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Lighting up the villages: livelihood impacts of decentralized stand-alone solar photovoltaic electrification in rural northern Ghana

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Abstract

The dynamics of solar photovoltaic (PV) technology dissemination and utilization has taken center stage in recent years on a global scale, aiming to partly address prevailing rampant energy poverty situations particularly in developing countries. This paper evaluates a flagship electrification project called Ghana Energy Development and Access Project (GEDAP). We purposively sampled 250 solar users in 65 villages across 6 districts in the Upper West region which has the country's lowest level of electricity access and possibly the highest proportion of abject poverty among its inhabitants compared to the rest of the country. Based on the survey, it can be said that the overall impact assessment of the GEDAP-sponsored off-grid solar PV systems on the quality of life of the local beneficiaries was found to be positively marginal. Among all livelihood assets considered, social capital was markedly enhanced by the provision of modern energy services via isolated solar PV systems. Bottlenecks were identified, including limited system wattage capacity, slight dysfunction of some balance of components, higher interest rates, low technical know-how and inadequate monitoring, all of which are negatively affecting the sustainability of the project. Our findings also indicate that satisfaction derived from solar PV electricity supply among local solar customers differed for varied reasons as follows: moderately satisfied (43%), satisfied (52%), and dissatisfied (5%). For a decisive enhancement of rural livelihoods, we strongly recommend up-scaling system wattage capacity and coverage to build up new or improve upon existing livelihood assets through diversification of the income sources of the local inhabitants.

1.0 Introduction

1.1 Background information

Energy availability and its utilization remain crucially important for accelerated economic growth and technological advancement in today's globalized "village". The demand for conventional fossil fuel resources has shown tremendous increase along with its attendant global environmental consequences. The U.S. Energy Information Administration (EIA) recently forecast strong global energy consumption growth from 524 quadrillion British thermal units (Btu) in 2010 to 630 quadrillion Btu in 2020 and to 820 quadrillion Btu in 2040, representing about 56% growth between 2010 and 2040 **[1]**. Despite this substantial increase in energy consumption, in 2011 approximately 1.3 billion people had no access to modern electricity services, constituting about one-fifth of the global population, while over 2.6 billion people depended on traditional biomass for cooking and heating **[2]**. Of this un-electrified global population, about 599 million people, 68%, come from Sub-Saharan Africa alone **[2]**. Accessibility to reliable modern energy services has been widely documented as a potentially powerful tool for critical economic, environmental and developmental issues facing the world today as well as for achieving the Millennium Development Goals **[3]**, **[4]**, **[5]**, **[6]**.

Ghana has largely succeeded in implementing the National Electrification Scheme (NES) instituted in 1989, which was accelerated by the complementary Self-Help Electrification Program (SHEP) in 1990, with the ultimate aim of achieving universal access to electricity by 2020 **[7]**. This has contributed to the current electricity penetration rate of about 72% with an installed generation capacity of about 2000 Megawatt (MW), predominantly from hydropower and complementary combined cycle thermal generating systems as of 2011 **[6]**. Centralized grid-connected electricity generation is widely implemented in rural electrification (RE) programs in Ghana, as in many developing countries, due to its relatively cheaper costs and ability to provide a wide range of modern energy services to end-users. However, this grid-dominated electrification in Ghana has its own challenges, such as frequent power outages, power rationing and technical losses, making it difficult for the nation to be energy secure. In addition, with mostly low population densities and patchy, dispersed settlements in rural communities, centralized grid electrification may not be economically viable enough, in the short-term, to power these remote communities. Therefore, the need for intensified deployment of alternative, decentralized Renewable Energy Technologies (RETs), e.g. off-grid solar PV electrification in the case of Ghana, may be a much more suitable option. Globally, the installed solar PV capacity has augmented tremendously from 3.7 GW in 2004 to 139 GW in 2013 **[8]** (**Figure 1**). Decentralized stand-alone solar PV electrification, as a potentially viable means of RE for socio-economic improvement of rural populations, has also been widely sponsored in many other developing countries in Southern Asia, Southern Africa, East Africa and other West African states **[9]**, **[10]**, **[11]**, **[12]**, **[13]**, **[14]**, **[6]**, **[15]**, **[16]**. Similarly, Ghana has experienced an increasing historical trend of off-grid solar PV installations since 1991 **[17]**. However, this easily distributed solar PV technology is rather limited in scope and application in Ghana.

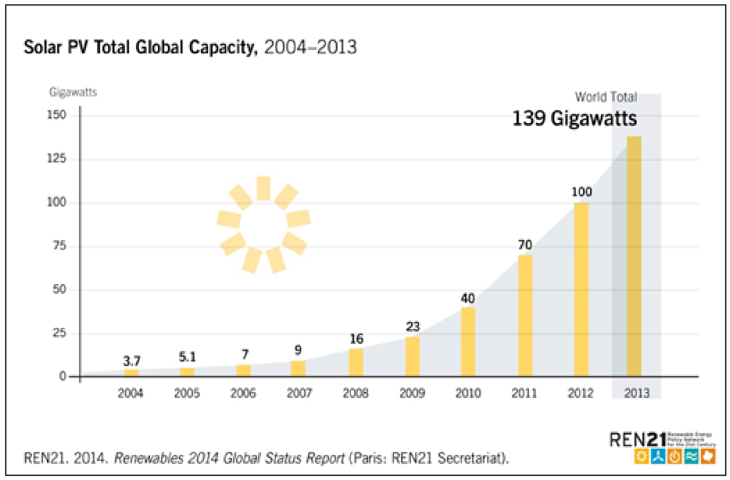
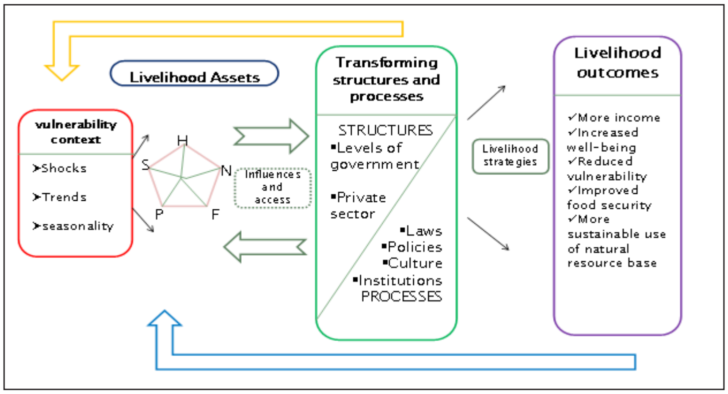


Figure 1: Increasing global trend of solar PV capacity installations from 2004 to 2013

Being located in the tropics, Ghana is endowed with an abundance of solar resources, receiving daily solar irradiation of between 4 and 6kWh/m^2 and a corresponding annual sunshine duration of 1800 - 3000 hours **[18]**. The Upper West region, where this study was conducted, has one of the highest direct solar irradiation levels of about 5.6 KWh/m^2 as compared to the rest of the country **[19]**, **[18]**. Yet this huge solar energy potential is still under-utilized. The Ministry of Energy and Petroleum (MOEP) projected an augmentation of the contribution of RETs to the national energy generation mix from less than 1% currently to 10% in 2020 **[18]**. To help realize this ambitious energy target, demonstrable efforts have been made through the implementation of some notable solar projects such as the Renewable Energy Services Project (RESPRO) in 1998 and the Renewable Energy Development Project (REDP) in 2000 until 2002 **[20]**, **[4]**, **[17]**, and the Ghana Energy Development and Access Program (GEDAP) on which this study is focused (see sub-section 1.2 for project details). A few studies carried out as part of RESPRO and REDP in particular indicated that they were unsuccessful and unsustainable **[21]**.

Currently, a total of over 6,000 off-grid solar PV systems have already been installed across the length and breadth of the country, representing an installed capacity of about 3.2 MW in the year 2011 **[7]**. As **[22]** argues, the popularity of the solar PV technology in itself is not sufficient to say that the lives of the rural poor are improving dramatically as a result of its introduction. Even though there has been emphasis on RET deployment efforts in the Ghanaian energy strategy, their contribution to improving local livelihood assets is not adequately understood and documented. Moreover, since the inception of GEDAP, no impact assessment has been carried out to see how the project is affecting the livelihoods of the rural beneficiary communities, apart from this study. Unlike many socio-economic impact studies of SHSs, which chiefly focus on social and economic aspects, this study included more livelihood capital forms, such as natural, human and physical, in the impact assessment of GEDAP. Thus, we used the elements of popular concept of sustainable livelihood framework in **[23]**, **[24]**, **[25]**, **[26]** to better understand how these capital forms were affected by the provision of modern energy services via solar PV systems (see **Figure 2**).



Source: Adopted from DFID **[25]**

Figure 2: Sustainable livelihood framework

This article therefore aims at bridging the gap in understanding regarding the off-grid solar PV electrification-livelihood assets nexus. We also sought to explain the multiple effects of solar PV electrification on livelihood capital forms for rural inhabitants at the household, community and national levels (**Figure 3**). We hypothesized that if rural private households are left without the provision of modern energy services through RE, this inaccessibility to electrical power will not only negatively affect their quality of life but also hamper sustainable livelihood improvement opportunities. The research objectives were three-folds: firstly, to find out the level of impact of the decentralized off-grid solar PV electrification on people living in un-served remote rural communities; secondly, to identify bottlenecks prohibiting successful deployment of solar PV technology; and thirdly, to assess the sustainability potential of GEDAP implemented with particular reference to solar home systems (SHSs), solar street lighting systems (SSLs) and solar refrigerators (SRs).

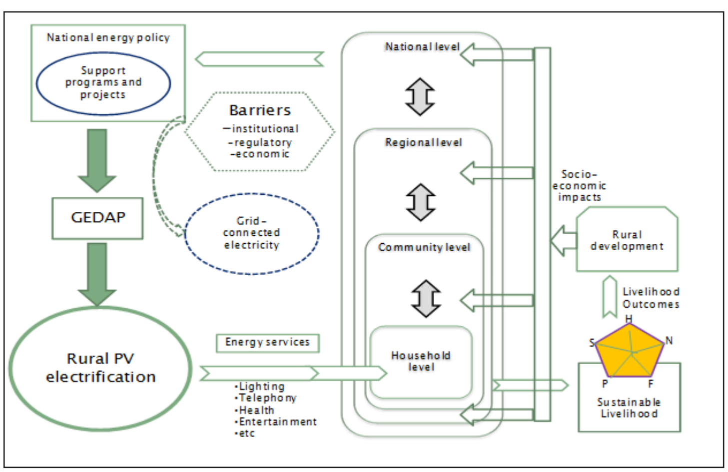


Figure 3: Diagrammatic illustration of the multi-functional dimensions of rural electrification in the context of Ghana.

1.2 GEDAP portfolio

GEDAP was implemented from 2007 to 2012. This five-year flagship energy project of the Government of Ghana received multilateral financial support from the World Bank, Global Energy Facility, African Development Bank, Global Partnership on Output-based Aid, African Catalytic Growth Fund, Swiss Agency for Development and Cooperation and Government of Ghana. The private sector also supported the project financially. GEDAP's approved budget was about US$235.28 million. The main developmental objective of GEDAP was "to improve the operational efficiency of the power distribution system and increase the population's access to electricity and help transition Ghana to a low-carbon economy through the reduction of greenhouse gas emissions" **[7]**. Though GEDAP covered a broad range of centralized power generation, transmission and distribution systems as well as RET development components (especially solar PV technology), this study focuses principally on the latter.

As of 2011, a total of about 106 CHIPS compounds[1] were provided with about 316 SHSs, SSLs and SRs with a combined wattage capacity of about 54,000Wp across the length and breadth of the country in the first phase of GEDAP implementation **[7]**. These SHSs, SSLs and SRs had varying wattage capacities (see **Table 1**). The SHSs had at most 6 light points. The rationale for targeting rural clinics in the first phase of GEDAP was probably motivated by the critical role these health centers play in saving many lives in less privileged rural communities where maternal and infant mortality rates are likely to be high. The cost and maintenance of the solar PV systems installed in rural health facilities were completely covered by GEDAP through the Ghanaian Government.

The second GEDAP phase focused on its individual ownership policy and was piloted in the districts of Sissala West, Sissala East and Lawra/Nandom. The rationale was partly to make SHSs more affordable and accessible to interested low income rural households to improve their livelihood. The financing model for the individual household SHSs was such that GEDAP absorbed about 80% of the start-up investment cost while the rest of the cost was borne by the beneficiary household heads who were took loans from rural banks with installment repayment regimes over about 2 years. Two private energy companies, namely Wilkins Engineering Ltd and Toyola Solar Company, were contracted to sell, install and maintain SHSs for the individual solar customers. While Wilkins Engineering Ltd only provided standardized 50Wp SHSs (with accessories like televisions, wires, cables), Toyola solar company on the other hand offered various options (50Wp, 30Wp, 15Wp, 10Wp) without accessories to suite the financial needs of individual solar customers (see **Table 1**).

Apart from lighting and refrigeration as primary intended uses, SHSs were also used for phone charging in rural villages (see Result Section for details on more energy services).

[1] CHIPS compounds refer to Community-based Health Planning and Services Initiative which was established in 1999 as a national health policy measure which aims to help address health barriers due to geographic locations such as deprived and remote areas of rural districts in Ghana. This will make healthcare delivery very accessible and will combat needless infant and maternal mortality in the country.

Table 1: Specifications of solar PV systems commonly used in GEDAP.

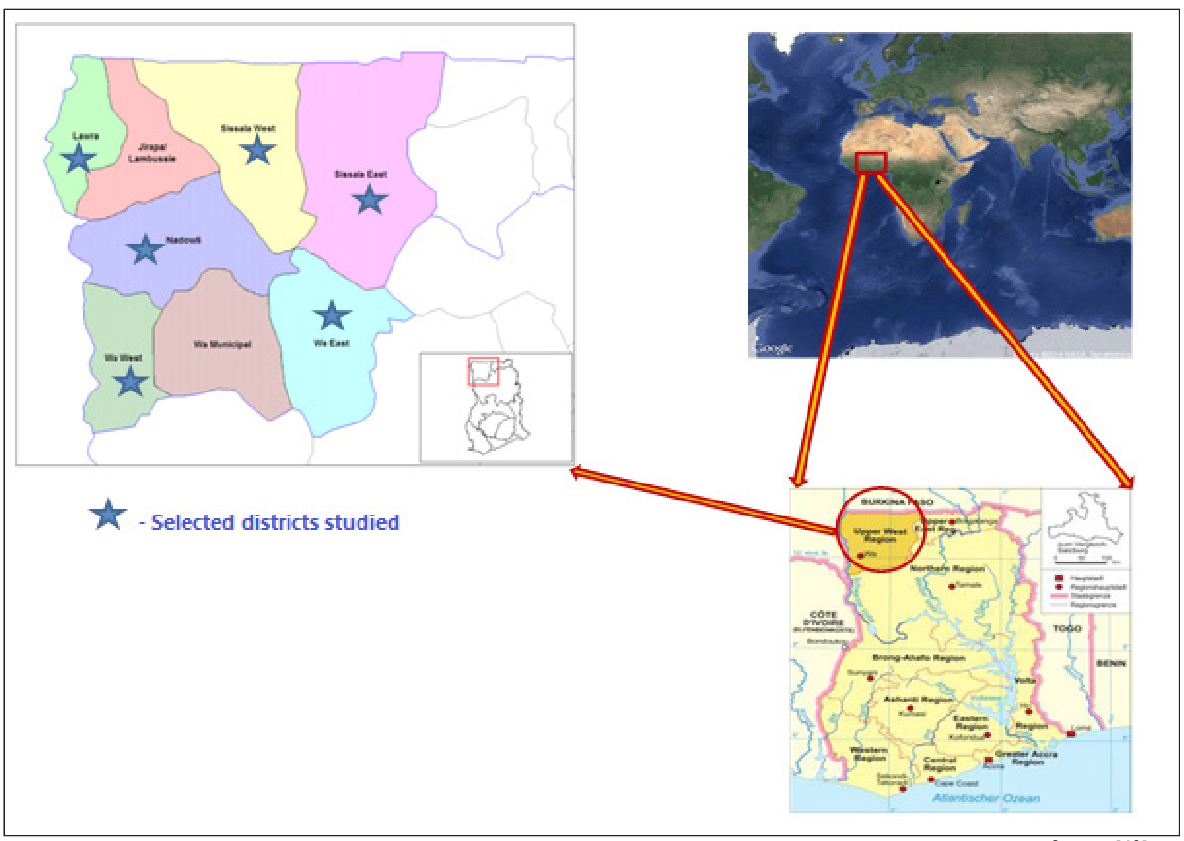
Applications and locations	Wattage capacity
Public rural clinics	
Solar home systems for nurses quarters	100Wp
Solar vaccine refrigerators in rural clinics	250Wp
Street lighting systems for health centers	300Wp
Street lighting systems for CHIPs	200Wp
Community centers	
Community street lighting systems	100Wp
Private households	
Wilkins solar home systems	50Wp
Toyola solar home systems	50Wp, 30Wp, 15Wp, 10Wp

2.0 Research materials and methods

2.1 Study area

The research was conducted in six administrative districts of the Upper West region (UWR) in northern Ghana (see **Figure 4**) from early March to late May, 2011. UWR has a land area of 18,476 km^2 constituting 12.7% of Ghana's total landmass and a population of 702,110, with 48.6% (341,182) males and 51.4% (360,928) females in 2010 **[27]**. As indicated in **Table 2**, UWR has the least electricity penetration rate in the country, 40% as of 2010 **[28]**. Thus, about 60% of mostly rural households have no access to clean, modern energy sources in the region. This region is ethno-linguistically diverse with major ethnic groups (local dialects) comprising Dagaabas (Dagaare), Sissalas (Sissali) and Waalas (Waali) respectively. This research targeted UWR because it has many installed GEDAP-sponsored off-grid solar PV systems, compared to the rest of the country, to help curb the problem of low electricity access and other socio-economic challenges facing the region. Due to a high level of poverty, the region experiences out-migration of the youth to the southern sector of Ghana in search of better economic opportunities **[29]**.

Approximately 90% of the inhabitants in the Sissala areas obtain their household income from subsistence agriculture **[30]** while about 10% of the inhabitants are in commerce such as buying and selling of food stuff, pito[2], poultry and livestock, clothing, flashlights and batteries, particularly during market days. This socio-economic situation is similar in the other studied districts.



Source: **[43]**

Figure 4: Map of Upper West region depicting the districts.

[2] Pito is a locally brewed alcoholic beverage and is prepared from guinea corn or maize and fermented with yeast. It is a favorite traditional drink in the three northern regions of Ghana.

Table 2: Regional electricity access in Ghana based on population size for 2010

Region	Access rate (%)
Greater Accra	97
Ashanti	82
Central	81
Brong Ahafo	68
Eastern	70
Western	68
Volta	65
Northern	50
Upper West	40
Upper East	44

Source: Ahiataku-Togobo [28]

2.2 Methods

2.2.1 Individual household solar PV survey

A reconnaissance survey was done together with a monitoring team from the Directorate of Renewable Energy Division. The rationale for the reconnaissance survey was:

1. to become familiar with the local environment within which this research was conducted and,

2. to know exactly where the individual household SHSs were installed.

The structured questionnaires were first of all pre-tested with a respondent from each of the Sissala West and Sissala East districts and was subsequently fine-tuned. The questionnaires addressed, among others, the following main issues:

- Available local energy sources before and after solar PV systems.
- Local perception on quality and quantity of available energy services including solar PV systems.
- Affordability of solar PV technology and financing model used in GEDAP.
- Maintenance and management of balance-of-components (BOCs).
- Bottlenecks and sustainability aspects of installed solar PV systems.

Using a purposive sampling technique, the individual SHS users were selected for face-to-face interviews. The questionnaires were administered with the assistance of local interpreters who translated questions asked in English into the local dialects (Dagaari, Sissali and Waali) for respondents who were illiterate. About 80% of respondents interviewed were household heads while 20% consisted of other household members. The household heads were particularly targeted because they were considered the spokespersons in their families in typically Ghanaian traditional settings. In terms of gender composition, 64% males and 36% females were interviewed due to the reluctance of female respondents to grant interviews for cultural reasons. The average size of the private households within the selected districts was about 6 people.

2.2.2 Communal solar PV survey

The survey also covered the communal solar PV systems. They are herein referred to as SHSs and SSLs installed mostly in CHIPS compounds and other public places such as local market centers, water collection points, community centers and schools within the selected districts. In this survey, at least one nurse from each selected CHIPS compound was interviewed in English regarding the general energy sources utilized and the functionality of the SHSs and SSLs with respect to delivery of health services to the patients. On average, 2 community nurses were residing in each rural clinic. Twenty-five out of about 32 beneficiary CHIPS compounds in the studied region were covered for the purposes of this study. The major criteria for selection of the 25 sampled villages included the presence of GEDAP-sponsored solar PV systems, accessibility to villages and a saturation point assumed to have been reached due to no significant new answers given by adding more respondents. Limited time resources was also a determining factor. However, a few SSLs installed via Ghana COCOBOD initiative at strategic public places such as market centers, water sources and community centers in Sissala East and Sissala West districts were also considered in this study. The deprived locations of such rural communities make them quite suitable for studying the impact of off-grid solar technology on their livelihoods. Group discussions and institutional interviews were also conducted for the purposes of triangulation. In total, 250 SHS users in 65 rural communities with approximately 409 installed solar PV systems within 6 selected districts were surveyed (see **Table 3**). Retrieval of relevant secondary data was also carried out.

Table 3: Sample design depicting details of districts selected, villages sampled, respondents interviewed and solar PV systems disseminated

Districts	Villages sampled*	Population size#	Respondents interviewed*	Installed PV systems§* (approx.)
Sissala West	10	49573	45	100
Sissala East	10	56528	35	75
Lawra/Nandom	12	100929	35	74
Wa West	14	81348	59	58
Wa East	9	72074	36	58
Nadowli	10	94388	40	44
Total	**65**	**454,84**	**250**	**409**

Source: §Data obtained from [7]; *Data obtained from fieldwork in 2011; #Data obtained from [27]

2.2.3 Data analysis

The primary data was analyzed using Statistical Package for Social Sciences (SPSS v. 22) and Microsoft Excel. In-depth content analysis of the interviews was done in order to gain insight into the contribution of off-grid SHS and SSL to the local inhabitants' livelihoods. For the economic evaluation aspect of GEDAP, the standard economic indicator tools such as Cost-Benefit Analysis (CBA) and Net Present Value (NPV) **[31]** were calculated for individual household solar customers in three pilot districts namely Sissala West, Sissala East and Lawra/Nandom. The economic analysis excluded SHSs and SSLs installed in public health facilities, schools and other public places due to the absence of initial costs borne by the beneficiary communities. We used the initial solar system costs (first investment costs) and benefits (avoided costs of using solar PV systems) in standard units (usually in US dollars) from the perspectives of local solar customers for the CBA/NPV calculations for possible direct comparison. NPV values are used for evaluating the economic merit of investment or development projects **[31]**. NPV was calculated using the mathematical formula below:

$$NB = B - C \qquad \text{Eq. 1}$$

$$NPV = \Sigma\, NBt / (1+r)^t, \text{ where } t = 1,2,3.....,n \qquad \text{Eq. 2}$$

B=Benefit(s) in terms of savings due to presence of solar technology,

C=Cost(s) of acquiring solar technology,

NPV=Net Present Value,

NB= Net Benefit,

t= Time (2 years),

r=Discount rate

3. Results

3.1 Rural energy sources and local satisfaction perception of energy services

From this survey, it was revealed that local people depended on a number of traditional energy sources such as lanterns, flashlights, candles, generators and oil-cotton mixed lamps for lighting before the solar PV systems were installed in the studied districts. While approximately 51% of local respondents relied on dry cell-powered flashlights for lighting purposes in the night, 46% of them used kerosene-based lanterns, 2% of them also used diesel powered generators and 1% of them used other sources such as candles and oil-cotton mixed lamps (**Figure 5**).

Bawakyillenuo **[20]** also reported that kerosene and dry cell batteries were most popular with people as energy sources in Ghana. More than half of the respondents who relied on using flashlights suggested that they were getting relatively better lighting from them as compared to other traditional sources of lighting. The unhealthy smoke from use of kerosene-based lanterns could lead to problems caused by indoor air pollution (IAP) such as chest pains and blackened nostrils, **[17]**, **[32]**, while generator use was associated with higher operational costs and excessive noise during the night. The frequent buying of dry cell batteries for their flashlights was also a financial burden for the local people to bear. This suggests that the traditional energy sources were used by rural people not because of their reliability and suitability but because of their availability, accessibility and affordability. For domestic cooking and heating, about 90% of respondents were dependent on unprocessed firewood, 9% used charcoal and about 1% made use of other sources such as kerosene and Liquefied Petroleum Gas (LPG).

With the intervention of GEDAP, beneficiary solar customers began to ''enjoy" the use of modern solar technology for better lighting and other associated energy services. In terms of local satisfaction perception of energy services provided by SHSs, 43% of the respondents were moderately satisfied, 52% were satisfied while 5% of them were dissatisfied with the solar PV electricity supply (**Figure 6**). Their reasons were varied. Those who were moderately satisfied indicated that existing solar energy services could be made better in terms of increasing quantity of energy supply and prompt handling of technical problems. The satisfied solar customers said that the solar energy services were more satisfactory than their traditional sources of lighting; while those who expressed their dissatisfaction about the solar PV systems pointed to frequent power cuts during the rainy season, unavailability of solar components on local markets, higher interest rates on the initial investment and that limited wattage capacity of the SHSs did not allow them to enjoy the full benefits of brighter lighting for longer hours in the night. These complaints were widespread among solar customers in some individual households particularly in Sissala West and Sissala East.

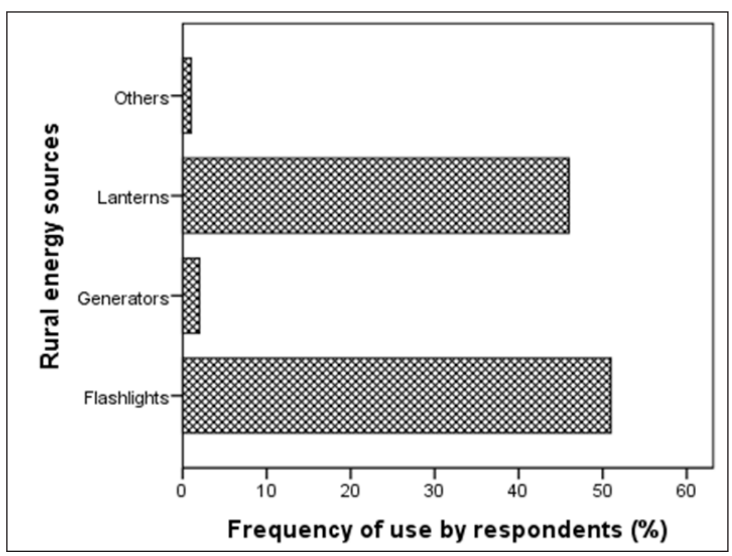


Figure 5: Rural energy sources and frequency of use by local people within studied districts.

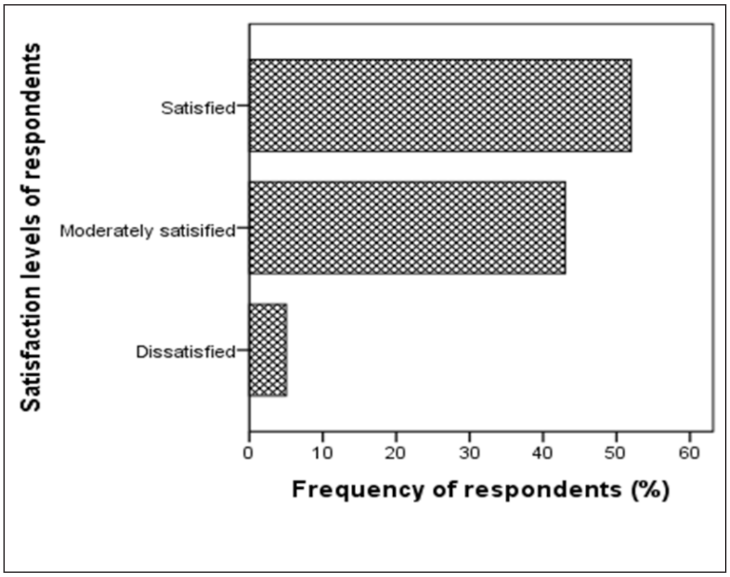


Figure 6: Local satisfaction perception of the off-grid solar PV energy services in both public health facilities and private households.

3.2 Solar PV impact on rural healthcare delivery

It was evident that the SHSs, SSLs and SRs mainly installed through GEDAP were found to be very helpful to the community nurses and the patients visiting such deprived off-grid communities. Obeng 17] states that the contribution of solar PV systems is strongly felt in a critical sector like the public health system located in off-grid rural communities. Our findings also revealed that the community nurses were able to use the better illumination of SHSs (see **Figure 7**) for emergency delivery cases at night (see **Figure 8**). This was a very effective replacement for the use of lanterns through which respondents complained of chest pains and blackened nostrils and flashlights with limited lighting during nocturnal emergency cases.

The proper functioning of SRs for 24hrs has contributed to infrequent travel by local nurses for long distances to district hospitals for the sole purpose of picking up chilled vaccines for vaccination exercises. This was similarly documented in Zambia by **[6]**. Similarly, **[32]** also reported improved health conditions, better personal hygiene and increased indoor air cleanliness as a result of renewable energy sources in Nepalese villages.

The nurses could conveniently read and write reports in the night with solar light as well as store perishable food stuff including drinking water in solar fridges. The SSLs installed within the premises of the health facilities provided the nurses and visiting patients' security (no fears of snakebites) at night which was not the case beforehand. Our findings with the SHSs installations show that they have reportedly contributed to about a 40% increase in successful deliveries and an approximately 50% increase in patients' attendance especially women and children at the Loggu health facility in the Wa East district. A similar trend was observed in the rest of the districts studied partly attributable to marginally improved health services.

Figure 7: Visual comparison between limited yellowish & smoky cotton lamp and far-reaching brighter solar PV bulb.

Figure 8: A community nurse checking the internal temperature of the solar-powered vaccine refrigerator and later attending to a 6-day old baby and mother at Nator CHIPS in the Nadowli district.

3.3 Solar PV influence on rural social services

The decentralized stand-alone solar PV systems were found in this study to be delivering a wide range of social services apart from improving primary healthcare provision to the disadvantaged rural dwellers in the studied districts. These included, among others, rural telephone use, entertainment/leisure, household and community security. With relatively high mobile phone penetration in Ghana, the only challenge confronting the residents especially in the remote rural areas is the non-existence of electricity **[33]**. Our survey findings revealed that the off-grid SHSs positively impacted rural mobile telephone use in the study area since rural dwellers avoided the herculean task of travelling longer distances only to recharge their phones at exorbitant prices. However, about 4 phones could be charged per day while general lighting could only last for about 1 or 2 hours per day due to limited wattage capacity. Those without SHSs had the opportunity to either charge their phones at neighbors' homes or some health facilities in all selected districts for free. This has allowed the local inhabitants to get in touch with close relatives and friends to exchange information and forge family relationships, as similarly documented in Nepal by Zahnd **[32]**. Those who had TVs attached to their SHSs had the opportunity to watch national and international news. Occasionally, solar customers together with other community members watched football games, especially in the evening as reported by respondents in Sissala West and Sissala East which hitherto was not possible.

The security of the household and community beneficiaries was considered in both GEDAP phases. The majority of the public health facilities visited were provided with security lights for resident nurses and visiting patients. For the individual solar customers, about 90% of SHSs with 50Wp provided by Wilkins Engineering Ltd had security lights while 10% of those SHSs with 30Wp and 10Wp, mostly supplied by Toyola Solar Company, were without security lights due the low wattage capacities. The installed SSLs via both GEDAP including those installed by COCOBOD Company also provided security for inhabitants (see **Figure 9**). The percentage share of importance of installed solar security lights was that, about 60% of the respondents indicated that they felt safer in their houses and communities than before. This is because the brightness of the solar lights drove away snakes and scorpions or allowed them to be seen and killed easily, which hitherto was only possible with the use of a movable light source (flashlights or lanterns). About 30% of the respondents were of the opinion that women and girls could safely fetch drinking water and perform other household chores due to brighter illumination from SHSs at night, while 10% of them reported a decline in domestic animal theft since thieves could easily be detected in these solar-electrified rural communities.

Figure 9: Solar street lighting systems (SSLs) installed at Kataah community center and clinic in the Wa East district.

3.4 Solar PV effects on natural environment and local climatic conditions

Though distributed off-grid solar technology does have positive environmental effects compared to conventional fossil fuel sources, it can possibly have negative consequences for the natural environment and local climatic conditions if not well managed. Our research findings revealed some teething problems with the BOCs of installed SHSs, while SSLs and SRs were still functioning properly. For the SHSs, a majority of respondents complained of the malfunctioning of the batteries (60%), solar bulbs (35%), switches (3%), controllers/regulators (2%) while none complained of panels and inverters (**Figure 10**). This shows that solar batteries, followed by solar bulbs are the weakest components of the solar PV system. According to **[34]** the batteries and regulators of SHSs had frequent problems in their research involving five regions of Ghana. When asked about what they did with the defective BOCs, 90% of the solar customers indicated they would be thrown into the bush while 10% of them said the broken BOCs would be handed over to officials from solar companies or MoEP for disposal. **Figure 11** shows pictures of some broken BOCs in the studied districts.

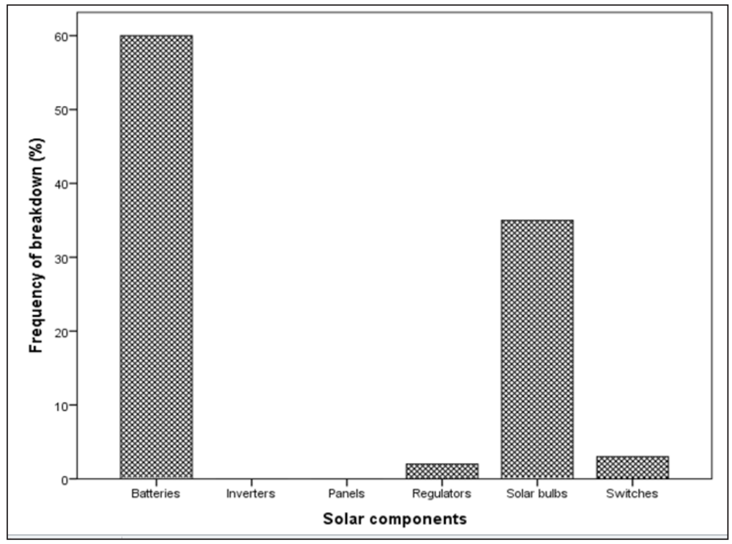


Figure 10: The percentage share of the frequency of breakdown of BOCs from solar PV systems.

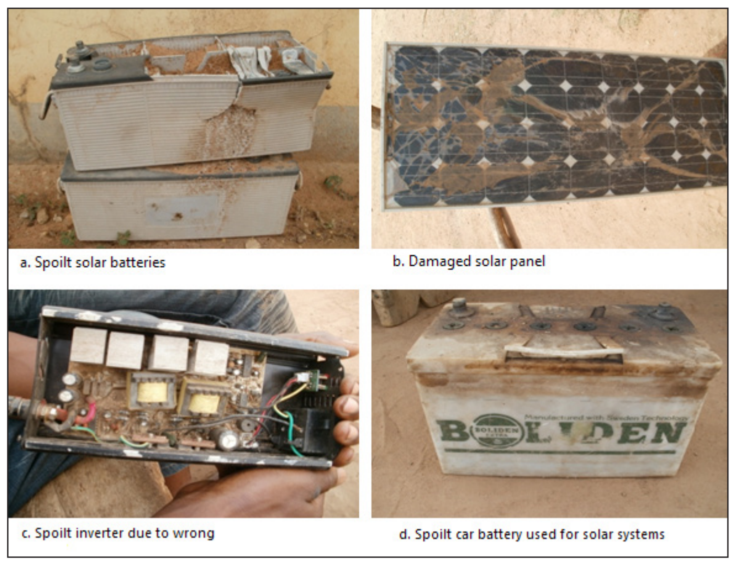


Figure 11: Damaged BOCs from solar PV systems and their potential cause of environmental pollution.

3.5 Solar PV influence on local economic environment

The impact of SHSs on the rural economy was found in this study to be considered weak by private solar customers since the SHSs were not meant for generating productive power to run agri-businesses and irrigation facilities for diversification of income sources but mainly for lighting. The NPV values calculated at 26% for Nandom Rural Bank in Lawra/Nandom district and 28% for Tumu Rural Bank in Sissala West and Sissala East were -0.37 and -0.50 respectively (see **Table 4**). An improvement in sales of goods in local shops was also reported due to prolonged opening hours (1or 2 hours) attributed to installations of SHSs. This did not influence their profit margins in any way however. According to [32], the presence of even small indoor solar lights in homes in a Nepalese village encouraged men and women to engage in income generating ventures e.g. bamboo weaving in the evenings. A shop owner in Challu village in the Sissala East district indicated that he saved some money since he seldom bought diesel to power his generator in the shop as a result of off-grid solar electrification. Another shop owner in Nyantie, Sissala West, was also quoted as saying that:

"I used to close my shop very early, that is, around 8pm every day, but now, I close it at about 10pm daily, especially in the dry season due to more sunshine for the solar panel. I wished the SHS could support the use of a deep fridge but now it is not possible. I have moved my TV set to my shop which has attracted a lot of potential customers and that increased my sales".

Table 4: Economic indicators

Economic indicator	Lawra/Nandom district	Sissala West & East districts
Benefit/Cost Analysis (BCA)	0.38	0.29
Net Present Value (NPV)	-0.37	-0.5

*Average respondent price values considered per year.
*Exchange rate between US$ and Ghc used: US$= 1.52Ghc (09.09.2011).
*Private household analysis only (excluding public health facilities).

3.6 Bottlenecks identified

Deployment and implementation of the decentralized stand-alone solar PV projects in rural areas in Ghana cannot be without challenges and this study sought to identify such drawbacks with particular reference to the GEDAP initiative for better planning of similar projects in the future. In evaluating the impacts of GEDAP on rural livelihoods, the following bottlenecks were identified:

- **Systems capacity:** The installed SHSs had limited wattage capacity leading to limited provision of solar energy services i.e. mostly lighting purposes in private homes and refrigeration for vaccine storage in rural clinics and not for productive uses by local beneficiaries to improve upon and diversify their livelihoods.
- **Balance-of-components (BOCs):** The unavailability of basic BOCs such as solar bulbs, batteries and so on at the village level for possible immediate replacement of defective BOCs is a serious threat to the sustainability of the GEDAP initiative.
- **Technical know-how:** This research revealed that many solar users had little or no technical know-how on SHS management, probably due to high illiteracy and/or inadequate sensitization before installation of the SHSs.
- **Interest rate on loans:** The relatively high interest rate of 28% and 26% charged on loans by participating Rural Banks in Tumu and Nandom, respectively, for private solar customers coupled with a relatively undeveloped local solar market generally in Ghana is a potential setback to solar technology diffusion in particular.
- **Grid extension:** Rapid extension of cheaper grid-connected electricity to rural areas is obviously recommendable but it is a subtle competitor to the off-grid solar technology in the sense that, a new expensive solar technology with limited energy services for low income people cannot be competitive enough. It is partly for this reason that the World Bank representative in Ghana intimated that the off-grid solar electrification via GEDAP may be at the wrong place at the wrong time since Ghana is making huge RE gains via the ongoing SHEP program unlike in Bangladesh and Sri Lanka where such off-grid projects worked quite well previously (Per. comm. with Mr Sunil Mathrani, World Bank Representative in Ghana, 6th April, 2011).
- **Monitoring exercises:** Inadequate monitoring exercises by solar technicians at the time of conducting this research could be a potential threat to the durability of installed solar PV systems and their accompanying energy services.
- **Regulatory framework:** Fortunately, the enactment of the recent Renewable Energy Law (Act 832) in 2011, which encompasses a feed-in-tariff, obligatory purchase, easy accessibility to grid infrastructure for interconnectivity and the establishment of a Renewable Energy Fund to ensure economic returns on investments, has almost solved some institutional and regulatory barriers. This may make RETs more attractive to potential investors and thereby expand the local market for renewable-based energy sources in Ghana.

4. Discussion

4.1. Livelihood capital forms-energy services nexus

The relatively high energy poverty situation in rural communities in Ghana has the potential to further impoverish the lives of people in such generally resource-poor areas if concerted energy efforts are not continuously taken by key stakeholders to address it. The deployment of isolated solar PV systems via GEDAP in such areas has led to the provision of essential energy services for these underprivileged rural dwellers despite limited systems capacity. From our survey findings, lighting was the major energy service (80%) provided by SHSs and SSLs, followed by rural telephone use and entertainment/leisure (55%), individual and communal security (30%), health (25%) while local employment, and heating and cooking services were non-existent (0%) (see **Table 5**).

Within the sustainable livelihood framework, five main livelihood capital forms ('pentagon') i.e. human, social, natural, economic and physical [26] are discussed here with respect to the aforementioned energy services provided through GEDAP. Livelihood improvement opportunities can potentially be stimulated among rural dwellers with accessibility to timely decentralized renewable energy-based electricity in particular. It was pointed out by [35] that there was a nexus between livelihood diversification and RE within the context of Nepal. The five main livelihood capital forms are tabulated against available energy services generated from SHSs as shown in **Table 6**.

Table 5: The percentage share of energy services supplied by SHSs and SSLs

Energy services by SHSs & SSLs	% share of respondents
Lighting	80%
Rural telephony & entertainment	55%
Individual & communal security	30%
Education	10%
Employment	0%
Health	25%
Heating &cooking	0%

Note: Total percentage share is more than 100% due to multiple answers provided by respondents.

4.1.1 Human capital

The human capital constitutes individual skills, ability to work, good health and physical capacity vital for successful implementation of various livelihood strategies **[26]**. It was assessed to be moderately transformed by available energy services for rural folks. For instance, solar refrigerators were used for storage of cooled vaccines for immediate healthcare services delivery and possible retention of community nurses to help bridge the rural-urban divide in terms of health delivery. The SSLs installed at vantage points for provision of security at night for women, girls and other community members made them feel secure and able to continue to work. The limited deployment of SHSs in basic schools, but only for rural clinics, was not enough to help empower young children and adults through education. These small incremental energy services are crucial in villages with high illiteracy rates and unhealthy smoke from lantern use thereby increasing their human capital base.

It has been reported that utilization of SHSs could lead to minimization of IAP **[17]**, **[32]**. However, the limited wattage capacity of the installed solar systems in question has undermined adequate transformation of the human capital base of the rural dwellers. As a result of no human capacity building opportunities, local people acquired no extra skills to increase their technical know-how with the off-grid solar technology. When BOCs break down without immediate replacement or maintenance, local people could resort to use of kerosene-based lanterns and risk the danger of respiratory infections through IAP. It is estimated that about 1.5 million people, especially women and children, suffer from debilitating respiratory infections though IAP per year worldwide **[36]**. The percentage share of solar customers who indicated that there were modest changes to their human capital situation due to the energy services provided was about 20%.

4.1.2 Social capital

The implementation of decentralized solar PV systems in rural communities seems to have gone a long way to strongly raising the social capital base as compared to the other livelihood assets. Social capital refers to social networks, relationships and security systems through which people pursue different, coordinated and collective livelihood strategies **[26]**. Improved social capital of local people means that the common pool of social resources is positively utilized to improve upon quality of life of children, women and adults in society **[37]**. For instance, improved primary healthcare delivery and security at night aided by better illumination from SHSs and SSLs would keep local people strong and healthy to work and assist one another. Enhanced rural telephone use may also foster effective social networks and gatherings as well as stronger family relationships irrespective of their geographical location, which prior to the project was interrupted by lack of electricity for phone charging. It has been shown that improved lighting conditions in rural communities in Nepal led to social strengthening and 'self-initiated community development' **[32]**.

Installation of SSLs at strategic public places such as local markets, community centers etc. make it possible for local people to conveniently gather for community meetings and any social events at night without security concerns. The presence of SHSs (including TV sets) at private homes may serve as a source of information and entertainment for homes and communities as well as encouraging evening studies by adults and children, as was also documented in Nepal **[32].** The percentage share of respondents who have made improvements in their social capital asset base was about 50%.

Table 6: The influence of energy services from off-grid solar PV systems on respective livelihood capital types.

	Energy services from SHSs, SSLs and SRs via GEDAP						
Assets	Lighting	Telephony	Health	Employment	Security	Education	H&C
Social	+++	+++	+++	-	+++	+++	-
Human	++	-	+++	-	++	++	-
Natural	+	-	-	-	+	+	-
Economic	+	-	-	-	+	-	-
Physical	+	-	-	-	+	-	-

+++ = strongly transformed by energy services; ++ =moderately transformed/affected by energy services; + =weakly transformed/affected by given energy services; - =non-existent energy service under GEDAP and therefore no effect on respective capital form; H&C=Heating & cooling

4.1.3 Natural capital

The health of the natural environment is as important as the health of the rural inhabitants because they mostly rely upon the natural ecosystem's goods and services for their survival. Natural capital refers to the collective natural resource stocks and environmental services useful for livelihood improvement strategies [26]. Despite local people's endowment in rich natural resources, these resources are fast depleting partly due to unsustainable agricultural and wood-fuel production activities, usually with "low-tech" implements. Solar PV technology as a clean, $C0_2$-free, non-pollutant and renewable source of electricity has positive environmental footprint. It has been estimated that 50% of global CO_2 emissions from power generation could be cut by adopting a decentralized energy pathway [38] and that SHSs can be a good candidate for CO_2 emission mitigation in Clean Development Mechanism (CDM) projects in developing countries [39].

However, Since domestic cooking/heating needs and agricultural activities were not taken into account by GEDAP, rural populations could still resort to indiscriminate felling of trees for firewood, use of kerosene lamps and shifting cultivation coupled with improper disposal of solar components, all negatively affecting the local and global environment. Our results indicating 90% of local solar customers reported spoilt BOCs would be thrown into the bush (see Sub-section 3.4), clearly suggesting that they were not educated enough on safe disposal practices to ensure better protection of the natural environment while deriving benefits from the provision of solar energy services. Ten percent of respondents indicated that the natural capital was minimally affected with the renewable-based intervention as a result of the above limitations of the project.

4.1.4 Economic capital

The economic capital or financial capital denotes the economic potential of the rural residents, including basic infrastructure, production equipment and technologies and other economic assets which are essential for the pursuit of whatever kind of livelihood strategies [26]. Despite the rural inhabitants in the study area being confronted with limited economic opportunities as opposed to their urban counterparts in other parts of Ghana, they have an abundance of land which could enhance their economic situation with the right production equipment, technologies and suitable economic policies.

The negative values of NPV calculations for piloted individual ownership of off-grid SHSs in the Sissala West, Sissala East and Lawra/ Nandom suggest that it was not worth investing in. This could be partly attributable to the difficulty of fully accounting for the intangible economic benefits (cost savings) coupled with the high initial purchasing cost of the SHSs, including interest rates payable by local solar users. It is however envisaged that after the 2 year payback period for the loan, there may be more financial benefits resulting from no payment of monthly bills, free phone charging, and less dependence on usage of kerosene lamps and dry-cell batteries. Insofar as solar customers reduced the frequency of buying kerosene and dry-cell batteries on the market for their lanterns and flashlights, they might indirectly save money in the form of other savings. Indeed these indirect economic returns are still inadequate. Fifteen percent of solar customers especially provision shop owners reported transformation of the financial capital. The potential of solar technology to directly tackle local micro-businesses should be highly encouraged to help local end-users generate the money needed to keep SHSs functioning properly and improve their livelihoods in the long-term.

4.1.5 Physical capital

Any community infrastructure and other materials that are required to carry out essential livelihood programs are referred to as physical capital [26]. In many of the rural communities visited, they were confronted with limited infrastructure such as poor road networks and low quality built environment. However, there were few social amenities such as basic schools and health facilities. All the installed SHSs were mounted on aluminum roofed houses while SSLs were ground-mounted. The physical capital has almost remained the same except that the solar PV systems in themselves are some kind of infrastructure and that also added slightly to the existing local community infrastructure. About 5% of beneficiary solar customers said that the physical capital base was slightly affected and would require more quality and quantity improvement.

4.2 Sustainability of GEDAP

To evaluate GEDAP sustainability, we have looked at the three pillars of the concept of sustainability: social progress, economic growth and environmental protection [40]. In other words, how socially, economically and environmentally viable is the GEDAP initiative? The limited wattage capacity of the off-grid SHSs in somewhat vulnerable rural communities means that the quantum of social services provided are equally limited which can only partly meet some basic energy needs of the present generation whilst the possibility of meeting that of future generations is quite doubtful based on the prevailing challenges described in Sub-section 3.6. Those who could not afford the SHSs were automatically excluded for the present and this temporary social exclusion may undermine the long-term social viability of the project.

Despite the decline in solar cell production costs over the years [41], solar technology is still relatively expensive for many low-income rural people. Since the SHSs were installed not for productive uses but largely for lighting purposes, the economic benefits therein were negligible. The relatively high interest rates (28% and 26%) on loans obtained from participating rural banks for low income solar consumers has the potential of creating inconveniences for local end-users and the possibility of defaults on loan repayments. In the authors' opinion, the economic viability of the project is dangerously threatened. However, the idea of 'rolling back' the available pool of financial resources to be accrued from loan payments by solar customers and other sources of revenue to continue to operate and maintain the installed SHSs (pers. comm. with Mr. Seth Mahu Agbeve, Deputy Director of Renewable Energy Directorate of MoEP, 12th April, 2011) seems to be a feasible management strategy after the expiration of GEDAP. Environmental viability may also be threatened due to low technical know-how, improper disposal of broken BOCs and low environmental consciousness of the rural population. To focus more on technical aspects of the off-grid solar projects whilst neglecting the sustainability aspects may lead to failure of such projects, and a standardization process is therefore required **[42]**.

5. Conclusion and recommendations

This research reveals that the introduction of decentralized stand-alone solar PV electrification into the rural communities in question has minimal positive effects on their health, education, telephone use, social life, economics, security and environmental issues. This is partly attributable to the inadequacy of generated energy services, unavailability of BOCs, low technical know-how, inadequate monitoring and high interest rates (for private solar users). This could truncate the huge potential of easily distributed off-grid SHSs making them ''second class" energy options in the Ghanaian context due to a more competitive, cheaper conventional grid-connected electrification. In view of these many bottlenecks, there is an urgent need to up-scale measures by key energy stakeholders in Ghana to ensure the sustainability of GEDAP and subsequent off-grid RE projects.

Despite the shortfalls of the off-grid SHSs, more than half of local residents were satisfied with this new technology, meaning that energy-poor individuals may appreciate access to energy services even if they are small in quantity. Social capital was found to be markedly enhanced compared to the other forms of capital (economic, natural, human and physical) since energy services, especially rural telephone use, enabled local people to foster stronger social relationships and networks with relatives and friends in urban centers and elsewhere. Proper implementation of off-grid PV electrification may have multiple ramifications not only at the household and community levels but also at the regional and national levels of the country.

Since this study was conducted before GEDAP was completed, further impact assessment studies should be done to assess the long-term efficacy and sustainability of the project. The outlook for solar technology including other RETs in Ghana is very promising with the recent passing of the Renewable Energy Law (Act 832) in 2011. The devastating consequences of global warming as a result of environmental degradation and other anthropogenic activities have called for serious measures to curb the prevailing environmental concerns nationally and globally. This could be partly addressed with the adoption of renewable energy-based sources. It is envisaged that the findings of this study may be useful to academics, policy-makers and other energy-sector stakeholders for advancing the debate of environmentally-friendly energy technologies while promoting livelihood improvement opportunities, especially in energy-poor areas.

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