterprise electrification status, extended hours and income

From the results it appears that the availability of light after sunset is a major factor for extending working hours in off-grid rural enterprises. Nevertheless, the results did not indicate any statistically significant difference between the extended working hours of rural enterprises using solar PV lighting and those using kerosene lanterns. Despite the fact that the non-electrified enterprises depend mainly on kerosene lanterns for lighting they equally stay up to 5 h in order to compete for working customers, particularly farmers who buy their items after daylight hours when they return home from work.

Table 6
Mean income after sunset, type of enterprise and electrification status.

Enterprise electrification status	Type of enterprise	Additional income mean (cedis)	Std. deviation	No. of cases
Solar-electrified enterprise	Grocery trading	94,100	44,112	13
	Chemical selling	56,667	60,276	4
	Tailoring	50,000	0	2
	Drinking bar	30,000	14,142	2
	Total	74,764	46,727	21
Non-electrified enterprise	Grocery trading	36,308	29,491	13
	Chemical selling	75,000	35,355	2
	Tailoring	53,333	10,408	3
	Drinking bar	26,667	10,408	3
	Total	41,048	28,099	21
Total	Grocery trading	61,435	46,136	26
	Chemical selling	64,000	47,222	6
	Tailoring	52,000	7583	5
	Drinking bar	28,000	10,368	5
	Total	56,132	40,738	42

Measures of association: Eta = 0417, Eta squared0.174.
Levene' s test significance.
Equal vanance assumed F-value = 8.910, Sig. = 0.005, t = 2.753, df = 36.000, Sig. (2-tailed) = 0.009.
Equal variance not assumed (t = 2.617, df 25.023, Sig. (2-tailed) = 0.015.

It is assumed that the benefit of extending enterprise working hours is the additional income that could be obtained by the productive use of energy services that are affordable. According to UNDP (2001) for energy services to be affordable to the poor it has to be for end-uses that are directly productive and income generating. Several studies have concluded that the provision of off-grid renewable energy electricity does little to significantly improve quality of life unless it also enables income generation (Chaurey et al, 2004; Martinot et al., 2002; Etcheverry, 2003; Fishbein, 2003; Allderdice and Rogers, 2000; Pringle and David, 2002). Hence, the study examined the relationship between enterprise electrification status and extra income generation.

The results on mean income after sunset, type of enterprise and electrification status revealed the following: that, on the one hand increased mean income associated with the use of solar PV is observed in the grocery enterprises and drinking bars. On the other hand, the non-electrified chemical selling and tailoring enterprises gained more additional mean income than the solar-electrified ones. However, the total mean incomes of the solar-electrified enterprises exceeded those of the non-electrified enterprises and the difference was statistically significant. In order to make a significant inference about the relationship among type of enterprise, electrification status and additional income there was the need to disaggregate the data into the surveyed communities. By disaggregating the data, the results showed differing mean additional incomes from community to community. It was observed that in the cases of drinking bars, chemical selling and tailoring enterprises, data on mean incomes were only available in Bunkpurungu, Wechiau and Bunkpurungu respectively. There was lack of second community level data on mean incomes for comparison.

Given the results shown in Table 7, overall grocery trading enterprises indicated significant differences in additional incomes in the communities where data were available for comparison. For example, at Nkwanta and Kpassa the mean additional incomes of grocery trading enterprises with solar PV exceeded those without solar PV. Though in Kpassa, the solar-electrified drinking bar earned more additional income than the non-electrified drinking bar, data were insufficient to compare with other communities. In Wechiau and

Table 7
Average daily income after sunset by enterprise electrification status.

Type of enterprise	Village	Electrification status	Mean income	Standard deviation	Skewness	N
Grocery trading	Kpassa	Solar-electrified	¢114,000	¢45,284	−0.751	4
		Non-electrified	¢47.777	¢26,822	1.153	9
	Apollonia	Solar-electrified	N/A	–	–	
		Non-electrified	refusal to respond	–	–	1
	Kpalbe	Solar-electrified	¢l00,000	¢28,287	–	2
		Non-electrified	–	–	–	
	Wechiau	Solar-electrified	¢78,333	¢55,752	−1.485	3
		Non-electrified	refusal to respond	–		1
	Bunkpurungu area[a]	Solar-electrified	¢50,000	–	–	1
		Non-electrified	¢21,000	¢19,799	–	2
Chemical selling	Kpassa	Solar-electrified1	¢60,000	¢84,853	–	2
		Non-electrified	–	–	–	
Tailoring	Wechiau	Solar-electrified	¢50,000	–	–	1
		Non-electrified	¢75,000	¢35,355	–	2
	Kpassa	Solar-electrified	N/A	–	–	
		Non-electrified	¢65.00O	–	–	1
	Apollonia	Solar-electrified	N/A	–	–	
		Non-electrified	¢45,000	¢45,000	–	1
	Bunkpurungu	Solar.electrifled	¢27,500	¢31,820	–	2
		Non-electrified	¢50,000	–	–	1
Drinking bar	Kpassa	Solar-electrified	–	–	–	
		Non-electrified	¢8,533	–	–	1
	Bunkpurungu area[a]	Solar-electrified	¢30,000	¢14,142		2
		Non-electrified	¢26,667	¢10,408	–	2
Spare parts	Kpassa	Solar-electrified	¢25,000	¢35,354	–	2
		Non-electrified	N/A		–	
Electronic repair	Kpassa	Solar-electrified	¢60,000	–	–	1
		Non-electrified	N/A		–	
TOTAL						41

Note:
Between groups (combined): df = 1, F = 5.863, Sig. = 0.20
Measure of association: Eta = 0.362, Eta squared = 0.13 1.
[a] Bunkpurungu area comprised Binde, Najong and Kintango.

Najong, additional incomes of the chemical selling and tailoring enterprises without solar PV exceeded those with solar PV respectively. This suggests that additional income generation in these enterprises does not necessarily depend on access to better quality light such as solar PV light. These services are generally patronized when people need them and therefore lighting may be of relatively less significance except in certain seasons.

On the basis of the data, the empirical results of this study support the alternative hypothesis that in off-grid rural communities, grocery enterprises using solar PV are likely to increase daily income after sunset than those without**.** It is concluded that though both solar-electrified and non-electrified enterprises extended their working hours after sunset, it is only in grocery enterprises with solar PV that the additional income values provide convincing evidence in favour of the alternative hypothesis. The outcome of this inference is a major contribution to knowledge on the application of solar PV to create services that result in income generation opportunities essential for poverty reduction in off-grid rural communities.

Enterprise lighting services and night vendors

In the surveyed rural communities, brighter external lighting facilitated night businesses and these are the businesses that employ the poor (Kapadia, 2004). However, the impact of external lighting on night vendors is considered indirect rather than direct impacts. This is because this study focused on measuring impacts on project clients relative to incoming/potential clients. The data demonstrated focused on the number of night vendors (table-top vendors) who are likely to be affected without the external light of rural enterprises. With the exception of Bunkpurungu and Apollonia, the solar-electrified enterprises in Kpassa, Kpalbe and Wechiau indicated that the businesses of about two night vendors are likely to be affected without their external light in the evening. The non-electrified enterprises, however, indicated clearly that almost none of the night vendors are likely to be affected without their light.

The difference in the type of external lighting between the two groups of enterprises accounts for 11.2% (Eta squared = 0.112) of the variation in the number of night vendors likely to be affected. The amount of variation in the number of vendors likely to be affected that is explained by the type of external lighting is statistically significant but relatively small. Nevertheless, in view of the practical significance of the study, the results are significant for consideration in the planning of future projects. Practically, much attention should be focused on providing quality and brighter external lighting as well as the fixing position of the lights to impact on night vendors, who seize the opportunity to generate additional income after sunset in off-grid rural communities.

Table 8
External lighting of enterprises and night vendors affected.

Enterprise status	Name of community	Night vendors affected (mean)	Number of response	Std. deviation
Solar-electrified enterprise	Kpassa	1.8	10	2.3
	Appolonia	1.0	1	
	Kpalbe	2.5	2	2.1
	Wechiau	1.8	4	1.5
	Bunkpurugu area	0.6	5	1.3
	Asekye/Tom	2.0	3	2.1
	Total	2.0	25	1.8
Non-electrified enterprise	Kpassa	0.5	13	1.9
	Appolonia	0.5	13	1.9
	Kpalbe	0.0	1	
	Wechiau	0.0	4	0.0
	Bunkpuruga area	0.5	5	0.9
	Total	1.0	25	1.4

F = 4.173, Sig. = 0.021, dfl = 1, df2 = 45.
Measure of association: Eta = 0.335, Eta squared = 0.112.

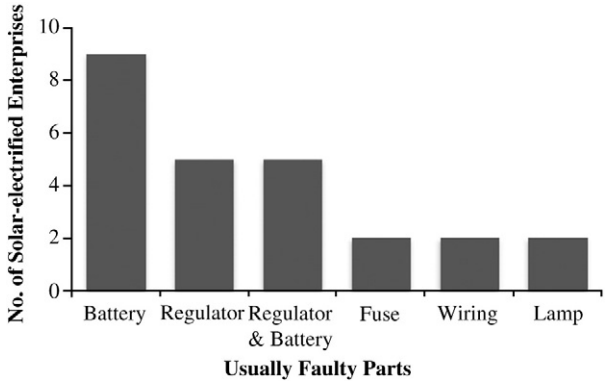

Fig. 3. Usually faulty parts at the solar-electrified enterprise level.

Faulty parts, affordability and sustainability issues

Though the responses of the enterprise owners indicated that car batteries and regulators were the most common faulty components; at all levels of application, car batteries appear to be the component causing most problems to end-users. Though PV components are costly due to importation (Martinot, et al., 2001; Energy Commission, 2004), it appears that when PV systems are used to enhance the opportunity for income generation the chances of maintenance are higher and hence systems can be sustained for long-term economic benefits.

A focus on productive applications of renewable energy is a development view (Martinot, 2001). Therefore effective approach to sustainability should include strategies that would respond to the differing levels of ability to maintain the systems. Rural enterprises are likely to afford service and maintenance costs. However, they would also require new opportunities for income generation. The lack of a substantial income generation opportunities may create less possibility for sustainability of the technology (Basnyat, 2004).

Factors limiting the extension of working hours by enterprises

Though rural enterprise owners have the goal of generating additional income to expand their businesses and enhance quality of life of their families, certain factors limit them from extending their working hours. The results indicated that the major factors preventing non-electrified enterprises from extending their working hours were poor lighting, high cost and scarcity of kerosene. These are among the major factors that influence rural dwellers to adopt solar PV systems (Chakrabarti and Chakrabarti, 2002). It is understood that the use of solar PV can eliminate the cost of kerosene for the rural poor (Cabraal et al., 1996; Plastow and Goldsmith, 2001).

In the case of solar-electrified enterprises power fluctuation due to low sunshine hours, weak car batteries were mentioned as the key limiting factors. The data further revealed that many of the solar-electrified enterprises were not limited in the extension of their working hours. The implication is that well maintained PV systems

Table 9
Ability to pay for component parts at the enterprise level.

		Enterprise electrification status		Total
		Solar-electrified enterprise	Non-electrified enterprise	
Could you pay for component parts?	Could not pay for	5 (20%)	5 (20.0%)	10 (19.1%)
	Could pay for	20 (80%)	20 (80.0%)	40 (80.9%)
	Total	25 (100.0%)	25 (100.0%)	50 (100.0%)

Pearson Chi-square value = 0.025, df = 1, Asymp. sig. (2 sided) = 0.874.

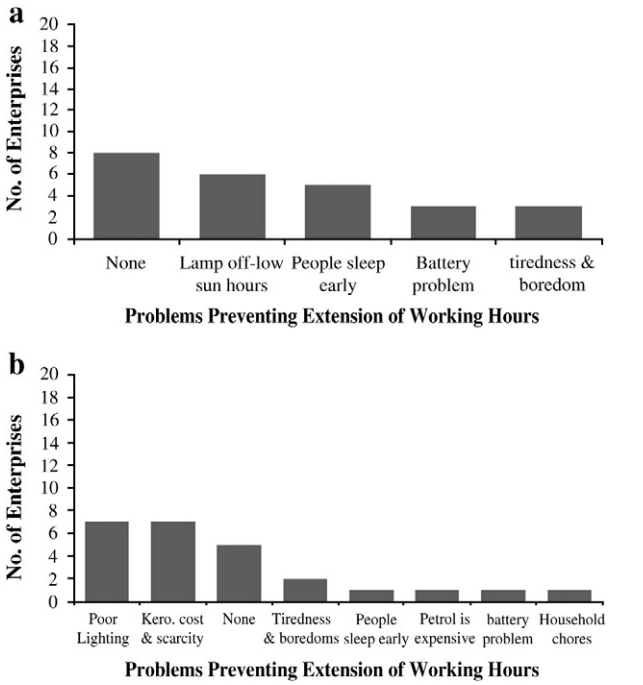

Fig. 4. Problems preventing the enterprises from extending working hours. (a) Solar-electrified enterprises. (b) Non-electrified enterprises.

that provide less interrupted are likely to make significant contibution to extend the working hours of rural micro-enterprises and create new income generation opportunities.

Conclusions and recommendations

In this paper, a set of indicators were developed to measure the impacts of public solar PV electrification on rural micro-enterprises. The investigation focused on the use of the indicators to assess impacts of solar PV electrification on off-grid micro-enterprises. It was also to analyse the relationships between enterprise-level electrification status and some stated economic outputs. The use of solar PV electricity was limited to lighting since it is one of the significant energy services much needed after daylight hours to extend socio-economic activities.

The results established significant association between lighting services and extension of working hours beyond daylight, indicating that a lighted environment is a significant factor for working beyond daylight hours. From the study, it was revealed that some costs are avoided by using public solar PV lighting in off-grid rural enterprises instead of kerosene lanterns. On additional income generation after sunset, the empirical results indicated a statistically significant association between solar PV lighting and increased income in grocery enterprises (mechandise stores). On the basis of the data, the empirical results of this study supported the alternative hypothesis that in off-grid rural communities, grocery enterprises using solar PV are likely to increase daily income after sunset than those without. It is concluded that though both solar-electrified and non-electrified enterprises extended their working hours after sunset, it is only in the grocery enterprises with solar PV that the additional income values provided convincing evidence in favour of the alternative hypothesis.

Though there were some differences in incomes after sunset between solar-electrified and non-electrified drinking bars, the data were not sufficient for a comparative analysis to be made. This issue therefore warrants future investigation as this study's cross-sectional data were not conclusive to support any hypothesis relating the association between the use of solar PV lighting and additional income

generation in drinking bars — a micro-enterprise commonly found in rural Ghana.

Indirect impact on night vendors was also investigated. It was established that without the external lighting of the solar-electrified enterprises, the businesses of relatively more night vendors are likely to be affected though the association is statistically significant but relatively small. However, in view of the practical significance of the study, the results are significant for consideration in the planning of future energy projects that seek to increase energy access.

In terms of affordability of component parts, it was established that rural micro-enterprises are likely to afford the replacement or repair costs of their lighting devices. It appears that when PV systems are used to enhance the opportunity for income generation the chances of maintenance are higher and hence systems can be sustained to derive the needed economic benefits. The lack of a substantial income generation opportunities may create less possibility for sustainability. Lastly, the indicators presented in this study were not intended to be conclusive. Several other enterprise-level indicators should be added with the goal of enhancing productive uses and economic output of off-grid rural micro-enterprises, bearing in mind the deficiencies related to data availability.

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