Energy and Environment Research; Vol. 4, No. 1; 2014
ISSN 1927-0569 E-ISSN 1927-0577
Published by Canadian Center of Science and Education

Quantitative Impacts of Solar PV on Television Viewing and Radio Listening in Off-grid Rural Ghana

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Received: March 24, 2014 Accepted: April 21, 2014 Online Published: May 14, 2014

doi:10.5539/eer.v4n1p62 URL: http://dx.doi.org/10.5539/eer.v4n1p62

Abstract

The use of solar photovoltaic (PV) for powering electronic devices such as radio and television can contribute to increase access to information and entertainment in off-grid rural communities. However, there is a lack of quantitative data on impact of solar PV electrification on television viewing and radio listening. This paper relied on primary data from cross-sectional surveys of solar-electrified and non-electrified households in rural Ghana using questionnaires which were developed into a database. The study results showed that solar-electrified households could view television for 2.5 hours/day, while in non-electrified households it was 1.5 hours/day. The avoided cost of television viewing using solar PV instead of car battery was US$ 1-3/month. The study found a linear relationship between incomes above US$ 1.08/day and television ownership. Further, the results showed that on average radio listening in solar-electrified households was 5 hours/day, while in non-electrified households it was 6.3 hours/day. The avoided cost of radio listening using solar PV instead of drycell batteries was US$ 1.08/month. We conclude that the difference in the results suggests an overall impact of solar PV on television viewing and radio listening. Once quantitative data are made available, the decision to use solar PV for off-grid electrification will be apparent.

Keywords: off-grid electrification, quantitative data, fee-for-service, avoided cost, Ghana

1. Introduction

It is globally accepted that electrification does not only stimulate economic growth at a broader level but also can enhance quality of life at the household level. It is generally agreed that the immediate benefit of solar phovoltaic (PV) electrification comes through improved lighting. All the same, in off-grid rural communities, the use of solar PV for powering electronic devices such as radio and television can significantly contribute to increase access to information and entertainment at the household level and this is reported in several studies (Wamukonya & Davies, 2001; Obeng & Evers, 2009; Bahauddin & Salah, 2010). But, there appears to be a lack of data on the quantitative impacts of solar PV on hours of usage and costs of television viewing and radio listening, particularly in off-grid rural communities, where access to electricity is relatively low.

While the electricity access of Ghana was about 72% in 2011, rural access was about 35% (Ministry of Energy and Power, 2013). For communities without access to the national grid, off-grid electrification using solar home systems, biogas, wind etc are being explored as alternative technologies (Ministry of Enery, 2010; Ghana Publishing Company, 2011). Since the technology radar of Ghana demonstrates the inclusion of solar PV, there is the need to quantify the potential contribution that can be derived from its application. The main objective of this paper therefore was to analyse the quantitative impacts of solar PV electrification on television viewing and radio listening focusing on hours of usage, costs of usage, income and ownership, avoided costs and any other relevant factors.

2. Methods

Cross-sectional survey was the main data collection method. The survey was conducted in sixteen rural communities located in seven districts of six regions in Ghana: Northern, Upper East, Upper West, Brong Ahafo, Volta and Greater Accra regions. The study locations were off-grid rural communities with relatively high poverty incidence (Ghana Statistical Service, 2002; World Bank, 2003). They include: 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); Nkoranza in Nkoranza district (Brong Ahafo 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. Figure 1 is the map of Ghana showing the study regions and electricity access in 2010. The entire land surface of Ghana receives solar radiation ranging between 4.4 kWh/m^2-day and 5.6 kWh/m^2-day and sunshine duration of about 1800-3000 hours per year (Forson et al., 2004; Energy Commission, 2009; Kemausuor et al., 2011).

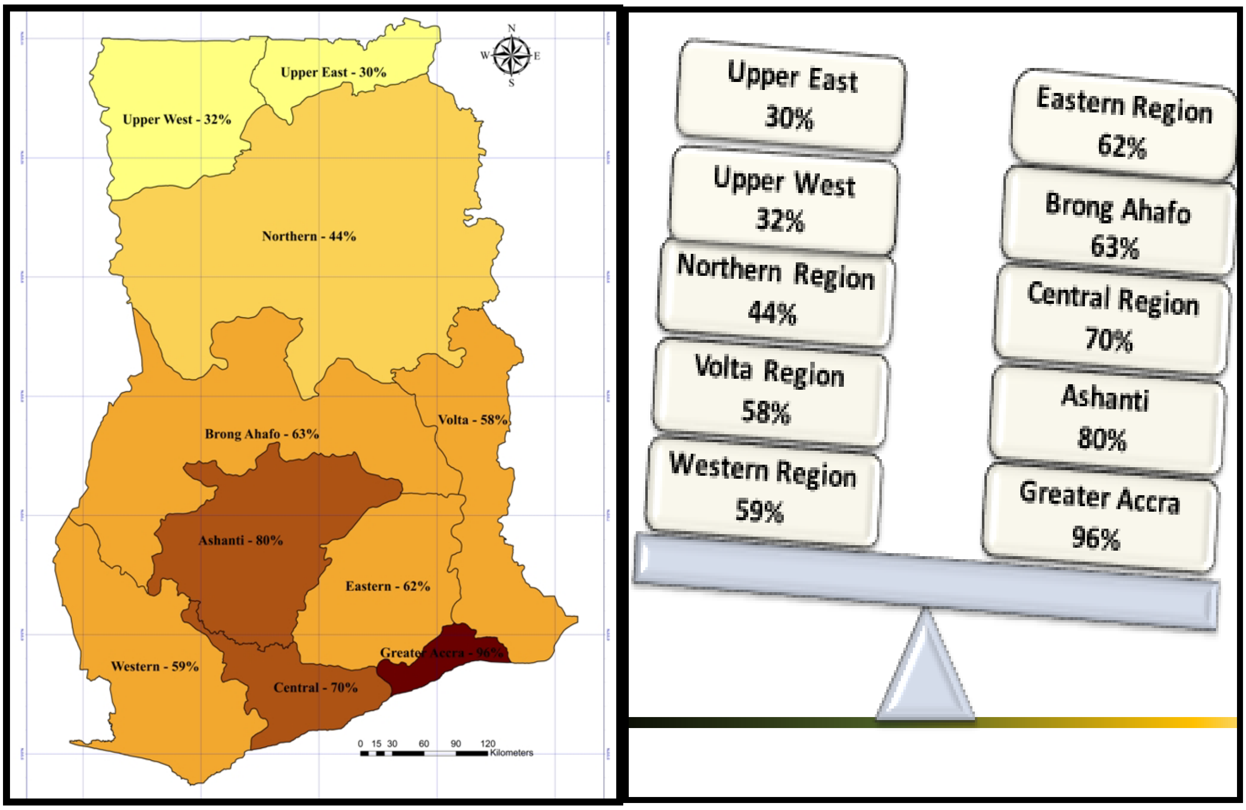

Figure 1. Map of Ghana showing the study regions and electricity access rate in 2010

A total of 209 household heads were randomly selected for the study: 96 solar-electrified households and 113 non-electrified households. In each of the regions research assistants from the Kwame Nkrumah University of Science and Technology, Kumasi who speak the local language were engaged in the administration of the questionnaires. A questionnaire contained 192 variables including indicators on demographic and socio-economic impacts, technology functionality and environmental impacts. A list of project beneficiaries (solar-electrified households) and incoming clients (non-electrified households) were used to select the households in a systematic sampling.

From the lists of the beneficiaries of solar PV electrification projects in rural Ghana, solar home systems (50Wp and 100Wp of both polycrystalline silicon and amorphous silicon module types) that have been operational for over three years and had not been earmarked by the Ministry of Energy for relocation 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) would have gone through a cycle of operation and maintenance and end-users would have learned some impact lessons. With an estimated average daily sunshine hours of 6 hours, each of the 50Wp and

100Wp panels could generate 300Wh and 600Wh of energy daily respectively (Energy Commission, 2009). Incoming clients (non-electrified households) were used as the comparison or control group because their lists were available for systematic sampling and they also appeared to be similar to the beneficiary group than random selected non-beneficiaries. The purpose of the questionnaire was to gather ex-post information that indicates change in the responses between households with and without solar PV.

2.1 Underlying Assumption and Data Analysis

The underlying assumptions that governed the interpretation of the study results were as follows:

- In the absence of the solar PV, solar-electrified households would have depended on car batteries and drycell batteries like the non-electrified households.
- The analysis relied on fee-for-service of US$ 1.63/month for a 50Wp solar home system and US$ 2.72/month for 100Wp system in the surveyed communities.
- A zero transportation cost was assumed in the analysis of non-electrified households because car batteries were sometimes carried on bicycles or transported free-of-charge to nearby towns for recharging.
- Access to solar PV might have contributed to the difference (or change) in response between the two groups (solar-electrified and non-electrified).

Using central tendency measures, dispersion and cross-tabulation the variables of interest were analysed in the relationship between solar-electrified and non-electrified. The difference in the responses between the two groups provided the basis for explaining how solar PV electrification has been responsible for the observed differences. Significant differences were analysed using statistics with p-values ($p<0.05$) considered statistically significant.

3. Results

3.1 Electrification Status and Television Viewing

Television provides access to information and entertainment to improve quality of life. The results in Table 1 revealed that, in the solar-electrified households, about 22% used solar PV to power their television, while in the non-electrified households (Note 1), about 5% used car battery to watch television and only 1% used a diesel generator. An overwhelming majority of 94% of the non-electrified households did not have access to television. A two-sided chi-square asymptotic significance (Sig. = 0.000), indicated significant difference in access to television between the two groups.

Table 1. Access to television by household

Access to TV	No Access	Access by Solar PV	Access by car battery	Access by generator**	Total
Solar-electrified household	73 (76%)	21 (22%)	2 (2%)	-	96 (100%)
Non-electrified household	106 (94%)	-	6 (5%)	1 (1%)	113 (100%)
Total	179 (86%)	21 (10%)	8 (3.5%)	1 (0.5%)	209 (100%)
	Pearson Chi-Square = 28.892		df = 3	Asymp. Sig. = .000	

Note: **Using "with" and "without" comparative method, the 1% user of diesel were placed under non solar-electrified (non-electrified households)

The study results presented in Table 2 revealed that on average, solar-electrified households could view television for 2.5 hours/day (median), while non-electrified households who used car batteries could view television for an average of 1.5 hour/day (median).

Table 2. Number of hours of watching television per day

	Mean	Median	Std. Deviation	Min.	Max.	n
Solar-electrified						
Farming	2.05	2.00	0.63	1	3.5	69
Teaching	2.20	3.00	0.45	1.5	3.0	12
Public Service	1.50	1.50	0.75	0.5	2.5	10
Social Worker	2.10	2.00	0.65	1.5	3.0	5
(Average)	2.25	2.50	-	-	-	
TOTAL						96
Non-electrified						
Farming	1.20	1.40	0.38	0.5	1.5	78
Artisan	1.30	1.30	0.54	0.5	2.0	10
Teaching	1.50	1.50	0.53	1	2	10
Public Service	1.00	1.00	0	1	1	10
(Average)	1.00	1.50	-	-	-	
TOTAL	1.20	1.34				108

3.2 Ownership of Television Because of Energy Services and Income

The study further examined whether the surveyed households owned their television because of the availability of energy services - solar PV, car battery, or generator. The results in Table 3 showed that about 12% of the solar-electrified households owned television because of the availability of solar PV. Households that acquired television due to the availability of solar PV were headed by people (4.2%) whose incomes fell within US$ 1.08–2.17/day, and household heads (7.3%) whose income are likely to exceed US$ 2.17/day. Non-electrified households that acquired television as a result of the availability of car battery were headed by people (1 percent) whose income fell between US$ 1.08–2.17/day. None of the households headed by people with income below US$ 1.08/day owned a television. The low significance values of 0.001 ($p<0.05$) for both Goodman & Kruskal Tau and uncertainty coefficients, indicate an association between income levels above US$ 1.08/day and television ownership.

3.3 Avoided Cost of Using Solar PV for Television Instead of Car Battery

The study analysed the avoided cost of using solar PV for television instead of car battery. Adapted from Maine State Planning Office, the avoided cost represents the amount of money that is not spent (therefore ‘saved’) by a household to recharge a car battery when solar PV option exists. According to Schmidt (2014) when an action prevents a future cost, the result is called an avoided cost if it is reasonably certain that the cost would have appeared without the action

For this purpose two indicators were analysed: (1) number of hours of television viewing per day; and (2) monthly costs of viewing television with solar PV and with car battery. Table 5 showed the average hours of television viewing per day and the cost avoided by the use of solar PV instead of a car battery. The results indicated that on average, solar-electrified households gained about 1.0 hour/day (30 hours/month) of television viewing than non-electrified households, who use car batteries. To determine the monthly cost of viewing television, the data presented in Table 4 were used to estimate the daily energy consumption and hence the cost of viewing television with a 50Wp solar PV.

Table 3. Assets owned because of energy services and income

Expenditure (Note 2) /Income Per day (USD)	Assets owned because of energy services	Solar-electrified Household		Non-electrified Household		Total	
Up to US$1.08	Radio	2	2.0%	5	4.4%	7	3.2%
US$1.08 – 2.17		4	4.2%	5	4.4%	9	4.3%
>US$ 2.17		7	7.3%	6	5.4%	13	6.2%
Up to US$1.08	Television	0	0	0	0	0	0
US$1.08 – 2.17		7	7.3%	1	0.9%	8	3.8%
>US$ 2.17		4	4.2%	0	0	4	1.9%
Up to US$1.08	Tape player	4	4.2%	3	2.7%	7	3.2%
US$1.08 – 2.17		11	11.4%	7	6.1%	18	8.6%
>US$ 2.17		12	12.5%	0	0	12	5.7%
Up to US$1.08	Table lamp	1	1.0%	0	0	1	0.5%
US$1.08 – 2.17		0	0	0	0	0	0
>US$ 2.17		0	0	0	0	0	0
Up to US$1.08	Fan	0	0	0	0	0	0
US$1.08 – 2.17		0	0	0	0	0	0
>US$ 2.17		1	1.0%	0	0	1	0.5%
Up to US$1.08	None	10	10.4%	32	28.4%	42	20.1%
US$1.08 – 2.17		17	17.8%	33	29.2%	50	24.0%
>US$ 2.17		13	13.5%	18	15.9%	31	14.8%
Up to US$1.08	Other	0	0	0	0	0	0
US$1.08 – 2.17		1	1.0%	0	0	1	0.5%
>US$ 2.17		2	2.0%	3	2.7%	5	2.4%
Total		96	100%	113	100%	209	100%

US$ 1.08 – 2.17 per day

Goodman & Kruskal Tau value = 0.441 Sig. = .002; Uncertainty coeff = 0.266 Sig.=0.001

US$ 2.17 per day

Goodman & Kruskal Tau value = 0.249 Sig. = 0.008; Uncertainty coefficient = 0.253 Sig.=0.001

Table 4. Daily energy consumption of appliances (50Wp solar PV household)

Load	Daily Use		Wattage		Total Energy Consumption (watt-hrs)
Radio	5 hours	x	20 watts	=	100
Television (black & white)	2.25 hours	x	30 watts	=	67.5
Lighting	6 hours	x	2 x 7 watts	=	84
Total Daily Energy Consumption					251.5 watt-hrs

Using a monthly fee of US$ 1.63 being the fee-for-service for a 50Wp solar home system in the surveyed communities, the cost of television viewing was calculated as: [(67.5 watt-hrs/day) ÷ (251.5 watt-hrs/day)] x US$1.63 = US$ 0.44. On average the non-electrified households recharged their car batteries every week mainly for television viewing and they paid a fee of about US$ 0.54-1.00 per week. A zero transportation cost is also assumed because car batteries were sometimes carried on bicycles or transported free-of-charge to nearby towns for recharging. In Table 4 the avoided cost of television viewing by a household using solar PV instead of car battery is demonstrated.

Table 5. Avoided cost of T.V Viewing by solar PV instead of car battery

	Solar-electrified Households (with solar PV)	Non-electrified Households (with car batterry)
No. of hours of TV viewing per day (black/white)	2.0 - 2.5	1.0 - 1.5
Average hours of TV viewing per month	2.25 x 30 = 67.5	1.25 x 30 = 37.5
Cost of battery charging for TV viewing per week	-	US$ 0.5-0.6
Monthly costs of viewing TV (with solar /with car battery)	US$ 1.00	US$ 2.17
Cost of TV viewing per hour	US$ 0.015	US$ 0.058
Avoided cost per hour	US$ 0.043	
Avoided cost per day (@ 2.25 hours/day)	US$0.10-0.117	
Avoided cost per month	US$ 3-3.51	

3.4 Electrification Status and Energy Device for Radio

In off-grid rural communities radios are normally powered by dry-cell batteries, car batteries, solar PV, or generators. In Table 6 the proportions of energy services used for powering radios in the surveyed communities are shown. While the non-electrified households relied mainly on dry-cell batteries (81%) and car batteries (4%); solar-electrified households used mainly solar PV systems (69%) and dry-cell batteries (24%). Only 11 % of the respondents did not use a radio. In all about 89% used radio.

Table 6. Type of energy services for powering radio in households

Type	Solar-electrified	Non-electrified	Total Respondents
No radio	7 (7%)	16 (14%)	23 (11%)
Solar PV for radio	66 (69%)	-	66 (31%)
Drycell battery for radio	23 (24%)	92 (81%)	115 (55%)
Generator for radio	-	1 (1%)	1 (1%)
Car battery for radio	-	4 (4%)	4 (2%)
Total	96 (100%)	113 (100%)	209 (100%)

Note: Some of the percentages do not add up to 100 because they were rounded up.

3.5 Number of Hours of Radio Listening

In this analysis the number of hours of radio listening per day is used as a proxy for measuring the impact on households' radio information acquisition. The assumption is that consumers benefit if they obtain more listening time at a lower cost per hour. The results in Table 7 indicated that on average radio listening in solar-electrified households was 5 hours/day (mean), while in non-electrified households it was 6.31 hours/day (mean). A significant value of 0.001 ($p<0.05$) indicates a significant difference in radio usage per day between households with and without solar PV.

Furthermore, by introducing the type of occupation as a layer (intermediary) variable, the results showed that on average, farmers in non-electrified households listened about 2 hours/day more than farmers in solar-electrified households. Teachers in non-electrified households listened about 2 hours/day more than teachers in solar-electrified households. In non-electrified households, artisan(s) listened to radio for about 12 hours/day. There was no significant difference in the radio usage of charcoal burners in the two groups of households. Data for public workers were inconsistent. A significant value of 0.000 ($p<0.05$) for the linearity and association measures, indicate a likely linear association between occupation and radio usage per day.

Table 7. Hours of radio listening per day by occupation

	Mean	Median	Std. Deviation	Min.	Max.	n
Solar-electrified						
Farming	5.00	5.00	1.67	3	9	69
Teaching	5.00	4.00	3.95	1	11	12
Public Service	5.00	5.00	0.00	5	5	10
Social Worker	5.00	5.00	0.00	5	5	5
(Average)	5.00	5.00	-	3.5	7.5	
TOTAL						96
Non-electrified						
Farming	7.90	7.00	3.23	5	19	78
Artisan	12.20	12.00	1.75	10	15	10
Teaching	7.00	7.00	0.00	7	7	10
Public Service	9.50	9.00	1.51	8	12	10
Charcoal Burner	6.20	5.00	2.77	3	11	5
(Average)	6.31	7.00	-	6.6	12.8	
TOTAL						113

3.6 Hours and Costs of Radio Listening and Television Viewing

In off-grid rural communities, dry-cell batteries are among the major sources of energy for powering radio for entertainment and information. Though radio provides valuable information on health, education, politics etc to improve the quality of life of families and individuals, its recurrent cost can be relatively high if one depends solely on dry-cell batteries.

The results in Table 8 indicated a difference in average expenditure on dry-cell of about US$ 1.0 per month being the amount avoided by using household solar PV instead of depending solely on dry-cell batteries for radio listening. Knowing the average hours of radio listening per day, the number of listening hours per month was calculated. Dividing the total cost of dry-cell used per month in both households by radio listening hours per month, the cost per listening hour was relatively less in the solar-electrified households than non-electrified households (Table 9). A significance value of 0.000 ($p<0.05$), indicate a statistically significant difference between the households with and those without solar PV. Table 10 and Table 11 provide summary data on hours and costs of television viewing and radio listening.

Table 8. Total cost of dry-cell batteries used per month by households

	Mean	Median	Std. Deviation	Minimum	Maximum	N
Solar-electrified	US$ 2.70	US$ 1.77	2.24	0.00	8.48	84
Non-electrified	US$ 3.78	US$ 3.26	2.54	0.33	10.09	98
Total	US$ 3.28	US$ 2.61	2.46	0.00	10.09	182
F-value = 9.296 df = 1 Sig. = 0.003						

Table 9. Price and quantity of radio listening in surveyed households

	Hrs/day	Hrs/month	Cost/month	Cost/hr	Assumption (average)
Solar-electrified	5.00	150	(US$ 2.70)	(US$ 0.018)	Cost per listening hour using solar PV
Non-electrified	6.31	189	(US$ 3.78)	(US$ 0.020)	Cost per listening hour using drycell radio

Table 10. A matrix of hours and costs of television viewing

	Solar-electrified household	Non-electrified household
Hours (mean) of television viewing per day	2.25	1.25
Hours (median) of television viewing per day	2.50	1.50
Cost of television viewing per hour	US$ 0.015	US$ 0.058
Avoided cost per month of television viewing using solar PV instead of car battery	US$ 3.00	

Table 11. A matrix of hours and costs of radio listening

	Solar-electrified household	Non-electrified household
Hours (mean) of radio listening per day	5	6.31
Hours (median) of radio listening per day	5	7
Cost of radio listening per hour	US$ 0.018	US$ 0.020
Cost of radio listening per month	US$ 2.70	US$ 3.78
Avoided cost per month of radio listening using solar PV instead of drycell battery	US$ 1.08	

In Figure 2 the costs of television viewing with and without solar PV are analysed. The results showed relatively low cost of viewing televison with solar PV compared to that of using car battery or a few cases using a generator. Again in Figure 3 the costs of radio listening using solar PV electricity were relatively low compared to that of using drycell batteries. Whereas solar PV systems have components to regulate usage and hence household users have limitations with respect to hours of usage. In the case of non-electrified households users usually contnue using their radio until their batteries gradually get discharged, hence they could have longer hours of usage that resulted in higher cost.

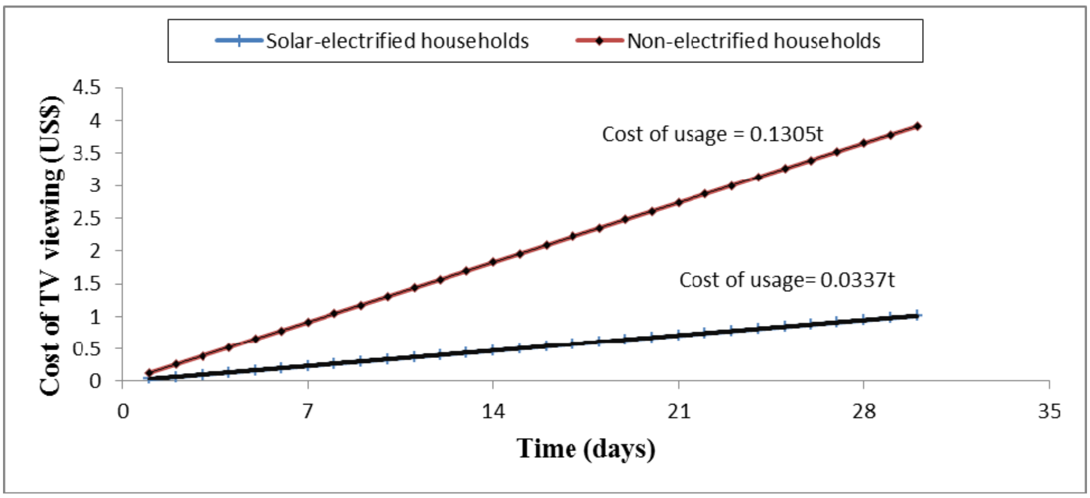

Figure 2. Costs of television viewing in solar-electrified and non-electrified households

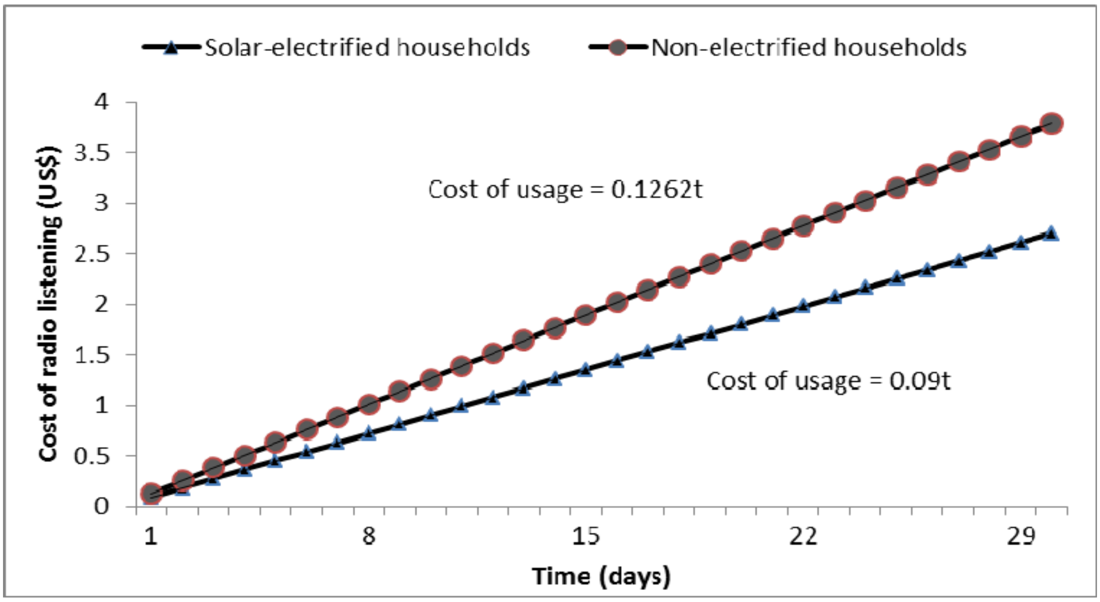

Figure 3. Costs of Radio Listening in Solar-electrified and Non-electrified Households

4. Discussion

With regard to television viewing, the results revealed that the proportion of solar-electrified households who used television was about four times that of the non-electrified households. The results further revealed that the availability of solar PV in the households was an important factor that influenced ownership of television. This finding confirms a study on the socio-economic impact of rural electrification in Namibia, which found that both grid and solar PV electrification enabled more households to own television and this was an important benefit (Wamukonya & Davies, 2001). Assets ownership is considered as a measure of wellbeing and living standards of a household or an individual (Ghana Statistical Service, 2005 a,b,c,d).

Household income emerged as a factor, which influenced television ownership. The results revealed that in both solar-electrified and non-electrified households, where televisions were used the incomes of the household heads exceeded US$ 1.08/day. None of the households headed by people with income below US$ 1.08/day owned a television. The study found a linear relationship between income levels above US$ 1.08/day and television ownership. The association between television ownership and higher income is reported by other studies (Madon & France, 2003). This result suggests that though the availability of solar PV enables households to have access to electricity for television viewing, the income factor is likely to eliminate the poor from the benefit of access to solar PV electricity for television information and entertainment. Households headed by the poor whose income fell below the US$ 1.08 (Note 3) /day poverty line (Reddy & Minnoiu, 2006; Zeller, 2004), are less likely to own a television and hence may receive relatively less information and entertainment through television viewing.

In terms of monetary benefits, the study found that in the surveyed communities solar-electrified households could avoid a monthly expenditure of about US$ 3.00 per household, being the estimated monthly cost of charging a wet battery for television viewing. According to Plastow and Goldstone (2001) rural households in developing countries typically spend between US$3 and US$20 per month on kerosene, candles, or other energy products. It is reported that in Sri Lanka and Indonesia, recurrent costs on kerosene, candles and batteries could reach $10-$30 per month (Cabraal et al., 1996).

Additionally, the solar-electrified households gained more television viewing hours (1 hour/day) or 30 hours/month than non-electrified households, who depended mostly on car batteries. These findings suggest that in off-grid rural communities: first, households with solar PV are likely to gain more hours of television viewing time; and second, spend relatively less money on the energy source for television viewing than households without, and hence achieve greater benefits and impact. Solar-powered television benefits rural households by providing access to health, education, business and environmental information to improve their standard of living. Rural solar PV electrification programmes must therefore be linked to programmes aimed at providing knowledge and information on agriculture, health, education etc. for quality of life improvements. Public programmes that help to expand access to and proper utilization of basic amenities assist in reducing poverty (Ghana Statistical Service, 2001).

Dry-cell batteries and solar PV were the two main energy carriers used for powering radio. However, the estimated consumption of dry-cell batteries differed between the solar-electrified and non-electrified households. The results revealed that the non-electrified households consumed more radio listening hours (mean of 6.3 hours) than solar-electrified households (mean of 5 hours) and hence paid more price per listening hour of radio. Average radio listening of 6.8 hours on weekdays and 6.4 hours on weekends were reported in a study in rural Kenya (Gathigi, 2009). High dependence on non-rechargeable dry-cell batteries is associated with high recurring cost. The impact of solar PV electrification on radio information is much felt if it improves listening hours at a lower cost compared to the use of dry-cell batteries. For this reason the number of hours of listening to radio was used as a proxy indicator for measuring impact on radio information acquisition.

Knowing the total hours of radio listening per month and the monthly cost of dry-cell batteries, the costs per hour of households with and without solar PV were compared. The results indicated a lower price per hour of radio listening in solar-electrified households than non-electrified households. In dollar equivalent, the costs per listening hours of radio obtained in both solar-electrified and non-electrified households are fairly consistent with the results of (Barnes, 2002); though there were little variations. The results suggest that rural households using solar PV electricity to power their radio are likely to benefit from lower cost per listening hour. This is a significant benefit, which can contribute to household savings to improve quality of life.

5. Conclusion

The study had shown that solar-electrified households achieved greater benefits by gaining more hours of television viewing and at the same time spent relatively less money compared to the non-electrified households. The results further demonstrated that the costs per hour of radio listening and television viewing were significantly lower in the solar-electrified households than non-electrified households who used dry-cells for radio listening and car batteries for television viewing. It was found that the availability of solar PV in households greatly influenced television ownership. Furthermore, the study revealed a linear relationship between household incomes above the international poverty line and television ownership. The difference in the responses provided by households with and without solar PV suggests an overall impact of solar PV on television viewing and radio listening. We conclude that once quantitative data are made available, the decision on the use of solar PV as a useful alternative for off-grid electrification will be apparent.

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Notes

Note 1. Non-electrified households were those "without solar PV" and therefore the very few users of diesel generators without solar PV were included in this category for the "with" and "without" comparative analysis.

Note 2. Expenditure was used as a proxy for income. The computed values were: US$ 1-1.08/day; US$ 1.08-2.17/day; and above US$ 2.17/day. See Table 3.

Note 3. The US$ 1 per day poverty line is actually US$ 1.08 per day (Reddy and Minnoiu, 2006; Zeller, 2004).