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Solar PV Rural Electrification and Energy-Poverty Assessment in Ghana: A Principal Component Analysis.

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Abstract

The relationship between solar photovoltaic (PV) rural electrification and energy poverty was assessed using social, economic and environmental indicator-based questionnaires in 96 solar-electrified and 113 non-electrified households in rural Ghana. The purpose was to assess energy-poverty status of households with and without solar PV systems, and to determine the factors that explain energy-poverty in off-grid rural households. Principal component analysis (PCA) was used to construct energy-poverty index scores (EPIS). On the basis of the results of the EPIS, about 80% of the non-electrified households were assessed as relatively energy poor compared with only 10% of the solar-electrified households. Three significant indicators increased linearly with increasing EPIS and therefore explained the variation in EPIS. They are monthly savings on lighting (r^2=0.214), number of children who can sit around lighting (r^2=0.388) and amount paid to obtain lighting/electricity system (r^2=0.261). On the contrary, EPIS decreased linearly with increasing monthly costs of kerosene, candles and dry-cell batteries. This indicates that increasing expenditure on kerosene, candles and dry-cell batteries is likely to affect household savings and investment in quality energy delivery systems that can increase EPIS. To improve EPIS, households should invest a bit more in reliable and quality energy delivery systems, which can help to improve their quality of life. The use of EPIS successfully demonstrated the difference in energy-poverty status between households with and without solar PV. This lays down a basis of understanding the relationship between solar PV rural electrification and energy poverty improvement in off-grid communities.

Keywords

Solar PV system, energy poverty, rural households, principal component analysis and Ghana.

1. Introduction

The vision of Ghana is to attain a middle level income status with average economic growth rate of about 8 percent in 2006-2015 and per capita income of about US$ 1000 by 2015. To achieve these targets access to modern energy services, especially electricity is very essential. However, over two decades, the electricity sector of the country has experienced inadequate supply of power as a result of low inflows into the reservoirs of the Akosombo hydroelectric dam and inadequate alternative generation capacity (Energy Commission, 2004). Though government policy is to achieve universal access to electricity by the year 2020, grid access level remains very low in the rural areas. Out of the 3,701,241 households in Ghana, only 24.9 percent of the rural households have access to grid-electricity compared to 81 percent of the urban households (Ghana Statistical Service, 2002, 2003). The consequence is that nearly 83 percent in the year 2000 and 75 percent of rural households depended on kerosene lanterns as their main source of lighting in the year 2003 (Ghana Statistical Service, 2003; 2005).

An important step in the country's electrification process is the integration of solar photovoltaic (PV) systems into the rural electrification programme to widen electricity access to rural households for poverty reduction (World Bank, 2003). Solar PV systems are considered because they are a viable complement to grid-based energy service delivery and within rural electrification they can find a cost-effective niche and sustainable market (Cabraal et al, 1996). Nevertheless, one of the challenges facing energy policy-makers, planners, practitioners and academics is the lack of feedback and evaluation on how existing solar PV rural electrification projects are contributing to improve energy poverty. This paper uses social, economic and environmental indicators to examine the relative energy-poverty status of rural households with and without solar PV.

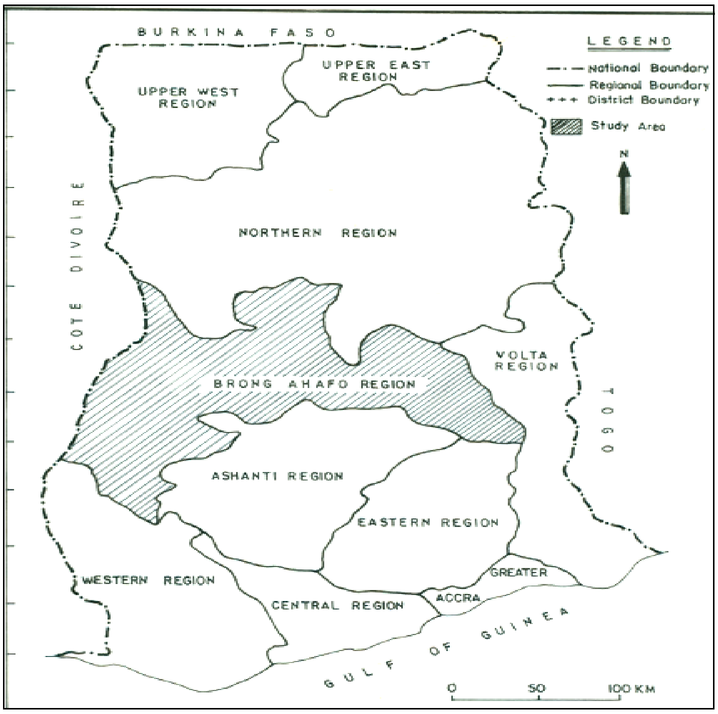
The purpose of our study is to assess the energy-poverty status of households with and without solar PV, and to determine the factors that explain energy-poverty in off-grid rural households. In this paper, energy-poverty is defined as the absence of basic energy services such as lighting, motive power etc. provided by electricity to support socio-economic development (Reddy, 2000). We used this definition in our study to identify particular groups within the surveyed households that can be classified as "energy-poor" households. By classifying households into energy-poverty groups, poor households can be identified to improve prospects for future project design.

2. Study Areas and Research Methods

2.1. The Study Areas

The main survey was carried out in seventeen rural communities located in six districts in five regions of Ghana: Northern, Upper East, Upper West, Volta and Greater Accra regions. The study areas include Kpentang, Kpenbung, Kambatiak, Bamong, Kintango, Chintilung, Tojing, Gbetmanpaak, Jimbali, Najong No.1 and Pagnatik all in the Bunkpurungu Yunyoo district of the northern region; Kpalbe in the East Gonja district, northern region; Tengzuk in Talensi-Nabdam district, Upper East region; Wechiau in Wa-West district, Upper West region; Kpassa in the Nkwanta district, Volta region; and Apollonia in the Tema district, Greater Accra region. Pretesting of the questionnaires was carried out in the Nkoranza district, Brong-Ahafo region. Figure 1 is the map of Ghana showing the study regions.

Figure 1: Map of Ghana Showing the Study Regions



Source: Geography Department, KNUST, Kumasi, Ghana.

The surveyed regions were among the six regions that recorded electricity access below the national average of 27.1%[1]: Northern region - 16%, Upper East region - 13%, Upper West region - 9%, Volta region - 17.5% and Brong-Ahafo region - 17.8% (World Bank, 2003). These geographical regions were selected because they have public solar PV electrification projects that have been operational over three years and are serving the needs of rural communities deprived of access to grid-electricity. Table 1 shows the electrification status and percent of households that depend on kerosene lantern in the surveyed districts.

Table 1: Electrification Status and Kerosene Lantern Usage in Surveyed Areas.

[1] This figure was reported by the National Development and Planning Commission - NDPC 94 (see World Bank, 2003: 191)

Village	Population[1]	District	% of HH un-electrified in the district[2]	% using kerosene lantern in the district[3]
Kpassa	18,000[4]	Nkwanta	86%	83.8%
Kpenteng	528	Bunkpurungu Yunyoo	87.6%	87.4%
Kpenbung		Bunkpurungu Yunyoo	87.6%	87.4%
Kambatiak	1,064	Bunkpurungu Yunyoo	87.6%	87.4%
Bamong		Bunkpurungu Yunyoo	87.6%	87.4%
Kinkango	859	Bunkpurungu Yunyoo	87.6%	87.4%
Chintilung	924	Bunkpurungu Yunyoo	87.6%	87.4%
Tojing		Bunkpurungu Yunyoo	87.6%	87.4%
Jimbali	1,590	Bunkpurungu Yunyoo	87.6%	87.4%
Gbetmanpak		Bunkpurungu Yunyoo	87.6%	87.4%
Najong No.1	1,909	Bunkpurungu Yunyoo	87.6%	87.4%
Pagnatiak	700	Bunkpurungu Yunyoo	87.6%	87.4%
Kpalbe	4,000[4]	East Gonja	91.8%	90.7%
Tengzuk	847	Talensi-Nabdam	-	90.7%
Wechiau	13,341	Wa West	75.9%	73.1%
Apollonia		Tema	-	-

[1] JICA/MOE, 2005
[2, 3] Ghana Statistical Service (2005a, 2005b, 2005c, 2005d)
[4] Field data, 2006

2.2. Research Methods

First, a set of indicators that reflect the multi-dimensionality of energy-poverty was developed through literature and reconnaissance survey. Second, generic interviewer-administered questionnaires based on social, economic and environmental indicators were designed for household surveys during the months of November to February 2005. The questionnaires were administered to 209 household heads: 96 solar-electrified households and 113 non-electrified households. A list of project beneficiaries (solar-electrified households) and incoming beneficiaries (non-electrified households) were used to select the households in a systematic sampling. Incoming beneficiaries were used as the comparison group because their lists were available with the solar energy committees established in the study areas or could be compiled. Incoming beneficiaries appear to be similar to the beneficiary group than random selected non-beneficiaries (SEEP-AIMS, 2000). The purpose of the questionnaire was to gather ex-post information that indicates difference in energy poverty as a result of the solar PV electrification projects.

2.2.1 Statistical Analysis

To analyse the relationships among the selected indicators, first a linear correlation analysis was performed. The correlation analysis proceeded by matching several variables to a benchmark indicator - monthly savings on lighting/electricity services. This indicator was chosen because: (1) it is a proxy measure of household income not spent on light/electricity services; and (2) it is a measure of the avoided cost of kerosene that can be used productively. The assumption here is that monthly savings on kerosene and batteries can be reinvested to improve household income and quality of life. Variables that correlated well with the benchmark indicator at a significance level of 0.01 (1 percent) were selected for principal component analysis. With a large number of measured indicators, a principal component analysis (PCA) was used to reduce the original number of indicators from 34 to 16. SPSS 11.0 for Windows was used to analyse the data.

2.2.2. Energy-Poverty Index Scores (EPIS)

By applying PCA, energy-poverty index scores (EPIS) were constructed. To use the scores for comparison, the study adopted the poverty classification used by Henry et al (2003). According to the authors, households with poverty index scores above +1.0 are classified as least poor households; scores between 0 and +1.0 are less poor households; between -1.0 and 0 are poor households; less than -1.0 are poorest households. After assigning households with and without solar PV to energy-poverty groupings, comparison was made and deviations between the two groups signified a difference between them.

3. Data Analysis and Results

3.1. Correlation and Reduction of the Original Variables

The prerequisite of PCA is to reduce the original variables presented in Table 2 to fewer variables to simplify the analysis. Two screening processes were carried out to reduce the number of indicator variables used for constructing household energy-poverty index scores. The approach requires trial and error and continual scrutiny of variables to determine which combination yields the most logical results (Henry et al, 2003).

Table 2: Household Indicators to Test for Correlation

Demographic Characteristics
1. Age of household head
2. Level of education of household head
3. Size of Household
4. Number of children in a household
5. No. of adult workers in a household
6. Occupation of household head
Social Indicators
7. Number of hours a day children extended their study time
8. Average number of children who could sit around lighting system to study
9. Number of children whose examination results improved
10. Number of hours in a day adults extended their study time
11. Number of hours in a day information was acquired through radio
12. Number of hours in a day information was acquired through T.V
13. Number of household chores women used lighting services to do in the evening
14. Spousal response on level of brightness of lighting services
15. Number of friends/relations gained as a result of electricity/lighting system
16. Number of adults satisfied with household electricity/lighting services
Economic Indicators
17. Monthly expenditure on household lighting/electricity services
18. Weekly expenditure on dry-cell batteries
19. Number of adults owing in the last six months

20. Number of hours in a day household activities were extended in the evening
21. Number of adults who acquired household assets as a result of lighting/electricity services
22. Annual cost of repair of lighting system
23. Time commercial food processing activity could be carried out
24. Amount lighting services contributed to increased income from food processing
25. Number of hours home enterprise was extended as a result of lighting services
26. Monthly income from extended work on home-enterprise
27. Monthly savings on current lighting/electricity services compared to previous services
28. Per capita monthly household energy expenditure
29. Monthly expenditure on food, clothing, education and other HH goods
Environmental Indicators
30. Number of HH members who reported of eye irritation problem
31. Number of HH members who reported of blackened nostril
32. Number of HH members who reported of noise from lighting services
33. Number of HH members who reported of perceived risk of fire
34. Number of HH members who reported of indoor smoke

Source: Fieldwork, 2005 HH = Household

3.1.1. Screening Process One

First the indicators presented in Table 4.1 were screened. After screening, 15 variables significantly correlated with the benchmark indicator - monthly estimated savings on lighting/electricity services - as presented in Table 3. Of all the correlations, the level of significance between each indicator and the benchmark indicator was less than 0.01 ($p<0.01$), indicating strong association.

Table 3: List of Indicators that Correlated with Benchmark Indicator

Indicator	Level of Significance	Value and sign of *correlation coefficient	Number of cases with missing values
1. Number saving on lighting/electricity services	0.000	0.675	1
2. Number having indoor smoke	0.000	-0.394	1
3. Number reporting of availability of spare parts	0.000	-0.393	1
4. Number satisfied with technical functionality	0.000	0.355	1
5. Number of children who can study around light	0.000	0.338	1
6. Number who reported of blackened nostrils	0.000	-0.282	1
7. Amount paid to acquire lighting/electricity system	0.000	0.253	1
8. Spousal satisfaction with level of brightness	0.001	0.234	1
9. Number who reported of eye irritation	0.001	-0.233	1
10. Number owing in the last six months	0.002	0.211	1
11.Number reporting of adverse impacts on children	0.003	-0.208	1
12.Number perceiving risk of fire	0.001	-0.230	1
13.Level of noise of energy services	0.000	-0.208	0
14.Number having access to radio	0.004	-0.201	1
15.Cost per month on car battery	0.004	-0.201	2

Source: Fieldwork, 2006 *Correlation is significant at the 0.01 level (2-tailed)

The list constitutes the first screening of indicators for the PCA method.

3.1.2. Eigenvalue and the Scree Test

The eigenvalues calculated for each component are presented in Table 4. Eigenvalues represent the amount of variance accounted for by each component. To estimate the number of factors with initial eigenvalues exceeding one (eigenvalue $\geq$1), 5 components were extracted as shown in the scree plot in Figure 2. The scree plot helps in determining the optimal number of indicator variables. The eigenvalue for the first component was 5.253, and accounted for 32.832 percent of the variance. Successive eigenvalues for the second, third, fourth and fifth components accounted for relatively small proportions of the variance - 9.419 percent; 7.405 percent; 6.936 percent and 6.271 percent respectively. In all the 5 principal components explained 62.863 percent of variances in the 16 variables (including the benchmark variable).

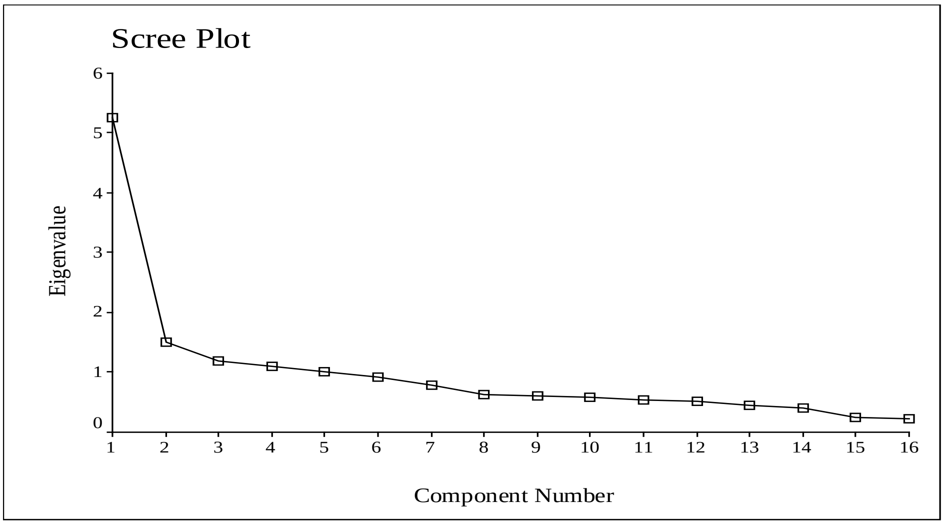
Table 4: Total Variance Explained by Factor Analysis.

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.253	32.832	32.832	5.253	32.832	32.832
2	1.507	9.419	42.251			
3	1.185	7.405	49.656			
4	1.110	6.936	56.592			
5	1.003	6.271	62.863			
6	.917	5.734	68.598			
7	.785	4.907	73.504			
8	.636	3.975	77.479			
9	.605	3.780	81.259			
10	.592	3.701	84.961			
11	.546	3.415	88.376			
12	.528	3.299	91.675			
13	.449	2.808	94.483			
14	.401	2.508	96.991			
15	.250	1.561	98.552			
16	.232	1.448	100.000			

Extraction Method: Principal Component Analysis.

Source: Fieldwork, 2006

Figure 2: The Scree Plot of Extracted Components



3.1.3. Screening Process Two

The output of the second screening process comprised the component matrix, common variance, communalities and the Kaiser-Meyer-Olkin (KMO) and Bartlet test. For this analysis the component matrix table was used to interpret results and refine the model. Results shown in the other outputs may indicate that changes are needed, but the results of the component matrix will indicate what changes should be made. It is the most critical output used for determining the composition of poverty index scores (Henry et al, 2003). With a cut off of 0.20 ($r > 0.2$), 16 indicators were extracted as shown in the component matrix (Table 5). These indicators were used to construct the energy-poverty index scores.

Table 5: Component Matrix

	Component
1. Number who reported of availability of spare parts	-0.736
2. Number who saved on lighting/electricity services	0.731
3. Number satisfied with technical functionality	0.697
4. Number of children who could study around light	0.641
5. Number affected by indoor smoke	-0.640
6. Monthly estimation of cash savings	0.613
7. Spousal satisfaction with level of brightness	0.599
8. Number who reported of blackened nostrils	-0.585
9. Number who owed in the last six months	0.581
10. Amount paid to acquire lighting/electricity system	0.532
11. Number who reported of eye irritation	-0.493
12.Number who perceived risk of fire	-0.481
13.Number who had access to radio	-0.475
14. Number who reported of adverse impact of light on children	-0.474
15.Level of noise of energy services	-0.454
16.Cost per month on car battery	-0.205

Extraction Method: Principal Component Analysis 1 Component Extracted

3.1.4. Data Quality: The Kaiser-Meyer-Olkin and Bartlett Tests

The Kaiser-Meyer-Olkin (KMO) method was used to measure sampling adequacy. Bartlet Test of Sphericity was used to test whether the correlation was appropriate for factor analysis and statistically significant at $p<0.05$. Table 6 presents the results of the Kaiser-Meyer-Olkin and Bartlett Tests. The KMO measure of this study was 0.848. This result was within the acceptable range (KMO≥0.7). The Bartlett's Test of Sphericity was statistically significant, Sig. = 0.000 ($p<0.05$).

Table 6 Kaiser-Meyer-Olkin (KMO) and Bartlett's Test

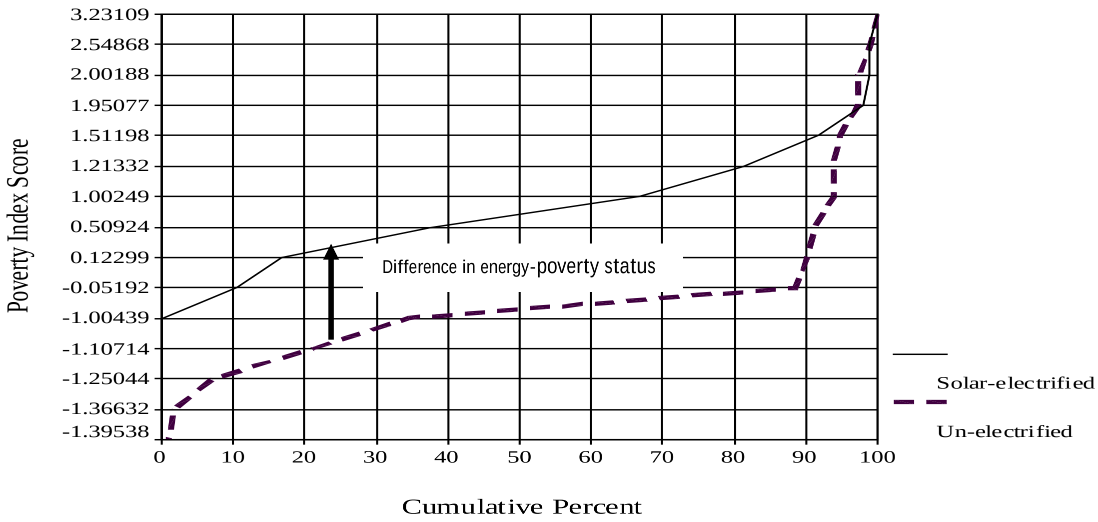
Kaiser-Meyer-Olkin Measure of sampling Adequacy		0.848
Bartlett's Test of Sphericity	Approx. Chi-Square	1052.588
	df	120
	Sig.	.000

Source: Own data, 2005

3.2. Energy-Poverty Index Scores of Households

By developing energy poverty index scores from multiple indicators, the relative energy-poverty of households with and without solar PV could be compared. Figure 3 shows the graph of the cumulative percent of energy-poverty index scores of households with and without solar PV. From the graph a fairly large margin of difference in energy-poverty scores exists between the solar-electrified and non-electrified households until they converged at the top 5 percent.

Figure 3: Cumulative Percent of Household Poverty Index



The relative energy-poverty of solar-electrified and non-electrified households can further be validated by cross-checking the average values of the energy-poverty scores. As indicated in Table 7, the average poverty index score of the non-electrified households was -0.63, while that of the solar-electrified households was +0.74. An independent t-test of means gave a significance value of 0.000 ($p<0.05$), indicating differences in relative poverty levels between the two groups.

Table 7: Mean Energy Poverty Scores of Households

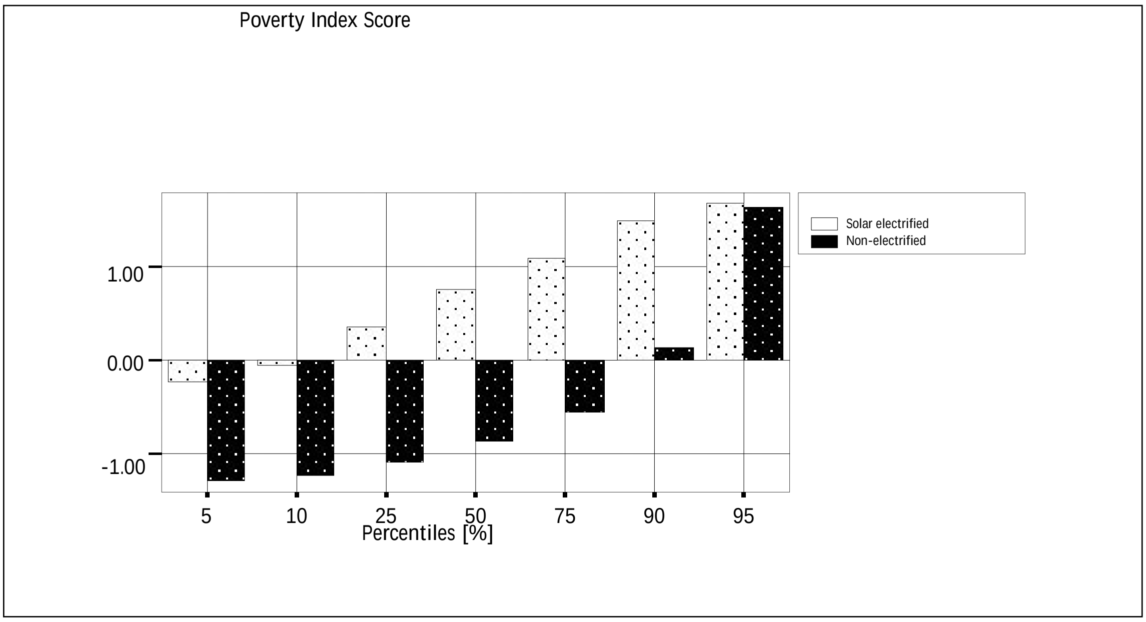
	Household Status	N	Mean	Std. deviation	Std. Error
Energy-Poverty Index Score	Solar-electrified	96	+0.7376851	0.61526467	0.06279519
	Non-electrified	113	-0.6267060	0.82057553	0.07719325
Equal variances assumed: t = 13.401 df = 207 Sig. (2-tailed) = .000 Mean Difference = 1.3643911					

Source: Fieldwork, 2005.

3.2.1. Identifying the Distribution of Energy-Poverty Groups

The purpose of this analysis is to identify the distribution of energy-poverty groups in the households with and without solar PV. To classify the households into energy-poverty groups this study employed the poverty classification used by Henry et al, (2003). The authors classified households with poverty index scores above +1.0 as least poor households; scores between 0 and +1.0 are less poor households; between -1.0 and 0 are poor households; less than -1.0 are poorest households. To identify the proportions of households who fall into each group the percentile distributions of the energy-poverty scores are illustrated in Figure 4.

Figure 4: Percentile Distribution of Household Poverty Index



Source: Fieldwork, 2005

The bar plots show unequal proportion of households in the classification. The results revealed the following distributions as tabulated in Table 8.

Table 8: Percentiles of Household Poverty Index Score

	Percentiles		
Poverty Index Scores	Non-electrified	Solar-electrified	Poverty Classification
Less than -1.0	25	0	Energy-Poorest household
Between -1.0 and 0	55	10	Energy-Poor Household
Between 0 and +1.0	15	65	Less Energy-Poor Household
Above +1.0	5	25	Least Energy-Poor Household

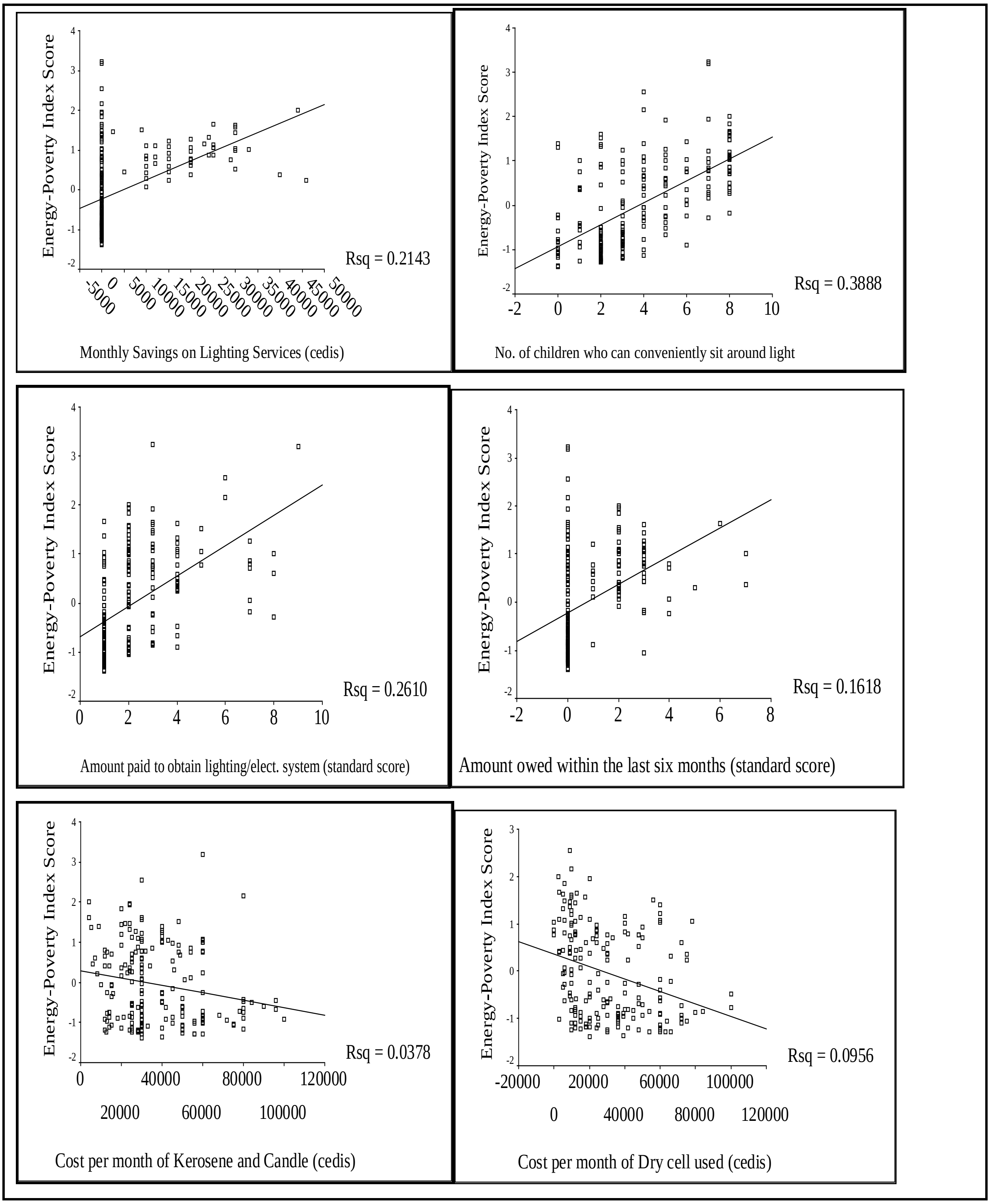
Source: Fieldwork, 2005 *Poverty classification is adopted from Henry et al. (2003)

3.2.2. Energy Poverty index Scores and key Independent Variables

Figure 5 revealed the variation among energy poverty index scores (represented by the coefficient of determination r^2) accounted for by some significant independent variables: monthly savings r^2=0.2143, number of children who can sit around lighting r^2=0.3888, amount paid to obtain lighting/electricity system r^2=0.2610, amount owed within last six months

r^2=0.1618, monthly cost of kerosene and candles r^2=0.0378, and monthly cost of dry-cell used r^2=0.0956.

Figure 5: Relationship between Energy Poverty Index Score and some key independent variables.



3.3. Test of Hypothesis: Monthly Cost Savings on Lighting and Energy Poverty Index Scores

By selecting monthly savings (avoided cost) on lighting as the benchmark indicator the study tested the hypothesis that "monthly cost savings from the use of solar PV lighting and energy-poverty index scores are positively and linearly related". This analysis is worked on the premise of a null hypothesis (H_o) that monthly savings on lighting contributes no information for predicting energy-poverty index scores using the straight line model against the alternative hypothesis (H_a) that the two variables are at least positively and linearly correlated. It is therefore hypothesised that Energy Poverty Index Score (y) is related to Monthly Cost Savings on Lighting (x).

Using a straight line model $y = \beta_o + \beta_1 x + \varepsilon$ (as indicated in Figure 6) to test the null hypothesis H_o against the alternative H_a that the linear model is useful for predicting y, we test H_o: $\beta_1 = 0$ and H_a: $\beta_1 > 0$, where β_o = y-intercept of the line; β_1 = the slope of the line; and ε = the random error. From the results in Table 9, $\beta_o = -0.216$, $\beta_1 = 4.564 \times 10^{-5}$, $\varepsilon = 0$. Therefore,

$$\text{Energy Poverty Index Score} = 4.564 \times 10^{-5} \text{ Monthly Cost Savings} - 0.216.$$

In the rejection region, the test statistic is $t > t_\alpha = t > t_{.05}$ for $\alpha = .05$. The degree of freedom (df) is given by df = (n-2) = 208 – 2 = 206. From Tables, the critical value for the test is $t > t_{0.05} = 1.645$. The calculated t value indicated in Table 9 was t value = 7.437. Since the calculated t value = 7.437 is greater than the critical t value = 1.645, the null hypothesis (Ho) is rejected and it is concluded that the slope β_1 exceeds 0 and hence it is positive. The value of the correlation coefficient r was 0.4591 and that of the coefficient of determination r^2 was ($r^2 = 0.2108$). The significance value of the F statistic shown in the Analysis of variance is 0.000 ($p<0.05$), indicating that the variation explained by the variable (monthly savings on lighting services) is not due to chance.

Table 9: Coefficient of Regression Line and Analysis of Variance

Coefficients of the Regression Line						
		Unstandardized coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	-.216	.068		-3.167	.002
	Monthly savings	4.564E-05	.000	.459	7.437	.000
Analysis of Variance						
Model		Sum of Sq.	df	Mean Square	F	Sig.
	Regression	43.855	1	43.855	55.304	.000[a]
	Residual	164.145	207	.793		
	Total	208.000	208			

[a] Predictors (constant), Monthly savings
[b] Dependent variable. Energy Poverty Index Score

4. Discussion of Key Results

In this study, linear correlation and principal component analysis (PCA) were used. Using household monthly savings on lighting as a benchmark indicator, 16 out of 34 indicators significantly correlated with the benchmark indicator. PCA was used to determine how information from the various indicators could be combined to measure a household's energy-poverty status. Each of the 16 indicators extracted for the construction of energy-poverty index scores measured some aspects of energy-poverty as a common underlying factor. The number of indicators extracted falls within the range 10 to 20, which is recommended for the construction of poverty index scores (Henry et al, 2003). Among the results only factors with eigenvalues greater than 1.00 are retained (see Brown, 2001; Nelson, 2005; StatSoft, 1984-2003). This led to the extraction of 5 principal components that explained 62.9 percent of the variances in the original data (Table 4). This means that it is possible to scale the 16 indicators down to 5 and still have the desirable representation (Chang and Chang, 2003). A graphical method shown by the scree test suggested that 5 factors could probably be retained (Figure 2).

However, it is noted from the results that as consecutive components were extracted they accounted for less and less variability in the energy-poverty component. The variances in the PCA explained by each component are called eigenvalues. The eigenvalue for the first component accounted for 32.8 percent of the variance; the second, third, fourth and fifth factors accounted for relatively small proportions of the variance - 9.4 percent; 7.4 percent; 6.9 percent and 6.3 percent respectively. Therefore, the first component has the largest eigenvalue and it is the combination that accounts for the largest amount of variance in the sample. The larger the eigenvalue the more that component is explained by the indicators (Henry et al., 2003). Because of this characteristic, only one can be considered to measure relative energy-poverty.

A component matrix output of the PCA extraction process indicates the degree of correlation between the component variable (energy-poverty status) and an indicator variable. From the analysis, indicators that emerged with high positive component loading coefficients were: number who saved on lighting services (0.731); number satisfied with technical functionality (0.697); number of children who could study around light (0.641); monthly estimation of cash savings (0.613); spousal satisfaction with level of brightness (0.599); number who owed in the last six months (0.581) and amount paid to acquire lighting/electricity system (0.532). According to Cohen (1988) correlation coefficients of +0.5 to +1.00 or -1.00 to -0.50 may be regarded as high, though such criteria are arbitrary and should not be observed too strictly.

Having positive coefficients imply a direct relationship between the indicator and the relative energy-wealth of the household. The concept of energy-wealth is described in the literature (UNEP, 2006). Negative coefficients such as the number of people who reported of availability of spare parts (-0.736); number affected by indoor smoke (-0.640); number who reported of blackened nostrils (-0.585) etc, implying an inverse relationship, were observed in households using kerosene lanterns. Several studies have reported that access to solar PV can reduce indoor smoke from kerosene lanterns (Martinot et al., 2002; Posorski, 1996).

The quality of the data used for the PCA was inspected using the Kaiser-Meyer-Olkin (KMO) measure and the Bartlett Sphericity test. The KMO measure of sampling adequacy shows the extent to which the variables belong together and thus indicates whether factor analysis is useful or not. The Bartlett's Test of Sphericity tests the statistical significance of the sampling data. KMO measure of sampling adequacy above 0.60 is considered acceptable; above 0.70 is good; above 0.80 is commendable; and above 0.90 is exceptional (Henry et. al, 2003). By this criteria, the KMO value (KMO=0.848) achieved by this study was commendable, hence the study proceeded to construct the energy poverty index scores.

Other authors have used the KMO criterion to inspect the quality of their data. For example, Henry et al., (2003) obtained a KMO value = 0.855 in their study on microfinance poverty assessment; Sricharoen and Buchenrieder (2005) had KMO value of 0.744 in their study on farm household poverty in northern Thailand. Chang and Chang (2003) reported of KMO value = 0.794 in marine environmental monitoring data analysis. Chiu et al. (2002) obtained KMO value = 0.932 in the analysis of the relationships among demographic variables. The KMO value obtained in this study compares favourably with previous research. Nevertheless, this work may be among the few studies on energy-poverty in which the KMO criterion has been used to inspect sampling adequacy and data quality.

The relationship between the benchmark indicator and energy-poverty index scores was also investigated. The purpose was to test whether a positive linear relationship existed between the two variables. A correlation coefficient value $r = 0.4591$ and a coefficient of determination value $r^2 = 0.2108$ were obtained. The variability of energy-poverty index scores appeared to increase with increasing monthly savings on lighting. On the basis of the sample evidence, the empirical results of this study support the hypothesis that monthly savings and energy poverty index scores are positively and linearly related.

However, the coefficient of determination value indicates that 21 percent of the variation among energy-poverty index scores is accounted for by the differences in monthly savings on lighting. A significant portion of the variation in energy-poverty index scores is accounted for by other variables, namely the number of children who can sit around lighting (38 percent), amount paid to obtain lighting/electricity system (25 percent). These three variables are significant, since they explained about 84 percent of the variation among energy poverty index scores. On the contrary, the findings indicated that monthly costs of kerosene, candles and dry-cell increased linearly with decreasing energy poverty index scores. The indication is that high household expenditure on kerosene, candles and dry-cell batteries is likely to affect household savings and hence lower their ability to invest in reliable and quality energy delivery systems to improve their energy poverty levels.

By using PCA, the results show that in terms of energy-poverty index scores, households without solar PV are assessed as poorer than households with solar PV. The interpretation is that households with solar PV whose average energy-poverty index scores were relatively high are likely to have some improvements in quality of life than households where there were inadequate energy service delivery systems. Inadequate access to energy services is closely linked to lack of economic and social opportunities contributing to poverty, poor health, reduced educational attainment etc (Anderson, 2000; Allderdice and Rogers, 2000; UNDP, 2004).

Analysis of the energy-poverty groups in the households with and without solar PV reveals unequal proportion in the energy-poverty classification. While only 10 percent of the solar-electrified households fall into the energy-poor group, an overwhelming majority of about 80 percent of the non-electrified households fall into the “energy-poor” and “energy-poorest” group. The ‘energy-poor’ are likely to be households using kerosene lantern for lighting; and may not have access to television and in some cases radio for information and entertainment. The remaining 20 percent of the non-electrified households fall into the “less poor” and “least poor” groups. This proportion may be households who use generators or have access to car batteries that enable them to watch television and in some cases light their table lamps. These findings suggest that there exist a large proportion of rural households in the surveyed communities that are deprived of electricity services essential for energy poverty reduction.

It is reported that off-grid rural households without solar PV mainly depend on kerosene lantern for lighting (Ghana Statistical Service, 2003, 2005). The energy-poor are those affected by the absence of basic energy services provided by electricity to support their socio-economic development. The concept of energy-poverty has been discussed by several studies (Cecelski, 2003; Reddy, 2000; UNDP/KITE, 2006). Using energy-poverty index scores, this study's finding of 80 percent non-electrified households being energy poor appear to be consistent with literature (see Table 1). The Lack of electricity is mentioned as one of the characteristics of rural poverty in Ghana (Akuapem North District Assembly, 2004; Asante-Akim North District Assembly, 2004). On the basis of the average energy-poverty index scores, it is concluded that overall households without solar PV were more deprived in electricity services than households with solar PV.

5. Conclusion

In this paper solar PV rural electrification and household energy-poverty status were assessed using indicators. The study findings revealed that monthly savings on lighting, the number of children who can sit around lighting and amount paid to obtain lighting/electricity system are the factors that significantly explained the variation in energy poverty index scores. On the contrary, increasing monthly costs of kerosene, candles and dry-cell resulted in decreasing energy poverty index scores. The findings suggest that to increase energy poverty scores, households should invest a bit more in reliable and quality energy delivery systems, which can help to improve their quality of life.

From the energy-poverty groupings unequal proportion of households emerged in each group. On average households without solar PV were relatively energy poor than households with solar PV in terms of access to electricity services. This lays down a basis of understanding the relationship between solar PV rural electrification and improved energy poverty status in off-grid communities. The use of energy-poverty index scores successfully demonstrated the difference in energy-poverty status between households with and without solar PV. Lastly, empirical evidence supports the hypothesis that monthly cost savings from the use of solar PV lighting and energy-poverty index scores are positively and linearly related. Nevertheless, other indicators that can measure and account for more variations in energy-poverty index scores should be used in other case studies.

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