MASTER'S THESIS

The potential socio-economic and environmental impacts of solar PV mini-grid deployment on local communities: A case study of rural island communities on the Volta Lake, Ghana

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2016

JYVÄSKYLÄN YLIOPISTO

ABSTRACT

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Title: The potential socio-economic and environmental impacts of solar PV mini-grid deployment on local communities: A case study of rural island communities on the Volta Lake, Ghana.	
Subject: Corporate Environmental Management	Type of work: Master's thesis
Time: February/2016	Number of pages: 106
Abstract: Solar PV mini-grid electrification application has been introduced in Ghana to provide electricity for some rural areas that are located disproportionately beyond the reach of the national grid. Through the Renewable Energy Act (832) enacted in 2011, the government of Ghana has developed policy plan to vigorously increase the share of renewable energy sources in the generation mix to 10% by the year 2020. In accordance with the policy, the Ghana Energy Development and Access Project (GEDAP) under the Ministry of Energy (MoE) have undertaken the goal to deploy solar PV mini-grid systems to supply electricity to the rural island communities on the Volta Lake. By virtue of their locations, the island communities have existed for many years without access to electricity. This is because reaching these communities through the conventional grid appears highly impractical. Qualitative research, case study method was used to examine the potential socio-economic and environmental impacts of the solar PV mini-grid project on the local communities, specifically Pediatorkope and Atigagorme. Three research questions were answered using qualitative content analsysis approach. Generally, the findings show that the solar PV mini-grid electricity is an ideal energy alternative for the island communities on the Volta Lake in Ghana. However, there are variations regarding the socio-economic and environmental impacts of the project on the communities. In terms of economic impact, given the energy level or capacity provided, the electricity fulfills the provision of light to boost and extend hours of petty trading and selling activities at night in the communities. The capacity does not support higher applications such as refrigerators, which could help improve the economic conditions of the fishing communities. Government intervention in the form of subsidies will be necessary to sustain the electricity services so as to extend its impact on the communities. Ultimately, the solar PV mini-grid electricity is likely to yield much social impact on the communities than any of the dimensions revealed in the study. Finally, positive environmental impact of the project on the communities will be achieved when majority of the inhabitants are eventually connected to the solar PV mini-grid electricity. There is a challenge concerning recycle and disposal of systems components such as batteries and PV cells after end-of-life. The study concludes that electricity supply in rural areas should bring more than just light to initiate improvement in the quality of life of rural dwellers.	
Keywords: Social, economic, environmental, potential impact, solar PV mini-grid, local communities.	
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ABBREVIATIONS

ARE	**Alliance for Rural Electrification**
CIF	**Climate Investment Funds**
EC	**Energy Commission**
ESMAP	**Energy Sector Management Assistance Program**
GEA	**Global Energy Assessment**
GEDAP	**Ghana Energy Development and Access Project**
GNESD	**Global Network on Energy for Sustainable Development**
GVEPI	**Global Village Energy Partnership International**
ICSU	**International Council for Science**
IEA	**International Energy Agency**
IPCC	**International Panel on Climate Change**
KITE	**Kumasi Institute of Technology, Energy and Environment**
NREL	**National Renewable Energy Laboratories**
OECD	**Organisation for Economic Co-operation and Development**
PWC	**Price Waterhouse Coopers**
RECP	**Renewable Energy Cooperation Programme**
REN21	**Renewable Energy Policy Network for the 21st Century**

CONTENTS

1 INTRODUCTION

Solar PV mini-grid (SPM) electrification application has been introduced in Ghana to provide electricity for some rural areas that are located disproportionately beyond the reach of the national grid. Through the Renewable Energy Act (832) enacted in 2011, the government of Ghana has developed policy plan to vigorously increase the share of renewable energy sources in the generation mix to 10% by the year 2020 (EC, 2011). In accordance with the policy, the Ghana Energy Development and Access Project (GEDAP) under the Ministry of Energy (MoE) have undertaken the goal to deploy solar PV mini-grid systems to supply electricity to some selected rural island communities on the Volta Lake. Among those island communities are Pediatorkope and Atigagorme, which this study focused. By virtue of their locations, these island communities have existed for many years without access to electricity. This is due to challenges such as lack of access roads, settlement patterns, and high costs involved in reaching these communities through the conventional grid (Ahiataku-Togobo, n.d). Existing literature have argued that electricity, especially solar PV systems and mini-grid implementation holds the key to socio-economic and environmental development of rural communities to put an end to the effects of energy poverty (see Bhattacharyya, 2014; Bhattacharyya, 2015; Gurung, Gurung, & Oh, 2011; Mapako & Mbewe, 2004; Tsoutsos, Frantzeskaki and Gekas, 2005; Mohanty, 2004; Kirubi, Jacobson, Kammen, and Mills, 2009; Boyle, 2012). These authors advocate that solar PV and mini-grid applications are remarkably suitable for rural areas that are disproportionately located beyond the reach of the national grid. Boyle (2012), for example, states that solar PV mini-grid applications are appropriate for rural electrification because of its high level of location independence, modularity, fuel neutrality, zero emissions, and equipment stability.

The International Energy Agency (IEA) report (2014a), estimated that more than 620 million people in sub-Saharan Africa (SSA) live without access to electricity and a whopping 730 million people use and rely on hazardous and inefficient forms of energy. Precisely, 85% of the populations estimated above also live in rural areas (IEA, 2010). This phenomenon irrefutably has negative impact on the socio-economic well-being and environmental safety of people living in rural areas, especially island communities. Although, electricity is necessary for improvement in the quality of life of rural populations (RECP, 2014; IEA, 2014a), lack of access to electricity in most rural island communities in Ghana continues to downgrade any chance for the inhabitants to improve their socio-economic and environmental conditions. Moreover, considering that power generation through solar mini-grids for rural communities are generally of small capacity with loads ranging between 5 kW and 500 kW (World Bank 2008a), the socio-economic and environmental impacts of this particular project on the local communities raises some concerns. The concern is whether solar PV mini-grid electricity in the form being provided can impact the social, economic, and the environmental conditions of the local communities for which the project is being implemented.

Therefore, the exploratory empirical study was designed to examine the potential socio-economic and environmental impacts of the project on the local communities, specifically Pediatorkope and Atigagorme. In doing this exploratory research, case study approach was employed. The energy technology sustainability framework (ETSF) developed by Mainali, (2014) was used to analyse the impacts thereof. Research has shown that the most successful mini-grid developments are those designed, where careful considerations have been given to the local context in line with the social, economic, and environmental conditions of the local community (CIF, 2014; GVEP, 2011; World Bank, 2008a; ESMAP, 2007). This is the core motivation for this study.

1.1 Research motivation

The main drive for the research topic came from an internship with an Energy and Environmental Policy Company in Ghana in 2014. As an intern in the energy sector and in particular renewables for rural areas, I had the opportunity to work and observe many issues relating to the goal of increasing renewable energy deployment, specifically solar PV mini-grid, for rural Island communities. In connection to the fact that majority of Ghanaians live in rural areas (Ghana Statistical Service, 2012), often remote from the national grid and in abject poverty, awakened several concerns in my mind about the potential impacts of the project on the local communities. In Ghana, the concept is emerging and supposedly the first solar mini-grid for rural island communities is being implemented for some selected villages on the Volta Lake. This rationally presented a remarkable platform to investigate the potential impacts of the mini-grid electrification project on the local communities.

1.2 Research problem

Solar PV mini-grid electricity is being deployed in Ghana and in many developing countries, particularly in remote areas parallel to improved technology and further decline in the costs of owning and installing solar PV systems (See IEA, 2014a, p.12). While the system has been deployed on a larger scale in developing countries, mainly as an alternative clean energy source and for their contribution in the reduction of greenhouse gas emissions, its emphasis on the overall impact on local communities has rather been minimal (Kumar Sahu, 2015). Moreover, considering that power generation through solar mini-grids for rural communities are generally of small capacity with loads ranging between 5 kW and 500 kW (World Bank 2008a), the socio-economic and environmental impacts of this particular project on the local communities raises some concerns. According to Chung (2004), most renewable-based rural electrification projects are conceived without adequate identification of the needs and preferences of end-users. He contends that renewable energy-based rural electrification deployment are traditionally directed by a supply-driven paradigm that primarily focuses on the supply of electricity rather than the impacts on the communities thereof. This is evident in the renewable energy policy strategy of the Ministry of Energy (MoE, 2011) in Ghana. The Ministry has an ambitious plan to increase the contribution of RE sources (involving solar, hydro, wind and biomass) by 10% for grid, mini-grid and off-grid applications by 2020, with the aim to increase access to electricity in all parts of the country. However, the strategic plan does not specify how the deployment of RE sources and access will impact local communities, especially remote island inhabitants. This study fills this gap by focusing on the present solar PV mini-grid deployment for island communities on the Volta Lake to empirically investigate how the project will impact the immediate socio-economic and environmental conditions of the island communities.

According to the author’s best knowledge, currently, no study has been found dealing singularly with solar PV mini-grid deployment and its socio-economic and environmental impacts on local (rural island) communities in Ghana. Although, Mahama (2012) report of the first solar PV mini-grid installation (4.8 kWp) in Jena, a village in Northern Ghana, he did not consider the potential impact of the project on the local community. The author contends that countries, regions, and communities have embedded unique features that differentiate them from one another, hence, the need to recognize such differences in renewable energy deployment for rural communities in order to convey the impact that will be beneficial at the local level. The thesis seeks to critically identify the potential socio-economic and environmental impact of the solar PV mini-grid deployment for two island communities on the Volta Lake in Ghana.

1.3 Research task

The main purpose of renewable solar mini-grid deployment in isolated rural communities in developing countries is to increase access to modern energy so as to improve the quality of life of the people in three dimensional areas, which are social, economic and environmental, rooted in sustainable development (SE4ALL, Laumanns, Reiche, & Bechberger, 2004; IEAa) The body of ideas aforementioned and presented herein, influences this research to concentrate to answer the question: ***How can access to modern electricity impact the socio-economic and environmental conditions of the rural island communities on the Volta Lake?*** The research task hence sought to identify potential areas where the solar PV mini-grid electricity project can impact on the communities under study. It was undertaken through qualitative research method, precisely, interviews of community members and project experts to investigate the following three research sub-questions.

1. What economic impact can the solar PV mini-grid have on individuals and the entire island communities?
2. How can the mini-grid electricity improve social institutions and individual lives in the communities at large?
3. How will the implementation, use, and end of life of the solar PV mini-grid electricity impact the local environment of the communities?

1.4 Research structure

The proceeding research is structured as follows:

- Chapter 2 explores central theories, preceding studies, and key concepts of renewable energy resources and technology deployment with a focus on the impacts of solar PV mini-grid electrification for rural and isolated communities.

- Chapter 3 presents the case, its geographical area, and the availability of solar resource as well as the communities in its natural setting.

- Chapter 4 demonstrates the methodologies used in answering the research questions.

- Chapter 5 shows the findings of the research.

- Chapter 6 discusses the findings from the content analysis and critically makes nexuses with the theories and previous studies conducted in the field.

- Chapter 7 concludes the study. It echoes the entire study, encapsulates the main findings and discuses their relevance. Answers are provided to the main research question in the concluding chapter and study limitations, contributions, as well as suggestions for future research are presented.

2 THEORETICAL FRAMEWORK

2.1 The concept of renewable energy

Making and accelerating access to clean energy has consecutively received global attention (REN21, 2014). Renewable energy sources and technology encompasses solar, wind, wave, geothermal, tidal, hydro, and bioenergy energy, which in principle all receive their source from solar radiation (Boyle, 2012, p.14). Some of these are sometimes preferred for their greenness and relative easy application than others (Boyle, 2012). For example, wind and solar are highly preferred over bioenergy and hydropower for their broader applicability in various geographical locations, though, hydropower can add substantial amount to energy production, construction of dams has received several criticisms for causing ecological problems to local communities (Hancock, 2015). In subsequent writings, renewable energy will intermittently be abbreviated as RE.

Several authors and sources have defined renewable energy (sources) in various ways, with all definitions pointing to one direction of a "regenerative" resource as the name implies (see Sorensen, 2000; Quaschning, 2005, p.20; Twidell & Weir, 2006, p.7; Maczulak, 2010; Quaschning, 2010; Devine-Wright, 2011; Chiras, 2013, p.278; ScienceDaily; TREIA, IEA). Two of the definitions are worth quoting to support the thesis topic: (1) Twidell and Weir (2006,) define renewable energy as *"energy obtained from natural and persistent flows of energy occurring in the immediate environment"(p.7),* and (2) Quaschning, (2005) unequivocally define the term as *"energy resources that are inexhaustible within the horizon of humanity"* (p.20). These are precisely suitable to the context of this study because the solar power is generated locally and supplied to the inhabitants in the same community.

At the beginning of the 19th century, coal and crude oil were not significant as energy supplies for the world's energy demand as renewable energy sources supplied an estimated 95 per cent of all global energy needs (Quaschning, 2005; Fouquet, 2009, p.15). Firewood and some skills for exploiting wind and hydropower were prominent in the provision of essential energy demand while fossil energy sources remained secondary in order of importance (Quaschning, 2005; Quaschning, 2010; Freris & Infield, 2008; Maczulak, 2010). However, the beginning of the 20th century witnessed a shift of world's energy supply from renewables to fossil fuels as it was found efficient, cheaper, and relevant to support the accumulative popularity of industrialization and motorized road traffic, rendering most renewable energy resources less important in the global energy mix (Quaschning, 2010, p.5; Brown, 2008). This change might have also led to downgrading of rural energy demand, mostly in developing countries since such areas were less commercial and industrial intensive. Until today, fossil fuels have been exploited massively since its discovery to accelerate global economic growth, urbanization, food production, population, and human mobility, which is dubbed "development" to the detriment of the natural environment and development inequality, which the same resource has caused in most developing countries (Breiner, 2014; Sachs & Warner, 2001). Meanwhile, the world's continual reliance on a resource which production will shortly be deteriorating has also grown excessively (Brown, 2008, p.27). Current estimates have projected world's oil reserves between 40 and 45 years (Chiras, 2013, p.291; IEA 2013a; Quaschning, 2010, p.20). The imminent decline of fossil fuel reserves together with the environmental problems associated with the production and use has led to significant increase in the pursuit for non-depleting, green and equitable options, which distribution is independent of geographical location and this mirrors renewable energy resources (Chiras, 2013) mainly solar energy, which is also favourable for rural energy demand.

According to Freris and Infield (2008), renewable energy can primarily deliver the total energy services offered by conventional energy sources: electricity, cooling, and heating with further benefits and ability to provide energy to remote areas with no widespread energy transport systems as it remains naturally circulated resource. Quaschning (2005) buttress this observation by affirming, "renewable energies can, theoretically, cover the global energy demand without any problem". The above authors agree not to pontificate, however, that the transition from contemporary energy sources to renewable supplies will be achieved with no challenges. In their study, Javadi et al. (2013) found that though, grid connection is reliable, renewable energy sources are best suited for remote areas, which are far from the grid. This presupposes that there is vast amount of energy available in renewables that can securely serve rural communities and reliably replace their reliance on ineffective and unclean energy sources with improved technology and favourable energy policies.

Given the above analysis, there are still questions about whether RE can sufficiently meet current and future global energy demand in the forms and in a timely manner (see Trainer, 2007). While the position of skeptics may be granted based on their analysis, they cannot challenge the capability RE have to meet rural energy demand. Moreover, studies conducted by some researchers have proven the possibility thereof. Jacobson and Delucchi (2009) published a study to demonstrate the viability and further strengthened their arguments with two comprehensive research suggesting that global total energy demand for electricity and additional purposes, which they estimate at 11.5 – 16.9 TW by 2030, could be delivered by a large mixture of solar power plants, wind turbines, geothermal, water wave and hydro installations (see Jacobson & Delucchi, 2011 part I, & 2011 part II). Similarly, World-Wide Fund energy report (WWW, 2011) displays how following the decades to 2050, the world could merge solar, wind, hydro, geothermal and other RE resources to provide up to 95% of the world's ultimate energy requirement. In another development, Greenpeace (2010) Advanced Energy (r)Evolution scenario shows how over 80% of worldwide (decreased) energy consumption would be supplied by a fusion of various RE sources. Additionally, in 2008, Shell International Petroleum (2008) projected that by 2050; half of global energy production will come from RE sources, in particular solar energy. It appears that the present discoveries are being acknowledged in practice, as there is rapid RE technology improvement and acceleration of deployment in most developing countries, importantly rural and isolated areas where energy demand is well below urban demand levels.

Furthermore, awareness has increased considerably during the last decades regarding the potential of RE resources and technologies to meet rising energy demand in both developed and developing countries (REN21, 2014; Galarraga, Gonzalez-Eguino & Markandya, 2011; IEA, 2007). In the same way, the implementation of RE resources has been identified with the creation of jobs, acceleration of economic development, improvement in the quality of life of remote citizens in areas like healthcare, education, and reduction in carbon emissions (De Domingo, 2013; Belmonte, Escalante & Franco, 2015).

According to the IEA (2014c), global share of renewable power generation grew incessantly to approximately 22% in 2013 as compared to 21% in 2012 and 18% in 2007 respectively. In sub-Saharan Africa, until now, inadequate access to modern energy services has resulted in huge dependency on bioenergy in the form of wood fuels for cooking, heating and other purposes, covering 69% of renewable energy utilization (Mohammed, Bashir, & Mustafa, 2014). This has led to colossal deforestation and health problems in the sub-region (Hancock, 2015). There is therefore, a compelling urgency, deemed as precariously essential to address, liberate, and restructure the energy sector of SSA through rapid deployment of RE technologies, mostly, solar energy technologies, in which region, the resource is abundantly available and infinite.

Incidentally, humankind, largely in SSA and in Ghana has used renewable energies (wood fuels) for considerably longer than fossil fuels. Therefore, it is not as if RE is a new concept (Mohammed et al., 2014; Hancock, 2015). However, the realization that renewable energies will eventually stand as the only alternative for a safe and environmentally compatible energy supply, with current technologies able to solve rural energy poverty problems, and altogether ensuring sustainable human development is the main drive for global acceleration and deployment of renewable energy technologies (Quaschning, 2010; Foroudastan & Dees, 2006).

2.2 Solar energy

The energy directly or indirectly harnessed from the infinite source of the natural sun is called the solar energy (Akikur, Saidur, Ping, & Ullah, 2013). Solar energy is basically categorized into the following continuum: (1) passive and active (passive is solar energy recuperated without any mechanical action, that's, simple utilisation of daylight e.g., through building designs, whereas active is harnessing of solar energy to store or convert it into other forms, e.g. hot water systems, solar collectors etc.); (2) thermal and solar photovoltaic (solar photovoltaic exemplifying the state of the art in active solar electrification) and (3) concentrating and non-concentrating (the use of mirrors or lenses to focus sunlight), which are all based on energy directly ascribed to the light of the sun or generated heat from sunlight (Bradford, 2006; Chiras, 2013; Boyle, 2012).

Solar energy is classified as the earth largest source of renewable energy with active irradiance reaching the earth surface varying between 1 kW/m^2 at high latitudes to 0.25kW/m^2 at low latitudes (Timilsina, Kurdgelashvili, & Narbel, 2012; IEA, 2014b). The solar power that reaches the earth surface annually is believed to be a total of about 885 million terawatthours (TWh), which is 6200 times the commercial primary energy consumed by humankind in 2008, and 4200 times the total forecast of human energy in 2030 (IEA, 2011a). Figure 1 shows the relationship between annual solar irradiation, which far exceeds total global energy demand and all fossil energy reserves.

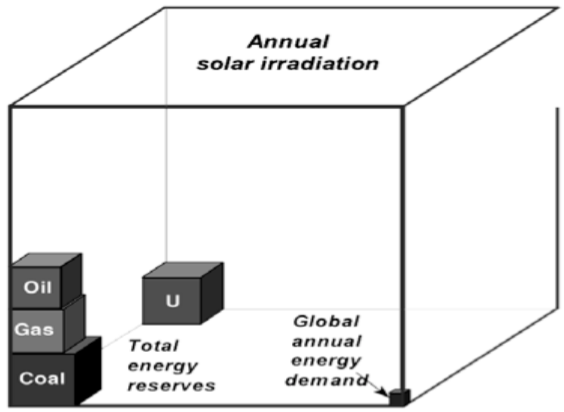

FIGURE 1 The annual solar irradiation (Quaschning, 2005).

Certainly, the resource potential of solar energy greatly outstrips the total global energy demand, which in principle, rural and isolated energy needs can easily be met through rapid implementation of solar energy technologies to deliver improvement to rural economic, social, and environmental conditions (Kurokawa, Komoto, Van Den Vleuten, & Faiman, 2007; Quaschning, 2005). For example, Quaschning (2005) recounts that the annual solar irradiation of Sahara and sub-Saharan Africa is about 2350 $kWhm^2$/year and the total annual irradiation reception of around 8.7 million km^2 far exceeds global annual primary energy demand, hence meeting local rural communities energy demand with renewables is comparably easy. Since the 1970s oil crisis, solar energy application has received increased attention worldwide and a number of solar energy sources have been implemented to provide electricity for rural and isolated communities in the form of stand-alone or hybrid systems, mostly in developing countries, which receives monthly average solar irradiation of $3\pm6kW/m^2$ (Akikur et al., 2013).

2.2.1 Solar photovoltaic technology and principle

Solar photovoltaic (SPV) technology is based on semiconductor materials designed to directly convert sunlight into electricity, thus; the electricity produced is delivered in the form of direct current (DC), which is suitable for several applications (Boyle, 2012; Thiam, 2010; ESMAP, 2007; Parida, Iniyan, & Goic, 2011). The IEA (2014b) highlight two components of solar radiation: (1) direct radiation coming directly from the sun, and (2) diffuse radiation reaching the earth indirectly once dispersed by the atmosphere, which are both relevant for solar PV. The development of solar photovoltaic technology as a premium method of harnessing energy from the sun dates back to the 1950s when high-efficiency solar cells were developed by a group of scientists at Bell Labs in the

United States. Since then, tremendous progress has been made in regard to increase efficiency, reduction in cost of production and price, and market expansion of solar energy systems (Boyle, 2012; Timilsina et al., 2012; IEA, 2014b; REN21, 2014, TPCT, 2013; Haukkala, 2015) over the decades. The recent improvement in the technology has coincided with continuous decline in the costs of owning and installing solar energy systems (see IEA, 2014a, p.12; GVEPI, 2011; RECP, 2014, p.25-28; Eder, Mustsaerts, & Sriwannawit, 2015; Bhattacharyya, 2014; Chiras, 2013; TPCT, 2013; Sharif & Mithila, 2013, p.344). This trend has made it more attractive for developing countries to implement the technology as steps to poverty alleviation, improvement in the lives of rural people, and a definitive climate change mitigation strategy (Ulsrud et al. 2011).

Though, solar PV applications have largely concentrated in Europe, notably Germany, for many years, there are evidence that China is poised to lead in global production and installation leading up to 2030, which is significant for the African market and deployment on a larger scale since PV costs will potentially drop drastically as a result of massive production by China (IEA, 2014b). At current estimate, the International Energy Agency predicts PV's share of global electricity reaching 16% by 2050 (IEA, 2014b). Between the year 2004 and 2013, nearly 139 GW PV capacity had been installed at the global level while the market prospect in sub-Saharan Africa has also proved promising with South Africa leading with (75 MW) installed solar PV capacity (see REN21, 2014, p.47-49; IEA, 2014b, p.9).

Solar PV is remarkably known for its suitability for rural and remote power needs such as lighting, water pumping, telecommunications, and also applicable in several domestic, commercial, and industrial structures, which integrate grid-connected PV arrays to resource a significant part of their energy requirements (Boyle, 2012). The appropriateness of solar PV for mini-grid applications lies in its high gradation of location independence, fuel neutrality, noise exclusion, zero emissions, modularity, and high degree of equipment durability (ibid). For example, land-based applications built on silicon materials for PV cells have a lifespan of 20 to 25 years operational warranty by manufacturers, though useful life is likely to last longer (Bradford, 2006).

Solar PV technology can be grouped into three major applications according to (ESMAP, 2007):

- Stand-alone solar devices particularly built for end use purposes, such as water pumping and home power, small radio set, and mobile phone charging;
- Small to medium solar power plants (mini-grids) designed to provide village-level electricity; and
- Grid-connected solar-PV power system, which is usually connected to a large conventional grid system to feed power into the public electricity grid.

The different applications make solar PV systems the most economical, environmental, and socially equitable option for meeting rural energy demands and improving the lives of those who earn less than USD 1 to USD 2 per day while spending about USD 0.4 per day on inefficient energies such as wood fuels, kerosene, dry cell batteries, and general application of diesel generators (Akikur et al., 2013; IEA, 2011a). This study reflects the second category where small-medium scale solar PV power plants are designed to serve small island communities of about 900 inhabitants with average of 150 households.

Solar PV modules are categorized into two main groups: wafer type (Crystalline or Multi-crystalline [c-Si]), and Thin films (a-Si, Cd-Te and CIGS) (see IEA, 2014b, p.28-30, for efficiency details) but the c-Si module dominates global market with 90% share and over 21% efficiency, making it appropriate for stand-alone and mini-grid applications in many instances (Bradford, 2006; IEA 2014b; IEA, 2014d; Timilsina et al., 2012; NREL, 2015).

2.2.2 Solar energy resource in Ghana and the Renewable Energy Act

Ghana's geographical location in the tropics positions the country to receive high solar radiation throughout the year in all the ten regions of the country. In Ghana solar energy assessment was undertaken in 2002 under the UNDP renewable energy project (Painuly & Fenhann, 2002; Gyamfi et al., 2015). This assessment was based on geostationary satellite Meteosat data and the average solar insolation (incident solar radiation) has been established as between 4.4 and 6.5 $kWh/m^2/day$, a sunshine duration of around 1800-3000h per year and an average annual solar radiation of 16-29 MJ/m^2 (Kemausuor, Obeng, Brew-Hammond, & Duker, 2011; Schillings, Meyer & Trieb, 2004; Painuly & Fenhann, 2002). These conditions are ideal for the exploitation of solar energy to improve the socio-economic and environmental conditions of isolated rural residents, considering the enormous solar radiation resources available in all the parts of the country, particularly in the northern parts where solar radiation is comparably higher and electrification rate is ironically very low (Gyamfi et al., 2015). Figure 2 below shows the annual average total daily sum of Global Horizontal Irradiance (GHI) in Ghana.

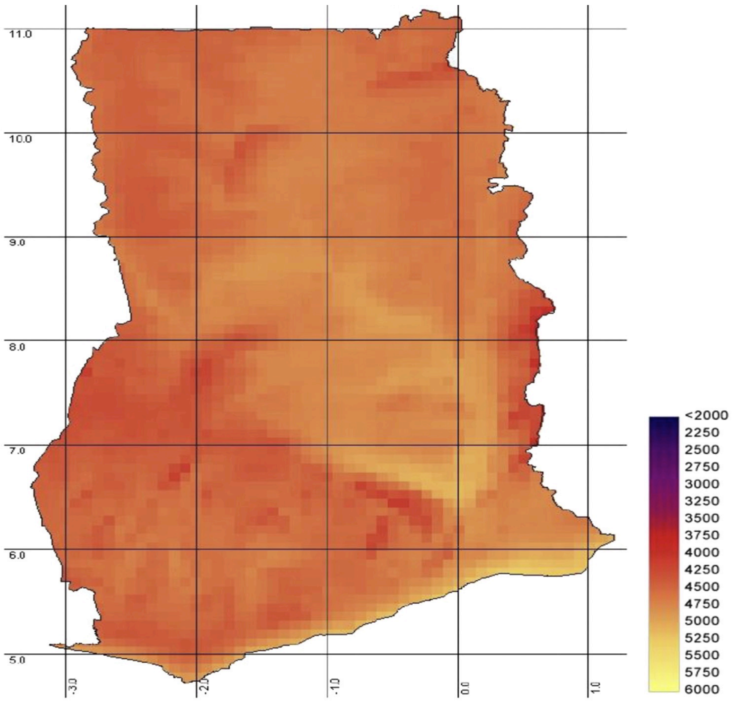

FIGURE 2 Ghana's annual average total daily sum of GHI in Wh/m²/day (Schillings et al., 2004)

To harness the abundant power available in the solar energy, the Renewable Energy Act (Act 832) was introduced in 2011 and passed into law to promote the development and utilization of renewable energy sources for electricity generation. Through the art, the government has developed policy to increase the share of renewable energy sources in the generation mix to 10% by 2020 (Ahiataku-Togobo, 2012). Simultaneously, the framework specifies government provision for electricity generation and supply from renewable energy sources and the creation of facilitating environment to attract investment into the renewable sector (Atsu, Agyemang & Tsike, 2016). The objective of the Act is to urge households, businesses, and communities to adopt renewable energy technologies and expand its use in their energy mix. The Act also aims at diversifying the sources of electricity supply in order to maintain energy security and also increase access to electricity to all communities and categories of users in the country (ibid). Though, the Act sets a determination to shape indigenous capacity in technology for renewable energy sources, its partially weak in specifying its impact on businesses and local communities to promote rapid adoption of renewable energy technologies in Ghana.

2.2.3 Solar PV technology awareness and utilization in rural Ghana

Solar energy utilization is not any new phenomenon in Africa, most importantly, in Ghana where abundant sunlight is being used directly to dry 'washed clothes', food, brickmaking, vegetables, etc. (Hilling, 1976, as cited in Amankwah-Amoah & Sarpong, 2015). However, the technology of harnessing energy from the sun and converting it into useful electricity can be regarded as alternatively advanced method of harnessing larger amount of energy from the sun to meet mankind energy needs. Several decades in the past, sizeable amount and a range of PV systems have been installed in most developing countries as demonstration units, of which their uses encompassed water pumping, telecommunications, battery charging, cathodic protection, refridgeration, to name but the very communal applications by international aid agencies to assist the rural poor in energy services (Chambouleyron, 1996). Unquestionably, some of these activities created some kind of awareness of the potential of solar PV technologies in meeting energy needs in developing countries.

According to Adanu (1994), solar PV electricity was introduced in Ghana in 1980 by non-governmental agencies, mostly religious missionaries that installed solar panels on church buildings and hospitals. Afterwards, some public organisations including Ghana Post and Telecommunications, Ministry of Health, Ghana Cocoa Marketing Board and others also adopted the technology and installed arrays of PV to augment their energy demands (Essandoh-Yeddu, 1997). By 1990, awareness level had unobtrusively risen and more applications were at function in schools, hospitals, and community sectors, while some 6,300 solar PV systems have been installed mainly in rural areas between 1987 and 2009 to provide basic energy services such as mobile phone charging, street lighting, water pumping and others (Amankwah-Amoah & Sarpong, 2015; Ahiataku-Togobo, 2012). Currently, 2 MW grid solar capacities have been developed at Pungu in the Upper East Region (AfricaReview, 2013). There is also collaboration between the World Bank and the Ghana Energy Development and Access Project (GEDAP) to supply rural homes in remote off-grid communities with solar systems, and about 2,700 households in 11 Districts have been supplied in the last two years (AfricaReview, 2013). In the last three decades, solar PV systems have multiplied in Ghana considerably (Atsu et al., 2016) but the mini-grid application is conceivably a new technology, which is intended to provide electricity to rural areas in Ghana where grid connection is unfeasible.

2.2.4 Energy poverty

Once the solar resource and PV technology awareness in Ghana have been established with favourable daily average insolation, it provides grounds for the possibility to deal with the issue of energy poverty in remote areas in Ghana since solar power offers potential solution to the ubiquitous problem of energy poverty. The appropriateness of the energy poverty concept in this study lies in its application to rural areas and disparity in energy access. Moreover, literature concerning the concept has mostly concentrated on rural areas where energy access has perpetually been poor (see Akpan et al., 2013; Zerriffi, 2011; Barnes, 2007; Cabraal et al., 2005).

Diverse definitions and concepts of energy poverty have been provided, but they all indicate a particular energy supply and consumption, which level is woefully inadequate to meet some essential needs (González-Eguino, 2015; Groh, 2014). Reddy (2000, p.44) defines energy poverty as "the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support economic and human development". This definition is particularly important in this study since it incorporates several remarkable features and distinctions. The absence of choice in the definition is exceptionally significant because being able to develop also means that a society or community has not been deprived of valuable options that empower it to choose and attain welfare in its full realization.

Lack of access to suitable forms of energy, may not only indicate a deprivation of fundamental services such as lighting and cooking for remote communities, but similarly additional elements that are indispensable for individual and collective development, such as access to proper healthcare, education, information, and protection of conceivable weaker groups in society such like women and children. Hence, Greenpeace (2001) refer to solar PV as "Power to tackle poverty". Additionally, the definition emphasizes the need to meet demand for energy services, which does not necessarily mean satisfying consumption but rather the provision of energy services from various sources of energy (González-Eguino, 2015).

Frequently, there is a reciprocal correlation between lack of access to sufficient and inexpensive energy services and poverty. The correlation is that in different situations, individuals who lack access to clean and affordable energy are often confined in vicious cycle of deprivation and lower income levels, which impair their ability to improve their living conditions. The paradox is that these people simultaneously spend substantial amount of their limited income on alternative energy forms that are comparatively expensive and unhealthy, which also provide poor, unreliable and unsafe energy services. These people constitute an overwhelming majority of the 1.4 billion who do not have access to grid electricity. (GEA, 2012, p.153)

The limitation thereof, has convincingly contributed enormously to the poverty levels, health risks, and environmental harm in developing countries, most severely in sub-Saharan African in which Ghana is a part. The poor has remained poor partly due to lack of access to electricity (Annemarije, Dijk & Clancy, 2010). For example, the WHO (2009) has identified that energy poverty causes more death than malaria or tuberculosis among low-income countries around the world through indoor air pollution as a result of the use of biomass for cooking and other inefficient lighting systems. Similarly, González-Eguino (2015) reviewed the consequences of energy poverty and found the impacts on health, economy, and the environment of rural inhabitants to be exceedingly disturbing. In support, Cabraal et al., (2005) revealed that the average hours per day spent in search of wood fuels (firewood) in Ghana is between 3.5-4 hours, which can provide wood for only 3 days. Cabraal et al., (2005) findings may even be underestimation of actual time spent on gathering firewood for energy purposes since in reality (referring to the author's personal experience) women and children in Ghana may spend 7-9 hours to gather 'quality' and sufficient firewood when the distance covered to and from house is accounted.

Therefore, it has become essential to overcome poverty, promote economic growth and employment opportunities, support the provision of social services, protect the environment and, in general, promote sustainable human development (GEA, 2012, p.153) among rural communities in developing countries through harnessing solar resources and extensive deployment of solar energy technology systems such as the mini-grid that provide clean, easy access, and reliable energy for isolated communities.

2.2.5 Rural electrification access in Ghana

Reducing poverty and creating an enabling environment for socio-economic development in rural areas have engaged the conscientious attention of successive governments in Ghana. As a result, deliberate efforts have been made by the government of Ghana to extend electricity access to all. While there is no one universal definition for energy access, access to electricity has been defined "*as the availability of electricity in areas reached by the grid or other off-grid electricity solutions*" (Mensah, Kemausuor, & Brew-Hammond, 2014). For example, in Ghana the rural electrification policy was initiated in 1970 to supply electricity to rural areas in the country where the national grid has not reached (ESI AFRICA, 2013). The IEA (2013b) broadly defines energy access as *"a household having reliable and affordable access to clean cooking facilities, a first connection to electricity and then an increasing level of electricity consumption over time to reach the regional average"*. Apparently, there is a weakness associated with the definitions because they fail to account for energy access that promote economic or productive use which is essential for development and poverty alleviation. Moreover, most of the definitions may be founded on hypotheses, which does not critically reflect local and cultural practices connected to energy needs and uses. In view of the above, the government of Ghana also introduced the National Electrification Scheme (NES) in 1989 to replace the rural electrification policy and to extend the national grid to all communities in the country with a population of 500 and above as an effort towards the goal of achieving universal energy access in the country by 2020 (EC, 2012; Mensa et al., 2014). The Self-Help Electrification Programme (SHEP) was also instituted within the framework of NES to accelerate the pace of electrifying all communities as a support to the main NES (Barfour, 2013). Through these programmes, Ghana has achieved a national electrification access rate of 72% as established by the Ministry of Energy through its 2010 national mapping of communities with and without electricity from grid connection (EC, 2012 Mensah et al., 2014; Mahama, 2012; Kemausuor et al., 2012; IEA, 2014a).

However, there is huge dichotomy between urban and rural electricity access in Ghana such that the ratio ranges between 90% urban access and up to 52% rural access (Hancock, 2015; GSS, 2007). Analyst propose that these outstanding percentages of the rural population without electricity, which are largely located in substantial distances away from the national grid and living in dispersed settlements with low electricity demand, can be covered by using renewable energy technologies of low carbon options such solar PV mini-grids to aggregate the national electrification access as they present a cost effective alternative to grid extension (Mahama, 2012; REN21, 2011). In this case, the Renewable Energy Act becomes relevant to accelerate electricity access to remote communities in Ghana. One of the policy instruments that have been progressively implemented to ensure supply and demand of energy in rural areas in Ghana is subsidy mechanism (Kankam & Boon, 2009). Currently, the mechanism has supported over 90% of rural electrification (mainly grid connection) in Ghana on both supply and demand side by the Government of Ghana (Mahama, 2012; Kankam & Boon, 2009). Conversely, the Renewable Energy Act passed in 2011 provide funds for production based subsidies and equity participation for mini-grid and off-grid renewable power systems for remote and island communities but does not emphasize any provision of subsidies on consumption side for the same group (EC, 2011).

2.3 Mini-grid technology concept

In recent years, the mini-grid technology has developed to a vibrant and fastest growing distribution segment of renewable energy around the globe (REN21, 2014). As a result, various governments have embraced it as an alternative to grid-based electrification, with capacity to provide access to clean electricity services to the poor who live disproportionately in remote areas beyond the reach of the grid, to boost social and economic development (Bhattacharyya, 2013; Bhattacharyya, & Palit, 2014; World Bank, 2008a). Apart from that, the support for low carbon energy mixes in reaction to climate change anxieties has granted further provision for this technically decentralized complementary choice to be feasible, in order to address both underdeveloped rural energy problems and climate change issues with clean energy technology (Hong & Abe, 2012; Bhattacharyya, 2013). Mini-grid applications are best suited for rural communities that are very remote to be connected to the conventional grid whose energy service needs are above the reach of individual solar home systems (SHS) with existence of multiple energy users (Hazelton, Bruce, & MacGill, 2014).

According to the World Bank (2008b), *"mini-grid applications are village and district-level networks with loads between 5 kW and 500 kW not connected to a national grid."* (p.13). Espinar and Mayer (2011), also define mini-grids as: *"a set of electricity generators and, possibly, energy storage systems interconnected to a distribution network that supplies the entire electricity demand of a localised group of customers."* (p.10). Deshmukh, Carvallo, and Gambhir, (2013) add to the definitions by defining mini-grids as: *"one or more local power generation units supplying electricity to domestic, institutional, and commercial consumers over a local distribution grid"* These three definitions seem to agree on an energy technology, which design is centred on satisfying a local energy demand.

Mini-grids are by nature entirely different from single consumer systems such as solar cell panel providing a single house with electricity, in which there is no interconnection between various customers (Ruud, 2013). Mini-grids vary in sizes or capacity and usually service a cluster of up to 500 households, small business, and community requirements such as vaccine refrigeration, supply of clean water, street lighting, schools, radios, audio and video systems, and PV powered telecommunications systems with total energy demand ranging between 20 to several thousand kWh per day (GNESD, 2014; REN21, 2014; Viral et al., 2013; Boyle, 2012). In this study, a mini-grid application is defined as "*a solar PV plant with a localized distribution network to isolated villages, or a cluster of settlements, providing alternating current (AC) with loads between 5 to 50 kWh*" which is consistent with the definition of the World Bank.

An important feature of a mini-grid is that it can operate autonomously and supply electricity to isolated rural populations in circumstances where connection to the national grid is practically impossible or economically unfeasible. Nevertheless, the technology may also be designed to integrate with the central grid and operate accordingly except when disconnection becomes important in order to maintain power quality at the local level (Espinar & Mayer, 2011). Otherwise, mini-grids may be designed to operate independently in remote areas on temporary basis while a community may be awaiting for the arrival of the mainstream grid and the system may eventually be joined to the central grid, demonstrating the flexibility of mini-grid applications (Espinar & Mayer, 2011; Ruud, 2013).

However, this situation is not applicable in this study where the locations been studied are isolated island communities exclusively out of the range of conventional grid. Kaundinya, Balachandra, and Ravindranath (2009) indicate that mini-grid system occurs in two distinctive levels: (1) village level in which the main goal is on providing electricity to meet the rural energy needs; and (2) industrial level where the focus is on delivering electricity to serve industrial activities and any excess amount generated are fed to the conventional grid. This thesis focuses on the first level. In IEA's Energy for all report (2011b), it is estimated that just 30% of the world's rural populace presently without access to electricity are best served by extending conventional grid, while the outstanding

70% are well-matched either to mini-grids (in total 65% of this share) or stand-alone off-grid systems (the rest 35%).

Mini-grids are categorized into five power sources comprising, diesel-based generators (conventional application), mini-hydro, biomass, wind, solar PV, or a combination of two or more of the above technologies (Franz, Peterschmidt, Rohrer, & Kondev, 2014). It is important to note that until now, a large number of mini-grids for rural electrification are still based on diesel for electricity generation (Franz et al., 2014). However, due to improved technology and continuous decline in the price of solar PV, as well as rapid deployment, it is likely that solar mini-grids will outpace and almost displace generator diesel-based mini-grids in developing countries in the near future. Therefore, using renewable energy mixtures contributes to cost reduction, enhancement in energy security, and ultimately minimizes environmental pollution (Franz et al., 2014). This research focus is on solar PV mini-grid.

2.3.1 Solar PV mini-grid system

Solar PV mini-grid comprise of several arrays of PV panels designed to generate electricity from the sun independently for local distribution that serve numerous applications at household, business, and institutional levels (Palit, Sarangi, & Krithika, 2014). At village-scale solar mini-grid systems, capacity usually ranges between 10 – 100 kW, which is of much bigger capacity than solar home systems (SHS) and electricity is converted to AC quality power for local distribution (Ulsrud, 2011), typically for a limited number of hours. The number of solar panels for a mini-grid is largely dependent on the calculated energy demand data of the particular community in which the project is being implemented. Based on the capacity, solar mini-grid can supply electricity to serve domestic applications, commercial activities (including video and entertainment centres, communication centres, small mills/grinders, shops, tailoring etc.), and community requirements such as street lighting, water pumping, schools, and vaccine refrigeration (Ulsrud, 2011; Palit, 2013;). This system is sometimes also referred to as stand-alone PV system because it does not combine other energy technologies to produce electricity.

The most significant aspect of solar PV mini-grid is that it utilizes a collection of lead-acid storage batteries to store and provide power in hours when the sun is unavailable (Mohanty & Muneer, 2014). Typically, a particular type of lead-acid battery known as deep-cycle battery produces the best output for mini-grid applications with longer life spanning from 5 to 7 years with energy capacity varying from 17 to 40 MWh and efficiency of approximately 70-80% than traditional twelve-volt car batteries (Bradford, 2006, p.100; Divya & Østergaard, 2009). For example, Bakkabulindi, Sendegeya, Da Silva, and Lugujjo (2014) selected deep-cycle lead-acid batteries for sizing storage in a solar PV mini-grid project in rural Uganda based on the huge energy demand. The battery storage facility also guarantees reliability of the system to provide constant energy supply. However, it should be mentioned that, the life span of a battery depends on how a system is sized to operate. Other components of solar mini-grid consist of power conditioning unit containing charge controllers, inverters, AC/DC distribution boards and essential cabling (Palit et al., 2014). Apart from the efficiency of the solar PV cells, the amount of energy that would be produced by the system also depends on a number of factors such as the daily or annual total quantity of solar radiation prevalent at the site, (normally calculated using meteorological data and HOMER software as part of the project feasibility studies prior to implementation), power-reducing effects of array shading by trees, adjacent structures and accumulation of dirt etc. (Boyle, 2012). In figure 3, a typical solar PV mini-grid system is illustrated.

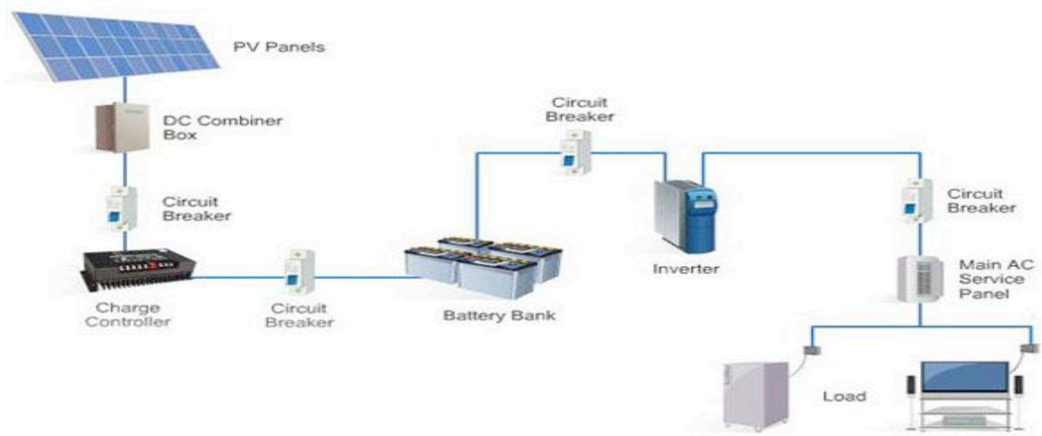

FIGURE 3 Solar mini-grid electricity system (Ruud, 2013)

Because of its high independence to provide quality energy for positive impacts, mini-grids (solar PV) has become suitable for isolated rural electrification and the IEA (2014a) has noted that 80 percent of SSA rural populations without access to electricity can be served by solar mini-grids. In the same report, IEA established that by 2040, two-thirds of the mini-grid and off-grid systems in rural areas are going to be powered by solar PV systems possibly because of improved technology, continual price reduction, flexibility in application, and rapid societal improvement potentials.

2.3.2 Solar PV-diesel hybrid mini-grid system

In a PV-hybrid system, a combination of two or more sources of energy systems, such as wind, hydro, biomass or diesel-based generator can be used to provide the required power of a community (Espinar and Mayer, 2011; Bala & Siddique, 2009). Hybrid power systems usually depend on renewable energy to generate

75-99% of total energy demand (where the renewable source is very reliable, a diesel genset is seldom used), which makes the application almost entirely independent to offer lower energy prices and benign environmental benefits in the long run (ARE/USAID, 2011). A diesel backup system is usually operated only when load demands exceed the capacity of the PV system while the battery storage is also exhausted (Bala & Siddique, 2009). In this approach, the main objective is to ensure reliability of the system at an affordable manner by adding one or more energy source(s) (Mohanty & Muneer, 2014). A typical PV-diesel mini-grid system entails solar PV module, diesel generator, charge controller, storage batteries, and inverter (Bala & Siddique, 2009).

The most commonly used hybrid system in developing countries for rural and isolated communities is a PV-diesel hybrid as they are thought to be the most cost-effective and reliable solution among mini-grids for most rural locations that can cover a variety of fluctuating load profiles (ARE/USAID, 2011; Bala & Siddique, 2009). Furthermore, the criteria for selecting a hybrid system for a location is also founded on the trade-off of reducing the use of diesel generator, which emits carbon dioxide (CO2), causing harm to the environment (Bala & Siddique, 2009). At low fuel prices and steady supply of diesel, this approach can be effective model for isolated rural electrification (ARE/USAID, 2011;). However, long transportation distances covered to supply diesel to rural areas eventually make this option more costly (Hazelton et al., 2014; Ruud, 2013;). A well-balanced and managed PV-hybrid can prove a very sustainable option for rural electrification that ensures improvement in the socio-economic and environmental dimensions of sustainability.

2.3.3 Socio-economic and environmental impacts of solar PV electricity systems on rural communities

This section is intended to review some of the previous studies that have been conducted on solar PV mini-grids in developing countries, mainly in rural and island communities. This is done as one of the ways to substantiate the findings of this study.

Many contributions have surfaced in literature dealing with the technical performance, socio-technical, socio-economic, and environmental impacts of SHS and solar mini-grid deployment on rural communities in developing countries (See Bhattacharyya & Palit, 2014, p.335; Bhattacharyya, 2015; Dubey, Jadhav, & Zakirova, 2013; Gurung, et al., 2011; Mapako & Mbewe, 2004; Rahman, Paatero & Lahdelma, 2013; Welsch et al. 2013; Brent & Rogers, 2010; ARE/USAID, 2011; Hong & Abe, 2012; RECP, 2010; Viral, Bahar & Bansal, 2013; Kemausuor et al., 2011; Mbaka, Mucho, & Godpromesse, 2010; Chaurey, Ranganathan, & Mohanty, 2004; Wamukonya & Davis, 2001). For example, Maharil and Kulkarni (2009) discuss the correlation between periodic fluctuation of solar radiation and the disparity in power generation that could negatively impact productive use of energy from solar mini-grids for realistic rural development. Evidence is provided from the studies of Shyu (2013) as he found that households in Saierlong and Namcuo communities in China were dissatisfied because of the insufficient electricity supply from a stand-alone solar PV mini-grid that resulted in a gap between electricity supply and demand. This was as a result of failure to carry out proper energy demand and willingness to pay (WTP) survey of both townships prior to the project implementation. The evidence demonstrates lack of emphasis on the impact of renewable energy deployment on local communities. In much the same way, Hazelton et al., (2014) identified load uncertainty, lack of effective business models, and power quality to be a problem in their review of potential benefits and risks of photovoltaic hybrid systems. Conversely, Bakkabulinda et al., (2014) resolve these issues by concluding that appropriate load sizing and selection of system modules for solar PV mini-grid can guarantee grid-quality supply of electricity to consumers to enhance productive uses. Other studies compare techno-economic characteristics of solar PV mini-grid and hybrid systems as well as individual SHS (Lal & Raturi, 2012; Akikur et al., 2013; Bhandari & Jana, 2010; Chattopadhyay, Bazilian, & Lilienthal, 2015).

Bhattacharyya (2015) posit that small mini-grid system for basic level of energy supply is inexpensive preference than providing consumers with solar home systems (SHS), and that at the beginning, the source should offer basic level of electricity together with production energy use during off-peak hours while the system may be enlarged afterwards as demand improves. This ensures a wider access to electricity in isolated rural areas that benefit all, especially students and not only those that can afford a solar PV at home (Gustavsson, 2007). This is in tandem with Ulsrud et al., (2011) argument that socio-technical design of energy technology should be effectively adaptable, acknowledging modifications and improvements since demand and practices of use are frequently difficult to predict and are molded only during the use phase of the technology.

Plausibly, majority of research on solar mini-grid originate from the engineering and environmental sciences. The few that come from the social sciences has concentrated on the socio-economic impacts of such energy source. For instance, Chakrabarti and Chakrabarti (2002) conducted a study on 'Sagar Dweep' island in India considering the environmental and socio-economic factors and found that solar PV was beneficial from a sociological perspective, which led to a substantial progress in trade and education as women received wider involvement in community activities and additional work. The study further concluded that in an attempt to calculate the actual cost of electricity generated by solar energy also require equal analysis of how and in what ways availability of electricity impacts the social and economic life of rural dwellers, most importantly isolated areas where grid-connection is impractical. Likewise, Palit et al., (2014) disclosed that solar mini-grid project in Chhattisgarh State, India contributed to the social development of the community through mobile phone, TV and radio use, leading to increase in flow of information and social awareness. Also reduction in the use of kerosene resulted in environmental benefits and resultant decline in total household expenditure on kerosene fuels. In Zambia, the introduction of solar PV electric services improved education as 82 percent of households reported that school children achieved extended hours of studies at night, which was previously opposite (Gustavsson, 2007).

Contrarily, Zomers (2001) many studies on the effects of electrification on education and children's study routines, identified that excessive exposure to TV and radio as a result of access to electricity and complementary home electronics can only improve students knowledge of the languages used in various broadcasts but likely to reduce the hours spent on studies. Confirmation from Kenya indicates that the role of solar PV electrification in expediting economic productivity and children education-related activities is rather insignificant compared to "connective" applications such as radio, TV, and mobile telephone charging (Jacobson, 2007).

Economically, Obeng and Evers (2010) have shown how micro-enterprises in some rural and isolated communities in Ghana extended working hours and saved money by switching from kerosene to solar PV electrification. The solar PV electrification accrued additional benefits in the community as night vendors; exceptionally women also spent less on kerosene fuels by selling items such as bread and beverages, fruits, porridge and many others in front of or close to a micro-enterprise as a way of benefiting from the external light without which their business activities halted after sunset. Kirubi et al., (2009) revealed an increased capacity to generate income from the supply of electricity from solar PV in a rural town in Kenya. In remote communities of Sunderbans, India, Chaurey and Mohanty (2007) have added their findings on the impact of socio-economic development of the region, especially for women through the provision of reliable electricity from a renewable solar source. In their study of quantitative impacts of solar PV on television viewing and radio listening in off-grid rural Ghana, Obeng and Kumi (2014) discovered that solar PV electrified households avoided substantial cost using solar PV electricity to watch television than non-electrified households that used car battery to watch television. Subsequently, solar PV users saved money and improved their finances than their counterparts. In much the same way, Gurung et al., (2011) established that installation of a renewable energy system for Tangting village increased household income levels significantly as the scheme unlocked opportunities for other employment after the installation. Contrary to the various literatures, Nieuwenhout et al., (2000) and Martinot et al, (2002) argued that no evidence had been found supporting widespread or substantial increases in rural income or productive activities connecting to solar electrification. Their arguments may be granted based on the year of their publications and the probability that substantive economic productivity and increase in rural income had not been realized with the prevailing solar PV technology at the time. The difference is that most of the above studies have been conducted seven and nine years later, which may signify technology improvement to grant some level of productive uses and increase in rural incomes associated with solar PV electrification. One significant economic barrier to widespread electricity access to rural communities is the initial connection fee, which in some cases is too expensive for some households and businesses to pay and get connected to reap the benefits of the electricity access thereof (World Bank, 2008a).

In the process of providing basic electricity services to isolated rural populations, solar PV advocates claim that the systems have also facilitated sustainable development by producing invaluable contributions towards environmental protection (e.g., Kaufmann, et al., 2000; Chaurey & Kandpal, 2010; Gurung et al., 2011; Goetzberger & Hoffmann, 2005). This is evident through the express benefits of solar home systems (SHS) and stand-alone solar mini-grids. Practically all SHS and solar mini-grids substitute electric light for all hydrocarbon-based energy sources and the displacement of kerosene lamps, domestic generators, candles, dry cell and car batteries constituting a greater part of direct carbon benefit in solar PV mini-grids (Kaufman et al., 2000). For example, SHS have displaced a colossal 15.2-21.3 litres/month of kerosene use in rural Argentina, 12.0 litres/month in Burkina Faso and 5.0 litres/month in Bolivia (Chaurey & Kandpal, 2010). Similarly, in Ghana, Obeng et al., (2008) found that enormous 89% of non-electrified rural households relying on kerosene and lanterns for lighting were affected by indoor smoke, whereas 40% of households combining two sources of energy for lighting, for example, solar PV and kerosene lanterns were affected by indoor smoke. However, the findings indicated that households that relied solely on solar PV lighting were not affected by indoor smoke, establishing further that solar PV lighting assists households to lessen the adverse effects of indoor air smoke. Moreover, rural dwellers rely heavily on dry cell batteries to power radio/cassette players and torchlight and also engage in indiscriminate disposal of used dry cell batteries that can pollute soil and water bodies with toxins, including mercury, which electricity from solar PV systems can displace (Kaufman et al., 2000).

Tsoutsos et al., (2005) state that photovoltaic (PV) are normally considered to possess benign environmental impact, generating no noise or chemical pollutants during use, however, generic impacts such as land use, batteries, and PV waste after end-of-life can present serious environmental concerns in large scale PV electrification. According to ARE/USAID (2011) hybrid genset-solar PV mini-grid, though, comparatively clean can produce noise pollution and have direct health impact on local users if the system is located inside or very close to the community.

What is more, deforestation in most developing countries, especially in Ghana has largely been blamed on the lack of access to appropriate energy sources in rural communities that causes people to depend heavily on biomass (woodfuels) for heating, cooking, and lighting purposes (Gyamfi et al., 2015; Arthur, Baidoo, & Antwi, 2011). In Ghana, the dependency on woodfuels (firewood and charcoal) between 2000 and 2008 was estimated at 72% (EC, 2000-

2008). In another studies, Duku, Gu, and Hagan (2011) and Gyamfi et al., (2015) showed that biomass contributed about 64% of Ghana's primary energy supply. The difference in reduction of biomass reliance may have been developed as a result of increase in solar PV electricity and lighting systems in the country over time, which is positive for the environment. Similarly, Gurung et al., (2011) found that the provision of a renewable energy source for Tangting community reduced deforestation and improved greenery in the village and also replaced the use of dry cell batteries, which disposal posed a threat to ecosystems. In situations of damaged or wear-out of systems components during operation, defect components require to be returned to the manufacturing company for recycle but this may be difficult in developing countries (Goetzberger & Hoffmann, 2005) where systems are mostly imported. Additionally, life cycle analysis of batteries for stand-alone solar PV systems have shown that batteries are accountable for most of the environmental impacts, owing to their rather short life span and heavy metal content (Tsoutsos et al., 2005).

The presentation of many of the literature contributions on solar PV systems have shown a good variation of socio-economic and environmental impacts of renewable energy technology deployment in rural areas, most importantly, solar PV mini-grids, which are all deeply rooted in sustainable development. Indisputably, the various findings and divergent arguments are highly relevant issues in every study of socio-economic and environmental impacts of energy technology for rural communities. In the following sub-chapters, the concept of sustainable development and energy technology sustainability for rural communities are discussed as supporting theories for this study.

2.4 Sustainable development

The concept of sustainable development is discussed succinctly as a basis for renewable energy technology deployment (solar PV mini-grid) in this study. The discussion is only envisioned to capture a local impact perspective of sustainability of a renewable energy technology, albeit not limited to global accrued benefits of solar mini-grid deployment.

In the discourse of renewable energy resources and technology deployment as well as potential impacts, the relevance of sustainable development has always been acknowledged since the various concepts are seamlessly interwoven and generally balance each other in theory. Indeed, sustainability has even become more inevitable subject in all development programmes around the world, emphatically, projects that have development agenda in deprived developing countries (Afgan, 2008), seeking to improve the socio-economic and environmental conditions of the local people. Analytically, access to clean energy plays a major role in the achievement of the Millennium Development Goals (see UN, MDGs, 2002), of which eradication of poverty, universal primary education, improvement in maternal health, and environmental sustainability among others (mostly in developing countries) are key concerns in sustainable development.

The World Commission on Environment and Development (WCED, 1987) through the Brundtland report has defined sustainable development as:

> *…."a development that meets the needs of the present without compromising the ability for future generations to meet their own needs." (p.16).*

Elsewhere, the Commission emphasizes fulfilling basic/essential human needs and extending it to higher opportunities of satisfying ambitions for a better life. But, the word "needs" could be misleading since it is very broad and relative in measuring development at different locations. However, the author contends that providing renewable solar mini-gird electricity for rural island communities fulfill a basic need that can extend to other opportunities for improved life and thus, define "needs and sustainability" as:

> *…the provision of a clean electricity services, which level firstly, meets basic lighting and can further support small-medium scale village economic activities such as (grinders/mills, groceries shop, video/entertainment centres, licensed drug shop, tailoring etc.), and improve health care, educational activities, and the surrounding natural environment, which accrued benefits may be relatively higher and better than a former energy source.*

This definition is also consistent with the one of sustainable energy defined by the ICSU (2007) as:

> *…"energy that provides affordable, accessible and reliable energy services that meet economic, social and environmental needs within the overall developmental context of the society for which the services are intended, but distributed equitably to meet local needs." (p.2).*

Elkington (1997) emphasized the significance of a focus on the triple bottom line (TBL) in the event of appraising sustainability. He argues that sustainability should not only base on economic importance, but also direct social value and environmental impacts a movement can bring to local surroundings. Although, Elkington's (TBL) concept has a business perspective, it is still applicable in reviewing the impacts of the provision of renewable energy for rural island communities. This is because the above concepts and definitions have frequently been used to elucidate the intricacies between social, economic, and environmental issues in sustainability deliberations of several projects when considering overall impacts (Sneddon, Howarth, & Norgaard, 2006; Mainali, 2014). The overall spirit behind sustainable development is that whether technology deployment or other human activities, the eventualities should lead to a more positive impact on the environment and human societies that can be sustained indefinitely than negative impacts that affect the same (Elliot, 2002). This is the goal of this research in trying to investigate the potential impacts of solar mini-grid on the local communities. But, the United Nations (UN, 2012) accentuate that providing sustainable energy for rural communities is a daunting task when the goal is geared towards complete improvement in economic, social, and the environmental conditions of the society.

2.4.1 Energy technology sustainability framework

The main theory of this study is based on energy technology sustainability framework (ETSF). The framework is employed to investigate the potential of the particular energy technology through a set of indicators so as to contextualize this research empirically and analytically. By considering the potential socio-economic and environmental impacts of the renewable solar PV mini-grid on the local communities, this paper is more or less assessing the sustainability of the energy technology for the island communities. This allows indicators to be selected and measured accordingly. The energy technology sustainability framework has been employed to evaluate the sustainability of rural energy access in developing countries, especially in regard to renewable energy technologies deployment (Mainali, 2014). It draws on composite indicators to measure complex issues that would have otherwise been difficult to evaluate individually (Rovan, 2014). Mainali (2014) developed and used the ETSF to analyse the sustainability of RE based rural electrification in several developing countries and found it appropriate in such studies.

In selecting the most apposite energy technology among several alternatives to serve a local demand, the need to evaluate the impact of the technology through the lens of sustainability is of paramount importance. But it is equally not easy to select a set of applicable sustainability indicators to examine the performance and impact of energy technology on a local community (Mainali, 2014). The introduction of novel energy technologies in an area will by no less means impact all the dimensions of sustainability relating to the community by their influence on the social, economic and the natural landscape of the area (Musango & Brent, 2011; Huber, 2004).

The OECD (2008a) proposes using composite indicators that provide simple comparisons of issues to illustrate complex and sometimes abstract subjects in a variety of fields such as social, economic, environment, and technological development. In principle, a composite indicator should be based on a theoretical framework, which permits single indicators to be selected, merged and adjusted in a manner that replicate the dimensions of the phenomena being studied (OECD, 2008b; Bandura, 2008). According to Rovan (2014). *''a composite indicator is formed when individual indicators are compiled into a single index, on the basis of an underlying model of the multidimensional concept that is being measured.'' (p.275).* He maintains that multidimensional concepts such as social, economic, environmental sustainability, human development, and technological development etc., cannot be thoroughly captured by independent indicators. For that matter, composite indicators have assumed prominence as a tool for summarizing complex and multidimensional topics (Rovan, 2014). From the above submission, it may be understood that composite indicators are critical tools for communicating energy matters connected to sustainable development.

Therefore, the single composite indicator employed in this study is energy technology sustainability index (ETSI) that describes the comparative performance of the technology in terms of (1) delivering efficient and reliable energy supply; (2) which is cost competitive; (3) with low environmental impacts; (4) having high social benefits; (5) and concurrently observing local involvement in various competences (Mainali, 2014). Apart from social, economic, and environmental dimensions of sustainability, several authors suggest incorporating two extra dimensions namely: technical and institutional when measuring the impact or sustainability of energy technology for rural electrification since reliability and efficiency are particularly important aspects in rural energy supply (see Ilskog, 2008; Ilskog & Kjellström, 2008; Brent & Rogers, 2010; Hong & Abe, 2012; Mainali, 2014; Mainali & Silvera, 2015).

Mainali (2014) has developed a conceptual framework that captures the different dimensions and features of energy technology sustainability and correlated indicators (see Fig 4), which this study replicates.

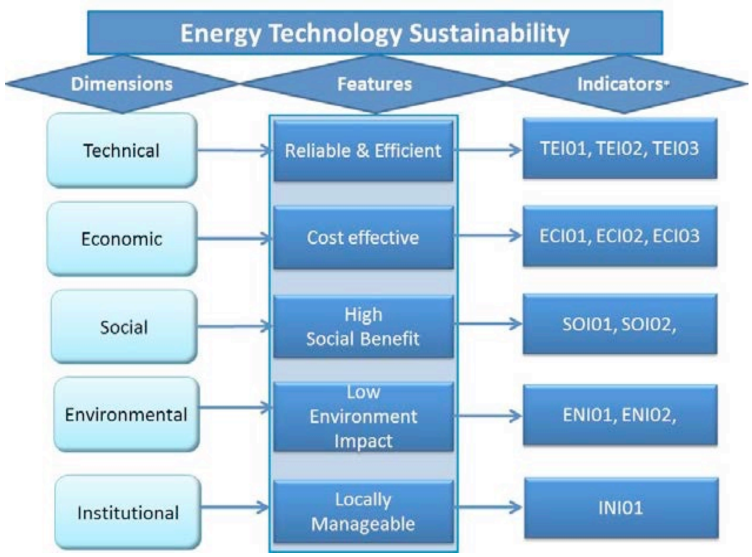

FIGURE 4 Conceptual frameworks of energy technology sustainability (Mainali, 2014).

In fig.4 Mainali (2014) interprets various indicators and analyses the sustainability of the energy technology based on the complex relationships between various dimensions and indicators as follows:

- Technical dimensions: TEI01 = Energy availability, TEI02 = System conversion efficiency, and TEI03 = Reliability.

- Economic dimensions: ECI01 = Technology upfront cost, ECI02 – Operations and maintenance costs, and ECI03 = Fuel costs.
- Social dimensions: SOI01 = Potential for employment, and SOI02 = Potential for various social end uses.
- Environmental dimensions: ENI01 = GHG emissions associated with electricity generation, and ENI02 = Land use and degradation due to energy production and consumption.
- Institutional dimensions: INI01 = Institutional capabilities required to manage the technology.

In economic dimension, it is obvious Mainali (2014) analysed the ETSF based on implementation and operational connotations and excluded the costs to consumers, which is an important factor to account for when analyzing the sustainability of energy technology for rural populations. However, the various indicators are herein explained differently to represent the context of this study as shown in table 1.

TABLE 1 Selected indicators for energy technology sustainability analysis

Dimensions	Indicators	Description
TEI01	Low	Energy level provide basic electricity for lighting, radio & telephone charge
TEI02	Medium	Energy level supports higher connective application such as TV
TEI03	High	Energy level supports productive use
ECI01	User costs	Costs of TEI01 energy level in relation to previous energy expenditure and living standards
ECI02	Support for local business activities	Potential of TEI02 energy level to support existing local businesses
ECI03	Prospects for other economic activities	Potential of TEI03 to generate new local economic activities
SOI01	Potential for employment generation	Number of direct employment opportunities created
SOI02	Compatibility of the technology with several end uses	Capability of using the electricity for various income generating activities, health care, education, gender empowerment and many social benefits
ENI01	GHG emissions	Life cycle GHG emissions and reductions in using the energy technology
ENI02	Land use & impacts	Amount of land use, degradation and benefits as a result of energy production and consumption
INI01	Operational & Management skills	Skills needed at the local level for operation and management of the technology

3 THE SOLAR PV HYBRID MINI-GRID PROJECT AND THE ISLAND COMMUNITIES

3.1 The mini-grid project

Under the Ghana Energy Development and Access Project (GEDAP, 2007), the Ministry of Energy (MoE) is undertaken renewable energy-based mini-grid projects to provide access to electricity to remote island communities on the Volta Lake. These renewable sources include solar, hydro, wind, and biomass. By virtue of the islands geographical location it is highly impractical to extend the national grid to these communities. Realistically, utilizing local renewable energy resources or a mixture of conventional diesel-based generator to build mini-grid system is implied to be the ideal way of meeting the energy demands of most of these island communities. Five communities have been selected for the mini-grid project but this study concentrates on two communities, which are Pediatorkope and Atigagorme. The system is a solar PV with a backup diesel-based generator to provide electricity to the remote communities. Note that the main goal of the project is to deploy a renewable energy resource to meet a local need of electricity thus; the diesel-based generator is strictly used as a standby intermittently. The system is configured to produce 89% of electricity from solar PV and 11% from generator diesel-based sources for the communities, making the system almost renewable (fig. 5). For this reason, the author deemed it relevant to focus the study on the renewable solar resource, which holds the biggest proportion of the project.

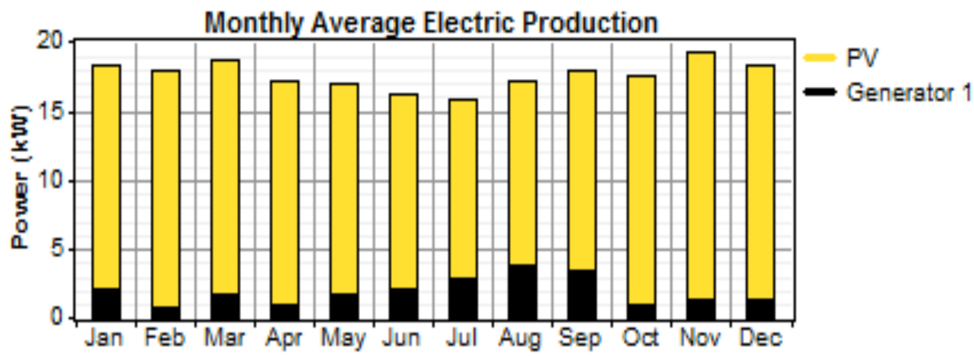

FIGURE 5 Monthly average electricity production from PV and generator (PWC/KITE, 2011)

3.2 Background of the Island Communities

This study was conducted in two of the rural island communities Pediatorkope (PED) and Atigagorme (ATG). The map (fig. 6) and table 2 below shows the geographical location of the Lake Volta (one of the largest man-made reservoirs in the world) (Breuning-Madsen, Lyngsie & Awadzi, 2012), island communities, and the commercial activities. See appendix 3 for the actual island landscapes and GPS coordinates of various structures.

FIGURE 6 Map of Ghana showing island communities on the Volta Lake

Table 2 shows the commercial activities in the form of petty trading and services and operators in both island communities. Also in table 3, the communities' energy sources, end uses and percentage use is illustrated.

TABLE 2 Commercial activities in Pediatorkope and Atigagorme

Commercial activities	Operators
Fishing and Oyster mining	Fish monger
Corn mill	Corn miller
Hairdressing	Hairdresser
Barbering shop	Barber
Dressmaking	Dressmaker/Seamstress
Mini-grocery sellers	Traders

TABLE 3 Energy consumption patterns of the communities (PWC, KITE, 2012)

Energy source	End use	Percentage	
		PED	ATG
Kerosene	Lighting	92.6%	75.2%
Dry cell battery	Lighting	82.2%	73.1%
	Powering radio	85.7%	88.5%
	Mobile phone charge	69.5%	61.5%
Candles	Lighting	7.1%	15.4%
Biomass (firewood/charcoal)	Cooking	99%	100%
	Smoking Fish	100%	100%
	Ironing	71.4%	42.3%
	Other	9.7%	5.8%
Diesel gensets	TV	8.1%	4%
	Mobile phone charge	12.5%	-
SHS	Mobile phone charge	11.9%	3.9%
	Lighting	2%	-
Car battery	Fan	3.6%	-
	TV	2.5%	-

3.3 Pediatorkope Island Community

Pediatorkope is a densely populated clustered traditional rural settlement located between latitude 3.822°N and longitude 0.628°E in the Dangme East District of Ada. The island constitutes five sub-communities, which population is about 1200 inhabitants with 132 households (KITE, 2014). Housing structures are traditionally thatched roofs and mud houses with exception of the health care and school buildings. The main occupations of the residents are fishing and oyster mining, serving also as the primary source of income followed by peasant farming for household consumption, while average monthly household income ranges between GHS 200 - 500 = USD 55.5 – 138.8 current foreign exchange currency rate estimate (Bank of Ghana, 2015). Note, the conversion is based on today's (July 8, 2015) interbank exchange rate of the Bank of Ghana in which 1 USD = 3.6 GHS and this is subject to change significantly by the end of this thesis. Hence, the reader is advised to use the most current exchange rate for accurate conversion. The community has average household size of 7 members with the majority having no formal educational. Institutions and infrastructures in the community involve clinic, elementary school, churches, and water pump purification system for the clinic. The community has no access to electricity and the inhabitants depend largely on biomass (firewood, charcoal), dry cell batteries, and kerosene as the main sources of energy for domestic and commercial uses. Figure.7 exhibits the solar resource availability on the island community.

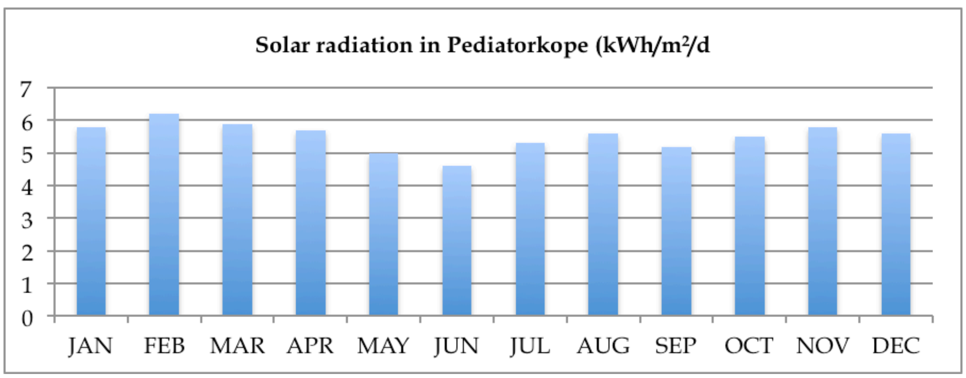

FIGURE 7 Daily average global horizontal solar radiation at Pediatorkope (Author's plot using NASA RETScreen online climate database for coordinates 3.822°N, 0.628°E)

3.4 Atigagorme Island Community

Atigagorme is located between latitude 7.67°N and longitude 0.056°W in Krachi West District of Volta region in Ghana. According to GSS (2010), the population of the community was estimated at around 710 inhabitants with about 90 households and a household size of 8 members. However, a recent household and energy demand survey conducted by KITE estimated the population at 600 inhabitants with about 72 households .The housing structure is the thatched roofs and mud buildings. Like Pediatorkope, the main occupation of the island dwellers is fishing followed by boat building, and peasant farming, which are the mainstay of the inhabitants and heavy reliance on biomass (firewood/charcoal), dry cell batteries, kerosene, candles, etc. as sources of energy for domestic and commercial purposes are currently inevitable. The average total monthly income of households varies between GHS 300 – 700 = USD 83.3 – 194 (BoG, 2015, see Note in Pediatorkope). The only institution at Atigagorme is a church. There is neither school nor clinic in this community. However, children attend school at a distant neighbor island community. Figure.8 shows the solar resource availability prevailing at Atigagorme locality.

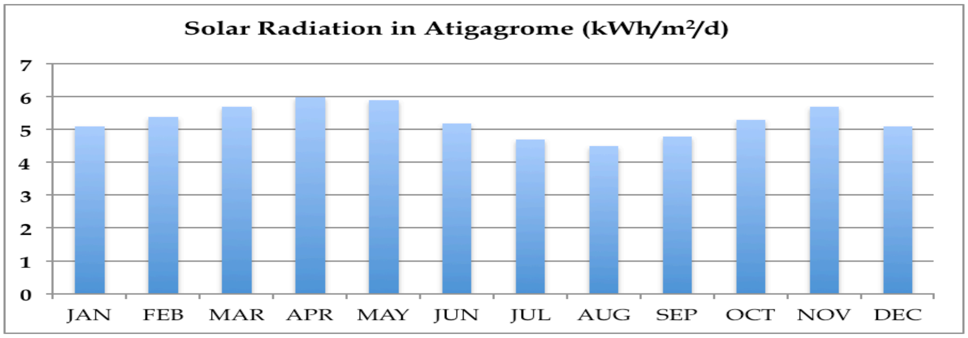

FIGURE 8 Daily average global horizontal solar radiation at Atigagorme (PWC & KITE, 2012).

The solar resource availability data of both communities have been taken using the geographical coordinates of the nearest commercial cities to the islands, Big Ada and Krachi, which are within the same prevailing weather conditions and this is a common practice in solar mini-grid implementation (Sharma, Palit, Mohanty, and Gujar (2014). An important aspect of renewable energy project implementation such as solar mini-grid is to fundamentally establish the existence and sufficiency of the renewable resource in the local environment as this project and study has already determined (Twidell & Weir, 2006). Power and Pachauri (2008, p.41) indicates that insolation is measured in kWh/m2/day, which ranges from an average of 3 kWh/m2/day to 7 kWh/m2/day worldwide, making the solar resource statistics of both communities well enough for the evaluation of systems performance and economics at a high level

4 METHODOLOGY

This section introduces the methodological choices made for this study. Reasons for the choice of qualitative research method as well as case study method has been provided in this chapter.

4.1 Research design

The selection of a research methodology and design is primarily founded on the description of a research problem or the subject being tackled (Creswell, 2009, p.3; Hesse-Biber, 2011). Qualitative research method has widely been applied in various research settings and defined by several authors as a process of exploring, interpreting, and uncovering complex actions and experiences of people and the world around them in a more subjective approach, rather than objective manner (Hesse-Biber & Leavy, 2011, p.4; Holloway, 1997; Creswell, 2003, p.51; Given, 2008). This method was chosen to allow the researcher to establish rapport with respondents in the interaction and participation process in order to gain deeper understanding of situations during data collection (Creswell, 2003). Qualitative researchers study things in their natural sceneries and endeavor to make logic out of the meaning people attach to them (Hesse-Biber & Leavy, 2011, p.4; Schwandt, 2007; Denzin & Lincoln, 2011; Patton, 2002; Stake, 1995). In fact, methodology is a skillful and putative way by which a researcher gathers data to help understand an issue as clearly as possible (Cohen, Manion, & Morrison, 2007). Thus, qualitative research method offers greater flexibility in research design, hence, I considered it appropriate to utilize the methodology to address and effectively solve the research problem.

4.2 Case study

The research was conducted as a case study since the issue being studied is in real life setting involving people and utility (energy) provision (Cohen et al., 2007; Yin, 2014). It was considered essential to conduct in-depth empirical research utilizing qualitative case study and participatory methods to gain insight into energy projects, as such methods assists the acquisition of first-hand data from the field and the local people (Cook et al., 2005). Schwandt (2007, p.28) states that, "in case study, the case itself is at the centre stage of the study" and not outside of the inquiry and the researcher may be trying to unearth the correlation between a phenomenon and the context in which it is happening (Gray, 2004). The goal of the researcher in this study was to uncover the relationship between energy access and potential impacts. Yin (2014), and Gray (2004) maintains that a case study approach is an ideal choice when the inquirer pursues answers to how or why questions, having little or no control over events being studied, and when the object under investigation is an existing phenomenon in a real life situation. Moreover, case studies are believed to be instrumental in broadening understanding of a particular problem, issue, or perceptions by pursuing to generate knowledge of the particular in diverse settings in order to make meaning of them (Skate, 1995; Silverman, 2005, p.126). Thus, I employed case study to explore how access to solar PV mini-grid electricity will impact the two rural island communities.

4.2.1 Case selection

The cases were selected through purposive sampling. Purposive sampling is used to sample cases or participants that are strategically important to address research questions at hand and may be used after a pre-test investigation has informed the right group for ones study (Bryman, 2012; Berg, 2001). According to Berg (2001) "a community can be defined as some geographically delineated unit within a larger society". Such a community is small enough to allow substantial cultural (or subcultural) homogeneity, diffuse interactions and relationships amongst members, and to create a social identification by its members (p.233). The two communities were selected based on their sizes, cluster of houses, social, economic and environmental characteristics, which presented them as interesting for investigation in relation to the electricity being provided. Some studies have identified the above criteria as a basis for designing rural electrification projects; importantly mini-grids and the selection of communities for impact studies may also reflect the same criteria (World Bank, 2008c; GNESD, 2014; Bhattacharyya, 2015). Besides, the case selection was influenced by the project's uniqueness as being the first solar mini-grid project for island communities in Ghana and the two communities finally inclined by the outcome of the pretest interview structure on the five communities. Therefore, selecting both communities based on the above conditions was important in order to adequately answer the research questions of this study and to contribute to existing literature in mini-grid implementation.

4.3 Data collection

Patton (2000, p.4) explains that qualitative research usually derives its data from fieldwork for further analysis. According to Creswell (2007, p.117-118), data collection provides added opportunity for evaluating research within an inquiry process. The aim of the researcher is to collect quality information that can ultimately address the research questions or phenomenon adequately. Gall, Gall and Borg (2007, p.228), states that questionnaires and interviews are the most predominant methods used in educational research for data collection about a phenomenon that are not directly observable. Interviews involves oral questions asked directly by the interviewer and oral responses by the research participant which are recorded verbatim with occasional brief notes taken by the interviewer while questionnaire are printed forms that ask the same questions of several individuals in the sample for which respondents record their answers in written form. Certain behaviour such as opinions, values, and experiences cannot be observed directly, but interviews can help to elicit substantial information about them from informants (Gall, Gall, & Borg, 2007.)

I chose interviews over questionnaire for my data collection because of its adaptability. I also took photographs in the form of observation to complement my data, as there is no rigid rules that prescribes what data a researcher should collect to explore a particular interest or problem (Gall et al., 2007, p.12). I pretested interview structure in the five communities during an initial visit, which outcome informed modification of the interviews and the final selection of the two communities. The actual field data was collected during a second visit to the communities in which I spent five (5) days in each village for data collection exercises. Data for this study was mainly collected from the communities (Pediatokope and Atigagorme) and project experts who were in the positions of engineering and top management. The field interviews was supplemented by relevant articles and information obtained from diverse sources such as ScienceDirect, Ghana Ministry of Energy (MoE), Ghana Energy Development and Access Project (GEDAP), International Energy Agency (IEA), National Renewable Energy Laboratory (NREL), World Bank, and others.

4.3.1 Sampling strategy and selection of the interview participants

The rationality of utilizing a sample of subjects in qualitative research is to make inferences about some larger population from a smaller one (Berg, 2001, p.30). In qualitative research work, the site or participants that will assist the researcher to understand the problem and the research questions is purposefully selected. It involves making discussions about who should be sampled, what method the sample ought to be and the number of participants (Creswell, 2009, p.178).

Convenience or availability sampling was used to select available and willing participants to be involved in the interviews. This method makes use of available respondents at hand who are also willing to engage in any form of discussion (Krueger & Casey, 2000; Berg, 2001). The distance between Accra where I was working and the island communities is about 450km. Considering the long distance needed to travel to the island communities, I had limited opportunity to conduct my data collection exercise within the five days I spent in each community. Therefore, convenience sampling was most suitable for my data collection in all the communities. Access to the communities was gained through my internship work. It was part of my responsibilities to travel to the island communities for community engagement, education, and data collection exercises. The community members were familiar with my work in the community, thus, requesting to conduct further interview concerning the project met with no resistance. A verbal consent in the form of discussion was sought from my manager/supervisor and the opinion leaders of the communities during my first visit. The data collection was conducted after the responsible authorities granted my request.

The initial process involved identification of occupied houses and households by the help of an indigene in the community. Further, GPS coordinate was picked for each house and unique identification number (UIN) was assigned to each household within the same house. This method assisted to identify the total number of houses and households in each community. Participants selected for the interviews included opinion leaders (chiefs, assemblymen, religious priests, school heads, and head of clinics), household heads or members, and commercial operators (petty traders). Each group of participants was selected on the same day of the interview, however, prior to the actual interview time, at least fives hours before the actual interview. I provided all selected interviewees with information written on a piece of paper stating their unique household identification number, group number, time, and place of the interview. I checked the information note of each participant upon arrival to ensure that they are the right participants selected for the particular group and I also kept the notes to avoid double participation.

4.3.2 Interviews

Interviewing has emerged as the dominant resource for engagement between the social sciences, business, and the society concerning issues that matter to us (Rapley, 2001). An interviewer may utilize the technique to elicit information or expression of perspectives from interviewees regarding complex matters, as interviewees may also chance themselves to explicitly expound key issues that matters to them (Maccoby & Maccoby, 1954). In a study phenomenon such as this where little is known, I considered interviews as spectacular and most appropriate method to unearth pertinent insights from group and individual interviewees (Gill, Stewart, Treasure & Chadwick, 2008).

I conducted semi-structured face-to-face interviews guided by open-ended questions with project experts and community members to obtain information regarding the potential impact of the implementation of the solar PV mini-grid electricity on the communities. In comparison with structured interview, semi-structured style offers more flexibility to both interviewer and interviewee to explore the dialogue potential for knowledge construction that are intrinsic in human conversation (Brinkmann, 2013). Accordingly, both parties can diverge so as to elaborate on an idea or answer (Gill et al., 2008). I combined focus group and individual interviews as well as active observation to gather data for the study since the approaches offered more opportunities to investigate the situation better than others as a case study (Gray, 2004, p.129).

The interview questions were designed to capture social, economic, and environmental issues. However, the actual interview advanced in high flexibility to allow multiple insights to emerge. Though, all questions were designed in English language, the group interviews at the community level were mainly conducted in the local 'Twi' language, whereas individual interviews involving project experts were conducted in English language. This was done because of the dynamics of the respondents and their ability to communicate in English language. Obviously, the method provided more flexibility, thus, extracting detailed information from respondents as they expressed themselves freely in a suitable language.

In total, eleven (11) interviews were conducted for the study. Nine (9) focus group interviews were conducted at the community level and two (2) individual interviews were conducted with project experts. Strategically, the number of the experts' interviews was minimized since the study concerned the local communities and the views of experts were unlikely to epitomize realistic potential impacts on the communities. Telephone numbers of all individual interviewees were obtained for further clarification when needed as they were informed.

4.3.3 Focus group interview

Focus group interview was employed for data collection at the community level. Five (5) group interviews were conducted at Pediatorkope and Four (4) group interviews at Atigagorme based on the size of each community. According to Silverman (2011, p.161 – 165), focus group interview is a way in which qualitative data is collected by engaging small groups of people who bear certain harmonies or share similar characteristics. Krueger (1994) also share the same view as Silverman. Blaikie (2005) states that, case study focuses on a social unit, a real individual, social event or group of people, which treats the individual, group or event as a whole. In practice, the case study keeps together as a unit, those characteristics that are significant to the scientific problem under investigation. I decided to seek for collective, however, divergent views of respondents concerning the research problem from a larger population; hence, focus group interview appeared extra dynamic and flexible to gather such data (Gill et al. 2008). The distinctiveness of focus group interview lies in its ability to produce information based on the group synergy (Green, Draper, & Dowler, 2003).

The total number of participants in the focus group interviews in both communities was forty-five (45). The participants consisted of opinion leaders (chiefs, assemblymen, religious priests, school heads, and head of clinics), household heads or members, and commercial operators (petty traders). In each focus group interview, there were five (5) members. The members comprised of at least one person from the groups specified above. This blend helped to keep the range of variation needed in focus group interview alive in the data collection (Schensul, leCompte, Nastasi, & Borgatti, 199). While an ideal size of noncommercial topics may range between six and eight members, however, a number less or more than the optimum can work perfectly dependent on the research focus and how the researcher manages the group (Krueger & Casey, 2000). I decided to make the group size less below the optimum in order to contain the group as an individual moderator and also avoid the problem of 'no show' with larger groups (Brinkmann, 2013, p.26). Bloor, Frankland, Thomas, and Robson (2001, p.26) believe that there is no such thing as optimal size of a group in research, but optimum size is the one that mirrors the social characteristics of partakers and the subject being debated upon. Moreover, in a casual engagement with some of the community members prior to the actual interview, I observed that individuals were very passionate about electricity, and so, they could also be very articulate and fluent in matters relating to electricity, therefore, smaller size was an ideal to stimulate enthusiasm and synergy among the group members.

Additionally, the cluster of the communities suggested common social characteristics (Krueger, 1994), which the researcher maximized the opportunity to save time by interviewing a couple of informants together in a group (Bryman, 2012). It was clear that individual interviews at the community level would have been too cumbersome for both data collection and analysis. I did not avoid using focus group interviews as suggested by Morgan (1998) because there was no statistical data and if any, it was readily available in the KITE end-user demand census (2014).

During the actual interviews, probing was utilized to obtain more in-depth answers from intriguing responses and occasionally allowed the participants to discuss an issue while I wrote brief notes of key points from their discussion. According to Rabiee (2004), focus group interview can generate voluminous data in a relatively short period of time. Therefore, I skillfully regulated the interview time and the maximum time spent on one group interview was forty (40) minutes and the least were twenty-five (25) minutes. In a polite and sensitive manner, I prompted the participants to mention the most important issues relating to the interview questions as a way of minimizing the amount of unrelated responses and capturing on the opportunity that semi-structured group interviews offers for the interviewer to focus the conversation on issues that he/she considers as relevant in connection to the research interest (Brinkmann, 2013.) All the group interviews in the communities were conducted at a neutral venue, which was familiar and convenient for all the participants; at a clinic centre and a school classroom after both centres had closed from busy work activities for the day. Again, all the group interviews were tape-recorded one after the other with at least two recording devices and concurrent brief notes were taken.

4.3.4 Field observation and photography

Structured observation is a systematic technique, which a researcher employs to explicitly generate physical data from the behaviour of individuals, an environment or events that appear naturally from social settings (Bryman, 2012; Cohen et al., 2007; Angrosino, 2007). Since this study relates partly to the environmental conditions of a community, I observed in situ, the environmental conditions of the island communities and captured photographs of indiscriminate disposal of used dry cell batteries and deliberate tree cutting as visible data to augment the study findings (See appendix 2). Creswell (2009) posits that an important category of data collection in qualitative research, in particular case study is visual materials such as photographs and artifacts that can broaden understanding in relation to the case being studied. Tangible evidence in qualitative research constitutes the foundation for our capacity to build rational conclusions about things as they appear to us through prolonged observation (Angrosino, 2007). In observation, researchers can obtain data in a manner that may not necessarily be known to the inhabitants, for example taking photographs and recordings that can be used as a physical evidence to strengthen interpretive results from qualitative research (Bernard, 2011).

4.4 Data Analysis

The practice of data analysis simply denotes a researcher's intention to make sense out of the raw text, audio, and visual resources collected from diverse sources (Creswell, 2009, p.183). The voluminous data was abridged by summarizing, reconstructing, and categorizing for a cogent interpretation (Miles & Huberman, 1994). Qualitative content analysis approach in conjunction with the energy technology sustainability framework is employed for data analysis of this study. Content analysis according to several authors has been defined as:

- "a method for describing the meaning of qualitative material in a systematic way"(Schreier, 2012, p.1)
- "a research method for the subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns" (Hsieh & Shannon, p.1278)
- "any qualitative data reduction and sense-making effort that takes a volume of qualitative material (interview transcripts, diaries, or documents) and attempt to identify core consistencies and meanings" (Patton, 2015, p.541)
- "a process designed to condense raw data into categories or themes based on valid inference and interpretation"(Zhang & Wildemuth, 2009)

The above definitions show that qualitative content analysis accentuates a cohesive view of speech/texts and their precise contexts. The choice of content analysis for this study is based on its emergence as one of the best methods used to analyze interviews with emerging and recurring themes, which are absent in other methods (Miles & Huberman, 1994). Moreover, this study deals with meanings that are less obvious to identify instead of highly standardized meanings, which are easily identifiable. For example, a research study that seeks to know gender balance in a school institution has a standardized meaning and can be easily identified (Schreier, 2012, p.2.)

Creswell (2009, p.185) has developed a systematic qualitative data analysis process that suggests a linear, hierarchical technique building from the bottom up, which follows steps from the general to the specific. The process is preferred in the data analysis of this study because it appears interactive in practice (see Fig. 10).

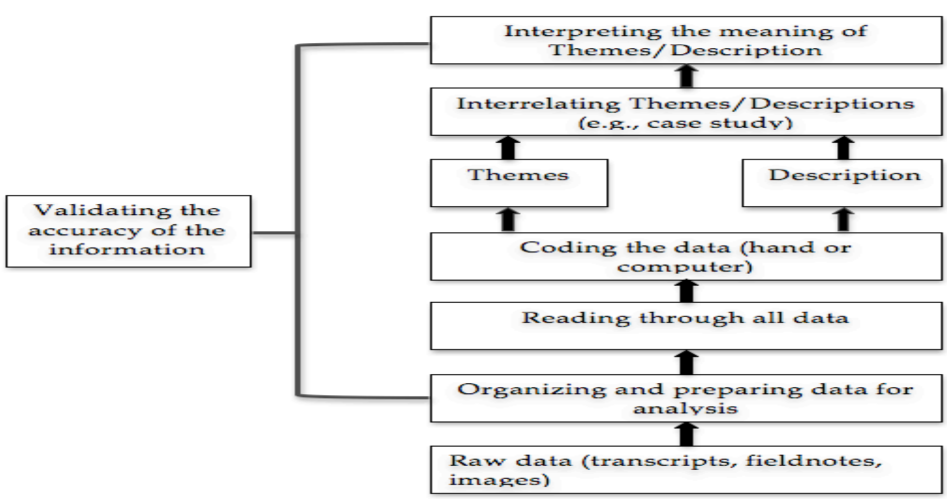

FIGURE 9 Data analysis procedure of the study (Creswell, 2009)

While data analysis has been construed to trail behind data collection process, others believe that researchers initiate the analytic undertaking during raw data collection. For instance, when they endeavor to cleverly facilitate the discussion to generate rich data, comprehend and decode what respondents are trying to say in line with the research focus or concept (Brinkmann, 2013; Rabiee, 2004.) Naturally, the above skills were employed during data collection to understand respondents' responses and the real meaning behind them.

By organizing and preparing the data for analysis, I listened to the recorded audiotapes several times to acquaint myself with the data to develop a general idea of key issues in the interviews. My experience in bachelor thesis and data organization was a guideline in this respect. Following almost two months of listening to the recordings, I began to transcribe the interviews into actual texts. According to Halcomb and Davidson (2006), "transcription refers to the process of reproducing spoken words, such as those from an audiotape interview, into written text". Fielding and Thomas (2008, p.257) propose that the choice for data transcription can either be selection of information that is relevant to the research or writing every spoken word by the respondent "the choice between selective transcription and verbatim." I engaged verbatim transcription for the individual interviews because there were few, two (2) of them as recommended by Fielding & Thomas, (2008). Though time-consuming and arduous, the advantage of verbatim transcription lies in the possibility to embrace multiple analytic strategies since no information is left out of the data (ibid). It should be mentioned herein, that some individual interviewees were further contacted to clarify some statements that were unclear to me.

For the group interviews, I translated and transcribed the first few minutes' verbatim and employed selective transcription for the subsequent minutes (ibid), since they were many and in the local language. My strategy was to acquire a guideline of how the interviews proceeded and what skeletal analysis could possibly be developed. Selective herein means I excluded the "messy" information such as err, hmmm, ah, aha, laughs, etc. in the interviews that were not necessarily useful for the purpose of the research. As experienced, selective transcription does not necessarily save time, as one would supposedly anticipate since excluding some "messy" words, reconstructing phrases and selecting some portions of the interview data require meticulous attention and special 'self-developed' skill and scheme. Also, it is likely that this approach can hinder manifold analytical possibilities if not carefully managed because some "messy" words may connote interpretive meaning, which may eventually be relevant for the study, but would have been omitted already. However, the brief notes taken during the interviews served as an important guideline for the selective transcription. Indubitably, during listening and transcription of the audiotapes, I noticed some key issues and words that respondents used in the course of the interview, which initially didn't 'catch' my attention at the time of the interview.

Moreover, I read through the transcribed data a second time to gain general understanding of what the information really meant. For example, the main analytic themes that were being developed, controversies, some expressions of passion and what areas does these relates, sincerity of interviewees and the information provided as I began to mark these issues with selected coding colours. A detailed analysis of the data was initiated at this point by employing a coding frame to organize the data (answers from various interviewee groups) into main categories reflecting the energy technology sustainability framework (technical, economic, social, and environment,). Schreier (2012, p.61) describes coding frame as "a way of structuring ones material, which consists of main categories indicating relevant aspects and of subcategories for each main category specifying pertinent meanings concerning this aspect." The coding was performed manually by hand.

The main themes that emerged from the data were further coded as subcategories under the main categories. Here, coding exercise was guided by the number of times an item or a theme was mentioned (Macdonald, 2008, p.295). The data from each community was analysed differently and common themes that emerged from the interviews were categorized. Afterwards, commonalities and differences in themes from both communities were also classified together accordingly. Finally, the themes were combined to represent the overall findings from both communities. The data from the project experts were also analysed together. To avoid mundane, recurring themes from both communities are presented together in the analysis.

5 RESULTS

This chapter presents the data analysis of this study based on the energy technology sustainability framework. The main categories of analysis are Technical, Economic, Social (Institution) and the Environmental impacts/dimensions. For simplicity, the analysis has classified institution under social dimension. The findings from both communities are presented together. However, a clear distinction is also made between distinct findings that distinguish both communities from each other in terms of electricity needs and perception of potential impacts. The abbreviations PED (Pediatokope) and ATG (Atigagorme) are used occasionally to differentiate responses from the communities. The themes derived from the analysis are presented under the main categories. While the thesis does not specifically cover the technical dimension of the solar PV mini-grid project, it is still relevant to underscore some key technical features that set the basis for analysis of the potential impacts. This is because technical dimension of solar electrification has a direct influence on the impact and sustainability of the project on local communites. The technical dimension of the solar PV mini-grid electricity for both communities is shown below.

TABLE 4 Technical dimension of the solar PV mini-grid

Community	Capacity	Level	Batteries	Operational Hours
Pediatorkope	50 kWh	TEI01 - 2	41power storage	24/7
Atigagorme	26 kWh	TEI01 - 2	28power storage	24/7

Readers should note that in Ghana, the word "light" is commonly used in the place of electricity. Thus, the word is frequently used in the excerpts from the participants' responses.

5.1 Economic impact

Economic activity drives development in any community. But it is certain that productive business activities will always require energy to succeed. Communities that lack access to electricity, mostly also lack basic infrastructures that can stimulate economic development to deliver a change in the lives of individuals and the community as a whole. Notwithstanding the above premise, the reality on how a particular source of energy/electricity affects the economic conditions of some island and remote villages has been investigated and answers are provided through the following research question:

Q1. What economic impacts can the solar PV mini-grid have on individuals and the entire island communities?

5.1.1 Bargaining power and a suitable price for harvest

The results show that the main occupation for both communities is fishing. The fishermen sell their harvest either on the same day to visiting traders or preserve the fish through smoking due to scarcity or lack of storage facilities such as refrigerators, aiming to sell the smoked fish at a later date. Moreover, they mentioned that smoked fish looses its market value, leading to a fall in price. According to the interview participants, the above scenario compels fishermen to sell their harvest at a very cheap price to visiting traders in order to avoid spoilage. The communities consider that the provision of electricity will encourage the acquisition of some storage facilities such as refrigerators to store their harvest and sell them later for a better price. Therefore, they attribute access to solar PV mini-grid electricity to the possibility to gain strong bargaining power for their harvest in the near future. In Atigagorme all the focus group interviews unequivocally stated:

> *"As a fishing community, we need refrigerators to preserve our fish harvest. Often, we are compelled to sell most of the day's harvest very cheap to visiting traders and they usually decide the price they want to give to us. We have little or no option to reject their offer because if we do, the fish will spoil in few days. So light should help us to acquire fridges to preserve our harvest and decide a suitable price ourselves"*.

Similarly, in Pediatokope, most participants reiterated the issue of falling prices with smoked fish.

> *"We smoke most of the fishes we catch from the lake and the problem with smoked fish is that it doesn't have the same market price as fresh ones. It usually looses its market value; hence the fall in price. For this reason, we hope that the solar mini-grid light will help us to get a better price for our harvest since we can purchase fridge to store our harvest and sell it fresh"*

One of the expert interviewee also established the fact that the solar electricity will assist the poor fishermen on the communities to store their harvest and determine the market price:

> *"The project feasibility studies showed that almost all the communities engage in fishing activities and their harvests are sold very cheap to external buyers. We believe as the project get implemented and capacity increases in the near future, they can buy storage facilities such as solar refrigerators to keep their harvest longer and determine a suitable price for it later.*

Apart from the possibility for the case communities to gain strong bargaining power and better prices for their harvest through energy access, another observation made showed that women spent considerable hours on fish preparation and preservation (smoking) of which the same hours could probably have been utilized for other productive activities if electricity were available.

5.1.2 Prospects for tourism business activities

In terms of economic impact of the solar PV mini-grid electricity project, one of the most important impacts the island communities are expectant of is that the electricity will propagate prospects for tourism activities or business ventures in the communities. The opinion leaders in the focus group interviews mostly responded in this direction of potential impact on the communities.

> *"We have very good and spacious island communities on the Volta Lake but almost all the islands are not properly developed to attract visitors and tourists because of the lack of electricity. With the construction of solar PV mini-grid electricity in the communities, we are hopeful that it will open up to the establishment of some tourism business activities and also provide jobs for the youth in the communities".*

In particular, the interviewees in Pediatorkope expressed concern about the deplorable state of their island community in comparison to estuaries along Big Ada, a city close to the island, which have been fairly developed for tourism activities. Their expression reflected a feeling of having been left out of development as a result of lack of electricity.

5.1.3 Prolonged business hours and expansion

It is recognizable that business activities can only be undertaken in light and not in darkness. Apparently, where there is darkness no business activity can thrive. Most of the commercial operators in the group interviews from both communities echoed the view that they have limited hours to operate their petty businesses within the day. The findings indicated that most small-scale business on the island communities are only operated between the hours of 8:00am in the morning and 5:00pm in the evening. The commercial operators reasoned that the introduction of the solar PV mini-grid electricity will help prolong business operation hours, especially at night and also create the possibility for business expansion as they can engage or add night business segments such as selling of "tea beverages, fried egg, "indomie" etc." to their business product lines. Excerpts of some of their expressions are provided below:

> *"I operate corn mill and usually I work during daytime because operating a corn mill machine with lantern is very risky. But when we get access to the solar mini-grid electricity, I can connect light to my shop and also operate at night to serve those who may need services at night. Also, diesel is expensive and sometimes difficult to come by because of our location, so getting electricity will reduce my cost and help my business to grow (ATG)"*

> *"Sometimes I think that if we have electricity I could operate my provision shop a little longer at night and also serve customers some beverages and delights such as tea, fried egg, and "indomie" just to bring people together to share some life at night (PED)".*

> *"Electricity will be good for us because it will help those of us who operate little shops to get light to extend our work to late hours so that we can earn some extra income to what we normally get from our usual operating hours because of lack of electricity (PED).*

In respect to this theme, an expert interviewee had this to say:

> *"As I mentioned earlier, this project is being implemented to bring some sort of improvement to the prevailing conditions on the island communities and one of such is that those who engage in small selling activities can possibly extend their usual business hours at night because of the access to electricity"*

An interesting aspect in the findings is that most of the micro businesses in the communities are operated either in front or inside homes of operators. This means, at least low-level domestic electricity/lighting such as TEI01 can simultaneously provide adequate lighting to extend business hours.

5.1.4 Potential increase in household income and dignity for women

It is likely that rural households can increase their income levels through access to electricity but dignity for women was a linkage and an extraordinary finding that came as a surprise even to the author. The women in the focus group discussions at Pediatorkope frequently aired this opinion as a potential impact. This is one of the findings that distinguish Pediatokope from Atigagorme in the economic impact aspect. The respondents mentioned that the solar PV mini-grid electricity could afford them the opportunity to engage in extra selling activities such as "pure" water and minerals to earn additional income to support their homes and also elevate their self esteem at home.

> *"As women in this community, our main job is to smoke the fish from our husbands' daily harvest and sell them. Over the years, the harvest has been very low, which affects our income. Apart from that there is no other job we can do to earn extra income to help home finances. But when there is electricity we can engage in the selling of "pure" water and some minerals to earn extra income for our home finances. Bringing extra income to the family can boost our image and respect at home (multiple responses paraphrased by the author).*

The respondents referred to the women in a nearby town, Big Ada and inferred that they may enjoy considerable amount of respect at home because they have the advantage to utilize electricity to earn extra income to support their homes.

5.1.5 Potential financial burden

Notwithstanding the above economic benefits, which the interviewees perceive the solar PV mini-grid electricity is likely to convey to individuals, businesses and the entire community, the cost of electricity is also a major concern to the people. They foresee the likelihood of financial stress/hardship which access to electricity can potentially result in their economic conditions. According to the findings, the following costs relationship to end-users has been identified.

TABLE 5 Cost relationship of energy to end-users

Average monthly expenditure on current energy sources		Connection fee for solar PV electricity	Proposed month electricity cost to end-users	
Household	Business	60 GHS = 16.7 USD	Household	Business
24 GHS = 6.5 USD	40 GHS = 12 USD		6-8 USD = 21.6-28.8 GHS	12-16 USD = 40 -57.6 GHS

"Unlike dry cell battery or kerosene where you can decide to or not to buy dependent on your financial condition at a particular time, electricity is directly opposite and you are obliged to pay monthly bills regardless of your financial circumstances at a particular time. We are not used to this kind of system, so I think that the obligation to pay monthly electricity bills can result in financial burden on our finances at some time (PED)".

"Though, electricity will be good for our community, we know that it is not for free and it is also very expensive if the government doesn't provide subsidies for us. If we have to pay the same amount of money as consumers in the city pays, then it will leave us very poor and in the end the government will have to shut the system down because it will be difficult for us to pay the electricity bill (ATG)"

According to the experts' views, relative financial burden can be considered in terms of the current energy sources and how much the people spend on them in contrast to the level of electricity that is being provided, the price for the service, and possibility for product uses.

" We can consider this in relation to the current energy sources of the people, how much they actually spend on them and what solar electricity will be provide. For example, if the solar electricity power can support productive uses, then it means the issue of financial burden on the users is somewhat solved. Moreover, the project will take into account income levels, ability and willingness to pay (WTP) of households, businesses, and institutions before they will be connected. Therefore, the WTP survey will possibly take care of all feasible financial burden that might arise".

However, the experts admitted that the use of foreign currency (US Dollars) to determine consumer price and utility cost valuation every six months is likely to cause unbearable financial burden on consumers because of the rising exchange rate of the USD against Ghana Cedi (GHS). Finally, the findings demonstrate that the communities are expectant the solar PV mini-grid electricity will offer better comparative economic prospects and cheaper energy for the communities than their current sources of energy.

5.2 Social impact

Access to electricity can potentially result in a number of social benefits that could accrue to a society or certain communities in relation to their prevailing conditions. The empirical study has shown how and in what areas solar PV mini-grid electricity can possibly influence. In this section, the following research question is answered:

Q2. How can the mini-grid electricity improve social institutions and individual lives in the communities at large?

5.2.1 Improved educational system

Education is regarded as a basis for every individual's progress and community development at large. But the same cannot thrive in the absence of some fundamental pillars such as electricity. To this effect, the results show unambiguous response from community focus groups and expert interviews that envision the impact of the solar PV mini-grid electricity on education as top priority above all other social potential impacts. In Atigagorme where the community has no educational institution, this is how an opinion leader expressed a collective view of the people concerning the electricity project.

> *''One of the most important social issues confronting this community is that there is no school in our village and as a result most of the children in this community do not have basic education. Even the few who go to school have to walk a long distance to another island community to attend class and this discourages them as they often stop schooling in the middle of their basic education. An educational facility is one of the biggest hopes we expect the solar electricity to bring to our community so that our children can have a complete education. Additionally, electricity will serve as a motivation for teachers to come and teach in this community."*

One issue, which both communities share in common in this area as the results indicate, is high rate of teenage pregnancy connected to education. The respondents were not hesitant to link the phenomena to lack of proper education and its complementary electricity. They articulated these views in different ways specific to their individual community characteristics.

> *"There is a high rate of teenage pregnancy in this community as you may have noticed. This is due to the absence of a school in the community. Girls get*

pregnant at a very tender age because they don't attend school. With access to electricity, we are hopeful that school building will follow suit because these two almost always goes hand-in-hand. Wherever there is electricity, there is a school (ATG)".

"In our situation where school children do not have light to study at night, girls engage in bad practices that leave them in early pregnancy and as school dropouts. Light can increase students study hours at night and prevent teenage pregnancy in this community. Our children can study further at night after their normal school hours so that their education can improve. Even some of the children can group together to study and share knowledge as they teach and learn from each other (PED)".

The above theme was not only communicated by parents in the group interviews, but also headmasters (school principals) and teachers in the focus group interviews also showed their concern for being able to provide better educational services to their students under the provision of electricity.

"Recently, the use of computer and internet to teach in schools has generally improved education in big cities. But how can one benefit from such advancements without electricity. Access to electricity could facilitate our work to provide some education on basic computer literacy to students in the community. One major challenge for this community is the lack of qualified teachers. Trained teachers are reluctant to come here and teach because it's an island community with no electricity. There are no classroom lights. We hope that access to electricity will somehow serve as a motivating factor for teachers and a solution to these challenge (PED)".

Experts in a project believably have the first hand information vis-à-vis the potential impacts of the venture as revealed in this case through the views of the expert interviewees.

"The truth must be told that solar power is usually generated between some limited hours and during those hours the utility is high to support several applications and services. In this case, the possibility to use computer or TV to enhance teaching and impart some computer knowledge to students during school hours when the generation capacity is at its peak is very high. The other issue is that the electricity can motivate teachers to go to the communities and teach when they are posted there. On the other hand, possibility still exists for prolonged hours for students evening studies, since the batteries stores power during the day and are used in the evening".

5.2.2 Improved healthcare services

Remote communities in Ghana are confronted with numerous challenges among them is poor healthcare services. It is true that healthcare requires quality energy to be functional at its maximum best. Therefore, one cannot rule out the fact that every level of energy has the potential to improve healthcare facilities and services to an extent that may be better than a previous service. The findings demonstrate that at Pediatorkope where the community already have existing community clinic, the electricity will augment the services provided by the clinic. The head of the clinic mentioned that most of the challenges facing the clinic and the community such as inadequate health professionals, maternal and infant mortality, and poor performance in the discharge of duties are directly linked to the lack of access to electricity.

> *"Electricity in this community will do us a lot good, especially for this clinic. There is a high birth rate in this community and mostly it is a nightmare to attend to a pregnant woman in labour at night because we usually perform the delivery under inefficient kerosene lamps and without any modern instrument. Again, the number of health workers in this clinic is far less below the island population but nurses are not willing to come and work here because there is no electricity in the community. Sometimes, even those of us working here feel very handicapped at work because we don't have good facilities to perform, as we ought to all because of lack of electricity (PED)".*

The respondents at Atigagorme were pessimistic about the relationship between electricity and a health facility. This community has no healthcare amenity and while they strongly linked electricity and school building at one place, here, they disassociate access to electricity from the guarantee that health clinic will be built in the community accordingly. However, they mentioned the potential for the solar PV mini-grid electricity to provide storage and preservation facilities such as refrigerator to preserve medicine for dispensing purposes.

> *"We don't think the solar mini-grid light will automatically cause the government to build clinic for us in the immediate term but some years later it is possible. We believe we will still travel to Kete-Krachi for major healthcare services. But what we hope for is that in the immediate term, it will be possible to have a refrigerator to preserve medicine to provide first aid in the community as when the light comes. Moreover, sick people can receive first aid and also buy medicine from drug operators at night"*

The responds from the project expert participants emphatically stressed that the solar PV min-grid electricity will positively impact the island communities in terms of healthcare services. They were of the view that apart from existing community clinics that will benefit from the electricity project, mobile healthcare providers are additional healthcare services that communities can also benefit from because electricity will facilitate their work to provide frequent and quality services to the island dwellers.

> *"Considering that only one community under this project has existing clinic is a serious issue. Perhaps, the one with a clinic is even operating under capacity because of several reasons that could be linked to lack of electricity. While the electricity will power the existing clinic to function at full capacity, mobile healthcare providers can also tap into the resource to provide frequent and quality services to many of the islands that do not have healthcare facilities in their communities. Besides, storage refrigerators for drug store operators can offer extended services at night".*

5.2.3 Kerosene displacement, prevention of child accidental poisoning, and decrease in indoor-air smoke

Kerosene has remained an essential widespread household fuel for cooking and lighting purposes, particularly in rural Ghana. Though kerosene appears a convenient source of energy for rural dwellers, its associated hazards pose negative impact on individuals and community. The results signified that some children between the ages of 1 and 4 have accidentally drank kerosene stored in bottles that was not properly kept out of their reach, causing some kind of poisoning. Participants from both communities mentioned experiences with child accidental poisoning from kerosene and reiterated that such accidents could have been avoided if there was electricity in the communities. Therefore, they held the opinion that solar PV mini-grid electricity shall replace kerosene and simultaneously prevent further child accidental poisoning with kerosene.

> *"My neighbour's child who was about 3 years old drunk kerosene which was in water bottle and suffered a lot of sickness afterwards. So this light can prevent this kind of accidents in our community (PED)".*

> *"Kerosene has caused many accidents for our children. For example, we can count about 5 children that have suffered from kerosene poisoning. These children accidentally drank kerosene in glass and water bottles that were not properly kept out of their reach. But in cities where there is light, these situations rarely occur. Therefore, when we also get light we will not use kerosene any more and our children shall be protected from kerosene poisoning (ATG)".*

When I probed how they handled the accidents, the participants said they usually give the affected children enough palm oil to drink in order to vomit the kerosene. The revelation indicates how frequent the accident may have occurred and the familiarity of the communities with the phenomenon that guided them to develop counter solution. Concerning the issue of decrease in indoor-air smoke, expert interviewees and health professionals in the community focus group interviews who are well informed about the effects of using kerosene lamps mentioned this.

> *"Combustion of kerosene releases some pollutants that can be dangerous for human health. These people use kerosene lamps for lighting and even sleep with it. So you can imagine the damage kerosene causes to their health. We hope that every household will be connected to the solar electricity to make kerosene displacement achievable in the communities. One of the education we intend to carry out in all the communities is to teach the people the cost and some dangers associated with kerosene use and encourage them to use the electricity for all their lighting purposes (Expert interviewees)".*

> *"We usually advise patients not to sleep with kerosene lamps, especially "bobo" that produces a lot of smoke because we know it is not good for their health, particularly when there are babies in the household. So the electricity will even alleviate our burden since it will provide the community with proper light (Health professional)"*

For community participants, their main concern was related to the supply of electricity levels, sufficient and reliable to displace inadequate and frequent rising cost of kerosene products because of the distance and location of their communities.

> *"Why should we continue to buy expensive kerosene when there is electricity? We are confronted with frequent kerosene shortage so the solar electricity will save us from the problem of kerosene scarcity and recurrent price increases. So if the electricity will be cheaper than kerosene and "tiger" (dry cell battery) we will stop buying kerosene and tiger (ATG)".*

> *"When we have electricity we will use it and stop buying expensive kerosene. But we hope that the electricity will also not be too expensive for us (PED)".*

5.2.4 Increase in access to information and entertainment

The world acknowledges being in information age. But electricity can either boost or limit the amount or the level of information, which a community can access, especially those living in rural areas without electricity. This is because presumably, significant amount of modern information is circulated through electronic medium that uses electricity power to operate. The participants stated that they are extensively marginalized in terms of access to current information at both local and global levels as a result of having no electricity in their communities leaving them in primitive lifestyle. They disclosed their intentions to acquire various electronic devices such as TV, Mobile phones, and computer to increase their information sources when the solar PV electricity finally becomes operative. Below are some of the excerpts from the interviewee participating community members:

> *"When we get electricity, we can buy TV to watch, learn and know what is going on in Ghana and around the world so that it will help us to somehow change the way we think and do certain things. In fact if a natural disaster will hit the world and kill people, we will probably be the first to die because we will certainly not hear about it and know how to avoid it if it is broadcast on TV (ATG)"*

> *"In this village, the only source of information is news on the radio, which is marginally insufficient. But when there is light we can have access to a variety of information because we can buy TV, computers, and advanced mobile phones that can browse the Internet. I am a teacher and in the school it will be possible to teach students how to use the computer to search for information on the Internet. This will improve our knowledge base in terms of information (PED)".*

Expert views admitted that increased access to information and entertainment is positive but have its negative side too, which they explain below:

> *"It is good for such isolated places to have access to information and other forms of entertainment as it can reduce birth rate. However, the same can be a snare for school children to devote time for studies during evening hours.*

Apart from the potential of increased access to information, the study findings disclosed that entertainment is one area, which the mini-grid electricity project can potentially increase in the communities. This a resounding potential which both communities are eager to experience as a result of the access to electricity. In Atigagorme, respondents echoed that:

> *"We don't have any source of entertainment because there is no electricity in our community but now that we are about to have access to light I think that we will have many things to entertain ourselves, for example TV".*

Also, the participants from Pediatorkope reiterated that:

> *Sometimes the youth of this community travel to Big Ada to visit the cinema and watch video/movies at night, which is not even safe. If we also get light we can buy TV, video recorders and other facilities that will entertain us. We know that a lot of entertainment programmes are shown on TV but we cannot enjoy it because we don't have electricity and TV".*

The participants also attributed lack of entertainment to teenage pregnancy and high birth rate in the communities.

> *"Currently, we don't have any source of entertainment in the community as a result of lack of access to electricity, therefore, we are forced to sleep early. When we go to bed too early, the only entertainment left to us is to have affair with our partners and consequently results in having more children (ATG)".*

> *"If there is entertainment, teenagers' (girls) will not get pregnant too early because both sides will have something else to engage them. So the electricity is very important to us as it would provide some sort of entertainment and potentially reduce teenage pregnancy in this community (PED)"*

5.2.5 Access to clean water

The provision of clean water is essentially linked to access to modern energy. This statement was reverberated by the participants in the case communities. The participants clarified that living in the midst of abundance of lake water should have given them access to clean water but it is rather opposite since there are no machines and electricity to filter the water for their use. Thus, they appreciated the importance of having electricity and the connectivity between access to electricity and clean water. In Pediatorkope, an opinion leader in the focus group interviews referred to the linkage in the following excerpt:

> *"As you can see we have abundance of water surrounding our island but we don't think we have clean water. We use the same lake water for all our domestic water needs and drinking. We judge its cleanliness from the appearance of the surface of the water, that's how crystal it looks and not whether it is safe or not. There are water pumps and filter machines available and with electricity the community may even get some donated to us to get access to clean water".*

Participants from the community clinic in Pediatorkope also disclosed that the clinic has water pump and filter machine that uses diesel but because of the rising costs of diesel the facility is rarely utilized to facilitate work at the clinic. Therefore, they opined that access to electricity is likely to put the machine to function at full capacity to supply clean water to the clinic to enhance healthcare services. Below is an extract of what the healthcare professionals in the focus group said:

> *"We have water pump and filter machines here but because of lack of funds and the rising cost of fuel they are not in operation. Electricity in the community can operate it to supply clean water for the most important services at the clinic. This*

> *will lessen some of the challenges involved in working in this rural island community" (head nurse).*

Probing further the source and how the clinic gets clean water for its operation, they said that:

> *"Well, every week a group of school children are assigned to fetch water from the lake to fill our tanks. We don't drink it, we only use it for washing purposes and where necessary, we boil before we use it".*

In Atigagorme, the participants cited a source (NGO) that had already informed the community about the unsafe condition of the lake water, which, required to undergo purification process before drinking. However, in spite of the warning, the community mentioned they continue to rely on the lake water to meet all their water needs since they lack the means to purify the water before use. Hence, they viewed the access to solar PV mini-grid electricity as a potential resource through which they could get access to clean water. These are two responds from the interviewees:

> *"We have heard of bole holes that uses solar light to pump clean water. Through this project, we may be fortunate to have the same kind of a system in this community".*

> *"One NGO informed us about the dangers of drinking the lake water but we have no option. With solar light, we may have machines to purify the water in order to have access to clean water".*

5.2.6 Safety and reduction of workload for women and children

The results show in one community that the safety of women and children, especially at night is a major concern to the community. In Atigagorme, the community has three sub-settlements that make the entire island community and people move to and from one sub-settlement to another to interact. Community members in the focus group interviews stated that movement at night is very unsafe for women and children. Therefore, they pointed out that solar electricity would provide the possibility for streetlights in the communities to protect movement of women and children at night. In the interactive interviews, this is how they conveyed this opinion:

> *"We are scattered among the three sub-settlements and as such we interact by going to and from one sub-settlement to another. Mostly, women and children feel very unsafe going from one place to another in darkness. We are expecting that through the project, streetlights will be available in the community so that movement will be safe for women and children at night.*

Again both communities showed that the electricity could help reduce the workload of women and children relating to fetching of water and searching for firewood.

"If we have solar water pump or pipe through the electricity, it can reduce women and children workload of fetching water and also searching for firewood everyday"

Despite this concern, they were still reluctant to mention any incident to merit their fear for women and children walking at night when I probed the response further. In Pediatorkope, the respondents only linked the potential to street lighting and students movement at night to study together in groups. An opinion leader in the focus group interview said this:

"Access to electricity will provide us with streetlights to help students movement at night to study together. For example, they can gather in a teacher's house to receive extra lessons at night"

In general, the expect interviewees mentioned street lighting as one of the components in the project plan that will provide protection for the inhabitants in terms of movement and activities.

"There will be street lighting in all the communities so that night activities will be safer and less dangerous for the inhabitants, especially women and children".

5.2.7 Community involvement and reduction in youth migration to urban areas

The findings of this study identified that community involvement was an important factor in the project. Therefore, community members are being involved in each phase of the project. Where dialogue was required, opinion leaders in the communities were fully consulted and where basic technical skills were needed, the project endeavour to identify community members who have such skills or train some young people to undertake such duties. Project experts explained in this manner:

"We are engaging the community members at various phases of the project where necessary. We dialogued with opinion leaders in the communities to receive approval on allocation and land use. Moreover, we are providing technical skills relating to electricity and operations to some selected youth, which include females in the communities to handle basic operation of the systems after installation of which they will receive some wages".

Interviews with the community participants emerged that the islands are experiencing increased migration of young population to nearby cities or capital cities in Ghana. The participating groups explained and attributed the cause of the youth migration to the absence of electricity and gainful employment in the island communities. The people were of the view that the project will assist to retain the youth in the communities through involvement and creation of gainful jobs. This is how the communities explained the phenomena:

> *"We have been experiencing frequent youth migration to cities mainly as a result of the lack of electricity. When we have light I think they will stay and help build our community (ATG)."*

> *"All the young people, especially the males are leaving to Big Ada and Accra (Capital of Ghana) because there is no electricity and jobs for them in this community. If we have light, at least they can do something little with it and earn a living. Then, they will not leave but stay here (PED."*

5.3 Environmental impact

Exploring the environmental impact of the solar PV mini-grid electricity on the local communities, the following question was asked. In addition, field observation and photographs were taken to support interview findings (see appendix 2).

Q3. How will the implementation, use, and end of life of the solar PV mini-grid electricity impact the local environment of the island communities?

5.3.1 Displacement of dry cell batteries

Dry cell battery is the predominant energy source having multiple applications in all the communities. The interviews as well as the field observation and photography made, clearly indicates that the solar PV electricity has high potential to displace the use of dry cell batteries and indiscriminate disposal on land and in the lake in the communities. The participants responded in the following manner:

> *"We throw the batteries away after it is 'dead' (end of life) because that is the normal way we do it once we don't have any need for the batteries anymore. We don't think it is wrong. Even fishermen throw their dead batteries into the lake during fishing at night because they use torchlights for fishing. We think if we light some of these problems won't be happening (ATG)".*

Likewise, interviewees at Pediatorkope decried that some of the disposed dry cell batteries are usually found in the lakes, which they inferred might contain some sort of hazards for the water bodies and their use. For this cause, they implied that an alternative energy source would be ideal substitute for dry cell battery use.

> *"The land is full of used batteries all over the community, even in the lake there are 'dead' batteries. Fishermen change their dead batteries and throw them inside the lake during fishing at night. We think it can be dangerous but we don't have alternative to the dry cell battery. Therefore, if Pediatorkope also get connected to light, we will use the electricity and put away the dry cell batteries which are not good"*

5.3.2 Reduction in deforestation

A set of respondents conceived that the solar PV mini-grid electricity could potentially reduce deforestation of the island communities, that's cutting down of trees for biomass energy (firewood). Although, higher proportion of the wood is used for cooking purposes, interview participants in both communities unanimously disclosed that mountain of firewood is occasionally used to provide light for certain festivities and entertainment at night (see appendix 2), which access to electricity has the potential to reduce the amount of trees that are cut for firewood (lighting use). The participants had this to say when asked how will the solar PV mini-grid impact their environment:

> *""We cut trees and leave them for a longtime to dry so that we can use it as firewood and light for certain entertainment and activities at night, so when the light comes we will not need to use such amount of firewood for lighting purposes (PED)."*
> *"We use the firewood for "burogya"(light) at certain periods such as funeral and festivities. It will be nice to have electricity for such occasions than using firewood that do not provide high illumination. When the light comes at least it will reduce the cutting down of trees for firewood for lighting purposes (ATG)".*

5.3.3 Recycling and waste disposal of solar panels and batteries

One of the important disclosures made during interviews with project experts was the absence of proper planning for system's recycling and disposal, especially after the solar panels and batteries have deteriorated. This revelation was made when I probed about how some components in the system will be recycled and disposed in case of breakdown, spoilage and ultimate end-of-life. Here are responses from both expert interviewees in relation to this theme:

"It appears no policy or plan exists that clearly underline how to discharge or dispose off the batteries and panels after its life span. Especially, considering the communities are islands and access to such places are comparatively difficult, it seems certain components such as batteries are likely to be left improperly disposed or under worse situation buried, which can result in high environmental damage, even release of acidic substances into the lake. If by five to seven years before batteries life span elapses and there is no concrete plan for disposal, then we can imply the end result will be environmental disaster".

5.3.4 Competition for land and with vegetation

The requirement for land for solar energy implementation is one feature of the renewable energy technology that could potentially pose a major threat to its vast development in Ghana, most importantly in rural island communities where land is already limited. The study divulged that some vegetation or trees close to proposed sites of the solar PV mini-grid system had to be removed in order to avoid partial or full shading of the solar cells in the module as the sun moves by it. A project engineer in the individual interviews said this was necessary in order to achieve maximum voltage to ensure high power output:

"There is something called shading of solar cell, which occurs when a stationary or any object in motion intercepts the solar irradiance and the surface of the cells. This can be a tree or any other object blocking the sun to certain extent. This affects objects like trees close to proposed sites because the will be the need to remove such objects. This is because shading of one cell reduces the current or voltage, affecting the power output of the system"

On the other hand, another expert interviewee opined that though, the current case project require insignificant land size for construction, the locations are still important because of the scarcity of land in island communities and future developments, which may require vast land for mounting of numerous solar panels:

"We consider that the current project require a small amount of land for implementation and that makes the proportion of land acquired somewhat insignificant when considering solar PV mini-grid deployment and competition for land. However, we can propose that future developments are likely to be threatened because of the amount of land that would be essential for implementation".

In other situations, some proposed sites were later considered inappropriate for either being too far or close to the community as well as inadequate solar insolation, which decision has the potential to affect land and vegetation at the new site.

6 DISCUSSION

Extant studies investigating the impacts of solar home systems (SHS) and solar PV mini-grid technology deployment have veered towards the presentation of generic economic, social, and environmental impacts. On the contrary, the purpose of this case study was to investigate and analyse how the implementation of solar PV mini-grid technology would impact specific local island communities in Ghana.

6.1 Economic impact

Generally, the results of this study have demonstrated that there is a seemingly positive economic impact of the solar PV mini-grid project that would accrue to the case communities. The main occupation of the communities suggests that the possibility to obtain strong bargaining power and a suitable price for fish harvest, among others is obviously a paramount potential economic impact of the project on the communities. Whereas in other places, mostly coastal communities in Ghana, fishing activities may have yielded significant income levels to fishermen, owing to ready market, access to electricity, and storage facilities (see Aheto et al., 2012), the case communities have faced with unfair trade and low market price syndrome that has confined them in a re-enforcing cycle of deprivation, low income levels and limited means to improve their living conditions (GEA, 2012) as a result of the lack of electricity and storage facilities, though they are evidently engaged in a gainful occupation.

The potential to acquire storage facilities such as refrigerators for fish preservation can also be analysed from two perspectives that's: (1) the level of energy provided, and (2) what kind of storage facilities (fridges) the system can support. Unlike conventional electricity, mini-grids provide a limited amount of energy, which at the initial stage may not bolster some appliances such as refrigerators for commercial preservation purposes. However, some solar-based refrigerators may be applicable in this case. Although, the systems have a back-up generator, continual operation is likely to increase operational costs, electricity cost to consumers and ultimately create more pollution to discredit the 'greenness' of the project. This underpins theory that at experimental stages, solar mini-grids are mostly implemented to provide basic energy services to rural communities without access to electricity (Mainila, 2014; Bhattacharyya, 2015). The aspirations of the case communities in relation to productive use of the electricity to preserve their fish harvest may not be met at current capacity as the primary goal of the project may be first and foremost, to ensure wider coverage and access by every household and institutions in the communities. Nevertheless, that impact can be possible in the near future as capacity is scaled-up. Brew-Hammond and Kemausuor (2009) have argued that efforts, which succeed in integrating productive uses and income generation opportunities into energy access initiatives, are key to universal energy access and poverty alleviation.

The socio-economic impact of tourism in development and poverty alleviation in rural destinations, specifically island communities have largely been acknowledged (Fun et al., 2014). The recognition is one fact, but another is that elements that drive such development must be readily available to stimulate the economic activity which has the potential to impact local lives positively. The Lake Volta has been described as one of the largest man-made Lakes in the world (Breuning-Madsen et al, 2012). Coupled with the serene environment surrounding the lake and indigenous lifestyle of the local people, the locations offers natural capital and cultural heritage that are key for tourism. It is conceived that community-based tourism has the potential to promote natural and cultural resource conservation and community development and contribute towards enhanced prospects for the improvement of community livelihoods, provision of complementary sources of income for rural dwellers and a variety of economic activities (Singh, 2008). However, lack of electricity can dissipate such natural resource and cultural heritage to leave an island uncharted territory for economic gains pertaining to tourism to improve the livelihood of its inhabitants as in the case of Pediatorkope and Atigagorme. The ETSF suggest the potential of the technology to generate new local economic activities, which altogether makes the technology economically beneficial to the populations. It is possible that the presence of electricity in the area can attract investors to develop the islands for tourism business. This does not necessarily depend on the energy level provided, being TEI01, TEI02, or TEI03 since tourism encompass diversity of interests and a moderately developed place could serve a particular segment of tourists that seek for a place with high nature value, indigenous culture, and basic social amenities. This show that renewable energy technologies such as solar PV mini-grids possess high potential to impact local communities in a manner that may be unexpected. Given, it should also be argued that electricity alone cannot build opportunities for tourism business in a location unless conscious efforts are made to promote the site as attractive for tourism in order to reap its economic benefits.

Obeng and Evers (2010) found that solar electricity made significant contribution towards rural micro businesses by extending working hours at night in some parts of Ghana. Indeed, without adequate lighting rural business operation is limited by time after which operation is no longer possible, which also determine the rate of business growth in rural areas. Most often, solution to rural micro business growth does not entirely depend on higher energy level such as TEI03. The findings have indicated that most of the micro business operations are undertaken in close range to operators' individual homes by which proximity domestic electricity/lighting can become applicable for extending business hours. This buttresses the point that the practices of use of electricity at the rural level may be difficult to predict (Ulsrud et al., 2011). This therefore, emphasizes the need for comprehensive impact assessment of renewable energy deployment on local communities. The argument does not however, provide the grounds to supply rural communities with a level of energy, which only sustain basic domestic energy needs when deploying renewable energy technology in rural island communities. This is a unique case demonstrating the importance of carefully considering the local context in renewable energy deployment such as solar PV mini-grid for rural communities (CIF, 2014; GVEP, 2011; World Bank, 2008a; ESMAP, 2007). Operating a hybridized system of power supply for rural island communities is one way of guaranteeing a continuous energy supply to support numerous activities to enhance the impact thereof. The combination of two sources of energy and power storage battery systems as well as the operating hours of this project is a plan that achieves the reliability objective of solar PV hybrid energy system for rural communities (Mohanty & Muneer, 2014; Espinar and Mayer, 2011). If the combination of various systems are used judiciously, where a diesel backup system is usually operated only when load demands exceed the capacity of the PV system while the battery storage is also exhausted (Bala & Siddique, 2009), the mixture will result in constructive impact on micro enterprises in the communities. Anything less than this is likely to compromise positive impacts.

Access to electricity in rural areas has the potential to divert attention from major occupations such as subsistence agriculture and fishing to other income generating activities that can improve the livelihoods of the residents. As my personal observation as well as the findings of this study indicates, it could be inferred that the inhabitants of Pediatorkope, especially women keenly seek for other avenues to increase their household income in order to make their membership in the family feel important. The quest is not based on the fact that women are entirely disrespected in their homes, but contributing ones quota to the welfare of the family has become a recent practice where women in Ghana conceivably feel and seek to strengthen their dignity at home. This may be linked particularly to the low level of fish harvest in the area, which the community consider as insufficient to bolster their household living expenditure. As Gurung et al., (2011) established, it is anticipated that the impact of this project will reminiscent the installation of the renewable energy system in Tangting, which brought significant increase to household incomes of the inhabitants. This particular finding amplifies the argument that through access to a reliable and affordable supply of electricity, rural households can create jobs at community level to accelerate rural economic development and women dignity (Kirubi et al., 2009; Gurung et al., 2011; GEA, 2012). However, given the energy level being provided coupled with the economic status of the island communities, the project is likely to face difficulty in achieving financial sustainability since the solar mini-grid electricity at the introductory stage primarily fulfill lighting needs (Bhattacharyya, 2015; Gurung et al., 2011; World Bank 2008a).

One of the fundamental sustainability elements in the advocacy for access to modern forms of energy in developing countries, most importantly rural areas is the affordability of the energy form being provided. While the economic dimension of Mainali's (2014) ETSF emphasizes the costs measurement related to implementation and operations, the adapted ETSF for the context of this thesis accentuates the relevance of a provision of energy form that is relatively affordable than a previous source of energy form, which is widely highlighted in energy delivery for rural communities (see GEA, 2012; Ulsrud et al., 2011). Provision of electricity for rural communities can potentially result in financial burden if the cost to end-users far exceeds a previous source of energy form. Some of the factors that need careful consideration in the attempt to find a balance between affordability and economic sustainability are accessible government subsidies, customer base, productive uses, and income distribution in the project communities (Ulsrud, 2011). These balances of affordability and financial sustainability are among other issues that require attention within and beyond the local level. The issue of monthly payment of electricity bills, which respondents refer to as a potential stress could be regarded as an initial experience of change effect, which is typical with every human institution. What matters most is rather the variety of purposes for which the electricity can be used. For example, where consumers find more productive uses for the electricity, it will accumulate economic development and subsequently curtail any financial burden. Therefore, without government intervention or subsidies sustainability will largely depend on product use of the electricity. Unlike Shyu's (2013) study of rural communities in western China where he identified that base-line survey of users' electricity needs and ability to pay was simply based on the opinions of experts and policy makers who had limited knowledge of the remote areas, which eventually jeopardized the project, the WTP survey conducted in this project is certainly a way to ensure end-users ability to afford the electricity and assuage any needless economic burden on consumers. Additionally, comparative analysis of end-users expenditure on current inefficient energy sources and the proposed utility monthly cost of the solar PV electricity indicate a relatively cheaper and better alternative source of energy if utility charges are maintained at longer intervals (e.g. 2 years). This harmonizes the definitions provided by ICSU (2007) and the author in relation to sustainable energy delivery. The utmost financial challenge for end-users in this project relates to the periodic valuation (every six months) of utility cost based on USD, which appreciate continuously against the GHS. This might lead to high electricity cost for the end-users and attendant financial burden as expressed by interviewees. Ultimately, this is where the application of government subsidy for rural electrification in Ghana becomes appropriate in order to sustain the electricity for local people (Mahama, 2012).

6.2 Social impact

Many findings of this study associated with the social impacts to a large extent reinforce literature that at current capacity, most solar PV electricity deployment in developing countries, particularly rural areas largely promotes social development (World Bank, 2008a; Jacobson, 2007; Cabraal et al., 2005). Moreover, the findings are in agreement with the social dimension of the ETSF that underlines multiple social benefits of renewable energy technology deployment for rural communities.

Evidence has shown that solar PV lighting and electrification systems have led to improvement in education for people living in remote areas (Chakrabarti & Chakrabarti, 2002; Gustavsson, 2007; Palit et al., 2014). It is generally acknowledged that there is a huge disparity in the quality of education between urban and rural communities in Ghana. The phenomenon has largely been attributed to the lack of access to electricity in rural areas. Consequently, electricity projects in rural areas receive massive approval by communities because they are often perceived as a solution to the absence of educational institution and poor quality of education. Though, access to electricity may not necessarily lead to the establishment of a new school or improvement in the quality of education in a community, its potential to impact children education, reduce teenage pregnancy, and also prompt a change in the educational landscape of the case communities cannot be underestimated. Understandably, by virtue of the locations of both communities together with the absence of electricity, professional teachers will tend to be highly indisposed to move to such areas to teach. This is where the solar PV mini-grid electricity becomes a valuable asset to potentially attract professional teachers to the areas to improve education. The Independent Evaluation Group (IEG) under the World Bank (2008a) in its impact study of support to basic education in Ghana discovered that a teacher's living conditions, including whether his or her home had electricity, greatly affected the incidence of absenteeism and teacher morale as a teacher complained: "What teacher will come here and live in a place with no electricity?" Remarkably, this account corresponds with a statement from an interviewee in ATG: "Wherever there is electricity, there is a school" and teachers are attracted to such areas. The nexus between rural electricity access and prolonged students study hours at night has been challenged in both literature and empirical studies (Zomers, 2001; Jacobson, 2007). As indicated in the results, informants' keenness to acquire TV and other electronic sets to increase their access to information and entertainment could potentially undermine electricity use for studies at night as school children's attention shift from studies to watching Television in the evening or at night. However, this does not discredit the opportunity, which the solar PV mini-grid electricity would provide for students in the communities to extend their study hours at night. Increased access to information can enhance education whereas increased access to entertainment means adults will no longer have to sleep too early, which the community members admit mostly result in high birth rate and population growth in the island communities.

Conditions of healthcare services hitherto stand as a daunting challenge to rural island communities in Ghana, which is relatively to due energy poverty. It is indisputable that healthcare requires quality energy to function at full capacity. Health facilities in the case communities can benefit directly from solar PV mini-grid electricity in two ways: by having modern equipment that requires electricity and by having longer operating hours (World Bank 2008a; GNESD, 2014). In the case of Atigagorme where there is no health facility, the solar mini-grid electricity offers mobile healthcare providers the opportunity to utilize the utility to deliver better health services on regular basis to the community. The project will also provide motivation to doctors and nurses as well as health volunteers to live and work in Pediatorkope which has a clinic as it does for teachers. These are demonstrable indications that establish rural clinics as vanguards against diseases and promotion of health and sanitation in rural villages. Yet it is no exaggeration to state that a number of clinics in rural communities in Ghana have no access to electricity and clean water. Solar PV mini-grid electricity holds the capacity to power water pumping and purification machines to supply clean water for health services and domestic uses for the inhabitants of the island communities with abundant but unsafe source of water. As mentioned by an interviewee, the presence of electricity in the communities may attract government and donors' attention to contribute towards access to clean water for the benefit of the entire communities. Pediatorkope clinic will benefit directly from the project since it has water-pumping machine that has remained dormant as a result of energy problem. Having access to clean water can also improve health in the communities, reduce diseases and frequent illness among the people, and substantially lessen pressure on insufficient health facilities and working personnel.

What is more, child accidental poisoning through kerosene can become worse in rural communities without electricity and health facilities. Likewise, effects of indoor-air smoke may lead to chronic diseases and 'silent deaths' among the people due to over dependence on kerosene. Studies provide some evidence that emissions from kerosene used for lighting or cooking may impair lung function and increase infectious sicknesses such as asthma, tuberculosis, and cancer risks (Lam et al., 2013; WHO, 2009). Therefore, it is important that electricity is first and foremost provided for rural dwellers so that heavy reliance on kerosene for lighting purposes can be reduced or entirely displaced in order to protect children from kerosene accidental poisoning and diseases associated indoor-air smoke. However, whether the people will switch from kerosene use to electricity or not largely depends on economic factors such as initial connection fee, utility cost per month as echoed in their responses and of course productive uses of the solar PV mini-grid electricity that would provide sustainable income to reinforce complete switch from kerosene. In situations where these conditions become unfavourable, reliance on kerosene will persist to endanger lives, though the amount of affected people will probably reduce owing to functional electricity in some households in the communities. Obeng et al. (2008) discovery of the relationship between solar PV electrified and non-electrified rural households and the effect of indoor smoke in some parts of Ghana provides reliable point of reference to believe that when rural households are provided with electricity, it helps to protect the population from negative effects associated with kerosene use and emissions.

Women and children in sub-Saharan Africa are considered to be the most vulnerable groups in the absence of electricity (IEA, 2014a). They are affected by energy poverty in every society (Reddy, 2000) as their development is hindered by the workload related to daily fetching of water and firewood for domestic use. Not only that, the absence of electricity also affect their safety in rural areas mostly at night. An energy level such as the one being provided in the case communities is absolutely a major step to ending energy poverty and its consequences on women and children in the island villages. While the energy level does not cover up to the requirement of a cooking stove, the light provided reduces the amount of hours and distances covered by women and children in collecting firewood in the communities that settles Cabraal et al. (2005) findings. It will also broaden the benefits of renewable energy implementation to women and children in rural areas of developing countries as found elsewhere that, following installation of a renewable energy plant for Tangting community, women and children were able to save time and spend their saved time in more productive works such as education, weaving and extra social activities (Gurung et al., 2001).

Finally, community involvement in the solar PV mini-grid deployment and many of the themes discussed above has high potential to retain the young population in the communities, thereby reducing youth migration to urban areas. It is worthwhile to speculate that the longevity, in other words, the sustainability of the solar PV mini-grid electricity will depend on regular maintenance of the system. In this context, the involvement of young people and technical training being provided to them becomes a valuable feature to extend the potential impact of the project on the communities. Ulsrud et al. (2011) states that some major problems linked to the operation of solar mini-grids include lack of involvement of local authorities and people as well as lack of inadequate maintenance procedure to ensure longevity of the project. As a result, many renewable energy installations have failed due to lack of local experience (Thirumurthy et al., 2012). In another extreme, implementation of renewable energy projects in rural areas and community involvement has traditionally experienced intrinsic gender bias (Cabraal, 2005), whereby women are frequently ignored. However, this particular project has endeavoured to achieve some level of gender balance by involving females at the community level. In effect, it strengthens women's empowerment and dignity at the grassroots.

6.3 Environmental impact

Typically, solar PV energy deployment has been deemed to have benign environmental benefits (Tsoutsos et al., 2005). Generally, this benevolent benefit is plausibly linked to the carbon neutrality of solar PV electricity production and utilization, which is devoid of greenhouse gas emissions (Goetzberger, & Hoffmann, 2005; Boyle, 2012). For example, Goetzberger and Hoffmann (2005) state that PV systems contain no effect on the environment from their operation. At the local level such as one in this study, environmental impact of solar PV electricity deployment and operation may not entirely concern reduction in greenhouse gas emissions but other impacts that promotes the local environment as those indicated in the results.

Displacement of dry cell batteries can be regarded as a direct environmental impact of the use of the solar PV mini-grid electricity in the localities. However, this will only be possible when majority of the inhabitants are connected to the electricity and fully utilize the utility at length where dry cell batteries will become automatically displaced to halt indiscriminate disposal on land and in the lakes that can pollute soil and water bodies with toxins such as mercury (Kaufman et al., 2000). No matter the amount of effect which disposal of used dry cell batteries cause to land and other eco-systems in the island communities, no amount of education provided to the inhabitants can displace the batteries except their source of energy is completely replaced. Some of the responses demonstrate their willingness to switch energy source to a better option that delivers environmental benefits for the communities.

Moreover, access to the solar electricity will reduce complete dependence on firewood for other lighting purposes at night. The pile of firewood (see appendix 2) described as amount occasionally burned to provide "burogya" (light) for some night festivities in addition to regular firewood for cooking and heating show the degree of deforestation, which lack of electricity can cause in the already deserted island communities. The capacity of the electricity though, cannot dislodge complete reliance on firewood, yet it will construct a positive deduction from firewood for lighting purposes at night to slow down the rate of deforestation and consequent desertification in the islands vegetation.

While the use of the solar PV mini-grid electricity system may foster benign environmental benefits to the island communities, recycling and disposal of solar panels and back-up batteries in case of defects, wear-out or end-of-life pose a potential threat to the environmental conditions and human health in the communities. This is because solar panels and back-up batteries are currently imported into Ghana and manufacturers do not have any recycling centres where damaged or wear-out components can be returned for proper disposal as specified by Goetzberger and Hoffman (2005). By 25 years ahead as the minimum life span of modern PV modules indicates (Bradford, 2006), if Ghana has not established environmental management policy and plan to identify PV waste and dispose components efficiently, it is likely to compound the existing environmental problems in the country. Comparatively, batteries require urgent waste management plan since its life span is within 5 and 6 years and the distance and location of the communities can compound efforts to recycle and dispose off waste materials appropriately. This can possibly result in the burying of waste batteries by the local people as the results implies.

In conclusion, requirement for land for the solar mini-grid implementation is an aspect that can compromise environmental standards and leave negative impacts on the environment and the communities at large. Most of the impacts can be anticipated during construction phase and its activities when land use and vegetation clearance become important which can also affect sensitive ecosystems in the area. Vegetation clearing though, inevitable in certain circumstances in solar PV mini-grid deployment, to some extent it critically compromises the sustainability of renewable energy projects. Although, the islands are considered to have small land available for farming, the amount covered for the projects in the communities is insignificant and does not affect any farming activities since construction sites are believed to be close or inside the community.

7 CONCLUSIONS

This thesis has investigated how solar PV mini-grid electricity deployment can potentially impact local rural island communities in Ghana. Solar PV mini-grid technology is fast developing in most parts of sub-Sahara Africa to accelerate access to modern electricity through renewable energy deployment. The study has shown that electricity is unquestionably a fundamental process for acquiring basic needs of life support systems and development efforts in isolated areas. Generally, the research has demonstrated that solar PV mini-grid electricity is an ideal energy alternative for the island communities on the Volta Lake in Ghana and the ways in which electricity will contribute to improve their livelihood are both many and varied.

Economically, given the energy level or capacity provided, the electricity fulfills the provision of light to boost and extend hours of petty trading and selling activities at night in the communities. The most productive and probably profitable use of the electricity for the island communities would have been linked to acquisition of refrigerators and preservation of fish harvest considering the main occupation of the inhabitants. However, as it stands the energy level is unlikely to support such productive use to maximize the economic impact on the communities. Like many solar PV mini-grid electricity in developing countries, particularly in rural communities, this system does not bolster the operation of heavy electrical machines for longer hours, which perhaps holds the key to economic development. But in the ensuing period such economic realization are likely to be met as capacity increases. Though, the locations possess geographical landscape aesthetic such as gorges, water bodies, and scenic views, electricity alone cannot turn such attractions into economic gains unless a conscious effort is made to match both resources for tourism development by responsible authorities. With a hybridized system, the combination provides solution to feasible erratic power supply, which can undermine dependability objective of solar PV-hybrid electrification system to accomplish extensive impact in the island communities. While technical reliability is assured, affordability also remains a crucial issue to determine the sustainability of the electricity for the rural island communities. The comparative analysis of consumer expenditure on current energy forms and the proposed electricity cost indicate that the solar PV electricity is relatively cheaper, but that will by no less means depend on utility cost stability or long term appraisal of utility charges. When reliability and affordability elements are effectively balanced, subsequently people will be empowered to create jobs at the community base to accelerate rural economic development and in part raise the dignity of women. In the absence of the above, government intervention in the form of subsidies will be necessary to sustain the electricity services so as to extend its impact on the communities.

Ultimately, the solar PV mini-grid electricity is likely to yield much social impact on the communities than any other dimension revealed in this study. This will underline literature that prevailing solar PV electricity deployment in developing rural areas promotes multiple social benefits at inception and experimental phases. First and foremost, the electricity will improve education in the island communities. There is a high possibility that access to electricity will drive motivation towards trained teachers movement and settlement to teach in various schools in the communities to accelerate improvement in child education. In part, the light will assist school children to study at night for significant hours if parents will guide their children in that direction. Parents' guidance is extremely important in this respect because access to electricity and increase in information and entertainment can compromise efforts in improvement in children education, as they are prone to entertainment activities rather than studying.

Furthermore, conditions of healthcare in the villages will begin to experience some level of improvement to prolong hours committed to service delivery, relieve transfer resistance from nurses and doctors to such areas, save lives, especially of women and children, increase access to clean water, and promote healthy life for productivity. Another important concluding remark worth making is that the electricity entails potential to lessen women and children workload or burden related to firewood collection and fetching of water if the people does not allow tradition to overshadow a change in their system of living. This is because in most cases, indigenous people have allowed culture and traditions to supersede changes in their system of living to subjugate positive impacts of the change in their society. Notwithstanding, the community youth involvement in the project can leverage obstructions to sustain and widen social impacts of the solar PV mini-grid electricity on the communities.

Additionally, the largest environmental impact, relating to displacement of dry cell batteries can be achieved in circumstances where majority of the inhabitants are eventually connected to the electricity and alternative source of light that does not utilize dry cell battery is provided for fishermen in the communities. Without these determinants, dry cell batteries will continue to be used alongside the solar electricity to challenge the system's potential to positively impact the environment. In terms of deforestation, the solar mini-grid electricity is unlikely to reduce its rate for two reasons: (1) the electricity does not cover power for cooking, and (2) the firewood occasionally burned at night as light for certain festivities may connote traditional meaning, which modern electricity or light may not be acknowledged as an alternative. Between 5 and 20 years from now if no concrete environmental policy or plan has been outlined to recycle and dispose off the system's components such as batteries and PV's, the probability of environmental damage will be high. Above all, the project required minimal land for implementation and as such its overall impact on agricultural land is very insignificant when considering solar PV mini-grid and competition for land. The use of solar PV in conjunction with diesel-based generator and their respective ratios can increase access to electricity, without undermining the environmental aspects of the communities.

In summary, the findings of this study, representing the views of the island communities and of project experts, have unambiguously implied that electricity supply in rural areas should bring more than just light to initiate improvement in the quality of life of rural dwellers.

7.1 Limitations and future research

Identical in all studies, this paper is no exception in limitations. To begin with, the study is based on the potential impact of the solar PV mini-grid deployment on the local island communities and the result may not reflect reality as when the project is completed and the utility commenced. There might be some crucial considerations in the course of the implementation to alter technical dimensions of the project, which result could ultimately render the findings of this thesis somewhat unreflective. Not only that, but also the actual use of the electricity by the populations is likely to reveal a different outcome than what this study has found. This is where future research of the impact of the project on the local communities becomes relevant to compare realism with the recent findings. Nevertheless, this limitation is by no means underestimation of the implication of this study in the context of rapid development of renewable energy technologies (solar PV) in developing countries, in particular Ghana and in the rural island communities on the Volta Lake and what needs to be considered prior to project implementation in terms of local impact.

In the second place, the sampling strategy and method "convenience or availability sampling" employed to select available participants for the focus group interviews in the communities could somehow be criticized as bias since it did not provide equal opportunity and chance for anybody to be selected. But as indicated earlier, the location of the communities coupled with time constraints did not permit the researcher to employ a sampling approach that could provide a fair chance for anybody to be selected into the case interviews. Besides, convenience or availability could also be debated as providing equal chance to anybody available at the set time to be selected. Future research could employ quantitative and simple random sampling approach in data collection to provide the same probability to each individual of being chosen.

Moreover, the selection of participants may appear imbalanced as community participants outnumber expert interviewees in the interviews. The study assumed this position to adequately reflect the views of the local participants who were the beneficiaries of the solar PV project as the thesis also focused on the local communities.

To conclude, the concepts of renewable energy, solar PV technology, energy poverty, sustainable development, and the energy technology sustainability framework are in fact two big subjects, which are studied or are researched separately. Merging different concepts in this case study posed some challenges. The last but not the least of the limitations is the avoidance of generalization of the findings of the potential socio-economic and environmental impacts of solar PV mini-grid on local communities. That is to say, the findings in the case study areas may not necessarily represent other island communities on the Volta Lake or elsewhere in Ghana.

7.2 Contributions and recommendations

In the process of rapid development of solar PV mini-grid electricity in developing countries, most importantly in Ghana and in rural or remote areas, this study makes significant contribution towards acknowledging the uniqueness of localities and given thorough considerations to the local context in renewable energy deployment. It also set the precedence for future developments in Ghana to cogitate and conduct prior socio-economic and environmental impact of the project relating to the specific locality in order to maximize the impact thereof. Most importantly, it supplements the renewable energy policy strategy of the Ministry of Energy (MoE) of Ghana by specifying how renewable energy deployment can impact local communities in Ghana and also resolves Kuma Sahu (2015) and Chung (2004) concerns that renewable energy-based rural electrification deployment has traditionally misplaced attention on the impact on local communities.

Furthermore, major concepts of the energy technology sustainability framework (ETSF) of Mainali (2014) has proven to be appropriate in this study and extending the framework's applicability in other studies relating to renewable energy technologies. Most studies that have investigated the impact of solar PV mini-grid electricity on rural communities have concentrated exclusively on the social, economic, and environmental dimensions (see Mainali, 2014; Bhattacharyya & Palit, 2014; Bhattacharyya, 2015; Gyamfi et al., 2015; Obeng & Evers, 2010; Gustavsson, 2007; Shyu, 2013; Gurung et al., 2011). The current thesis contributes to solar PV mini-grid literature by researching the potential socio-economic and environmental impacts of solar PV mini-grid deployment on local communities.

Finally, reflecting on the results, the study has two important recommendations to make. Firstly, the Ministry of Energy should set up a social enterprise to provide an alternative lighting system such as solar or rechargeable torchlight for fishermen usage during fishing at night in order to entirely displace dry cell batteries and indiscriminate disposal on land and in water bodies in the communities. On the same issue, should there be the need for dry cell battery use in torchlight for fishing, fishermen should be educated on proper disposal of used batteries whenever they are on the lake. For example, they should be taught to keep their used batteries in the boat and bring them inland for proper disposal. Secondly, the Ministry of Energy in collaboration with the Environmental Protection Agency (EPA) of Ghana should draw up environmental policy to address recycling and proper disposal of solar PV materials including storage batteries as the technology and the market develops in the country.

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APPENDIX 1 Interview questions

Community Focused group interview questions

1. What is the main occupation in this community or your main occupations?
2. What are your current sources of energy and what do you use them for: After use what happens?
3. Can you give me estimate of how much you spend on all energy sources in a month?
4. Do you need electricity in your homes and in the community?
5. When you get the electricity what will you use it for? Or how different would you use electricity from your current energy sources?
6. Do you think solar PV mini-grid electricity will be better than your current sources of energy?
7. How do you think the solar PV electricity can impact your lives and the community economically/financially?
8. Think about this community and tell me how solar electricity can affect it socially
9. In the same way, how do you think solar electricity can bring a change to the social conditions in your individual lives?
10. Do you think solar electricity can affect your local environment and yes how?

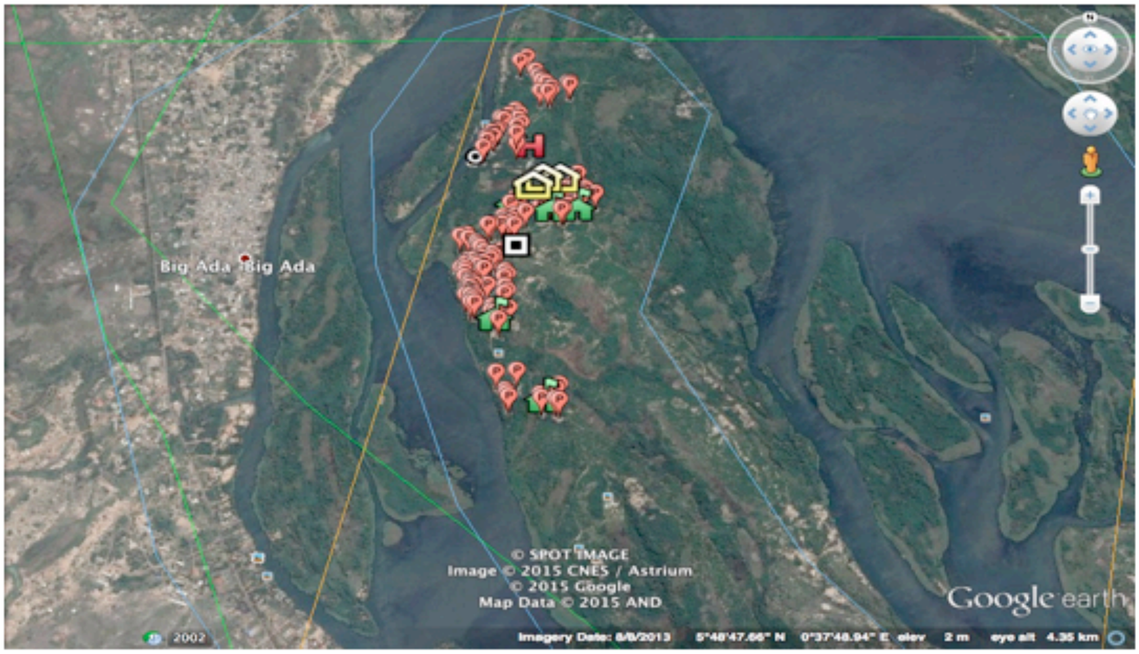
Interview questions for project experts

1. Can you tell me why this project is being implemented
2. What criteria did the project use to select the communities involved
3. What is the project suppose to deliver?
4. Will the utility be free of charge for the communities? If not how much do you estimate consumers are likely to pay in a month?
5. What is the level of electricity that will be supplied to the communities? And can the electricity supplied from the solar PV mini-grid support local businesses?
6. Do you think solar PV-based mini-grid is an answer to the needs of these people in terms of electricity?
7. In what ways do you think the project can affect the environmental conditions of the communities? Any environmental policy for the project?
8. Will the project involve the local people in implementation and management process and how?
9. To what extent can solar PV mini-grid affect the economic conditions of the communities?
10. In relation to social impacts, how is electricity from solar PV mini-grid beneficial to the communities at large?

APENDIX 2 Photos of dry cell battery disposal and tree cutting for firewood

APPENDIX 3 Landscape and coordinates of Island communities

Pediatorkope Island Community



Atigagorme Island Community

APPENDIX 4 Sample of data analysis

DATA ANALYSIS

Codes and Colours: Group= G Pediatorkope=ped Atigagorme=atg Experts=e

Social (Institutions) Economic Environmental Technical

Sample data analysis of community focused group interviews

1. What is the main occupation in this community or your main occupations? As you can see, our main occupation is fishing. Men do the fishing and women sell or smoke the fish G1ped. We are fishing community with small farming activities G3atg. Almost all the men in Atigagorme engage in fishing and women also smoke and sell the fish harvest G1atg. Fishing and oyster mining is what we do in this community G4ped.
2. What are your current sources of energy and what do you use them for? After use what happens? Here we use battery (dry cell) in torchlight, radio and for charging our phones and kerosene to give us light, and also charcoal and firewood for cooking and smoking the fish G3ped. As for the batteries we throw them away after they are dead G2ped. "Tiger" (dry cell battery) is what we usually use in torchlight for lighting purposes and also for fishing. Firewood is for cooking and smoking fish, and kerosene for lamps G2atg. We throw them away anywhere anytime they are dead G1atg. Most fishermen throw into the lake during fishing G4atg.
3. Can you give me estimate of how much you spend on all your energy sources in a month? We spend between GHS24 and 28 a month G5ped. At least GHS24 a month on energy G2atg.
4. Do you need electricity in your homes and in the community? Very much G1ped. Why not G3atg
5. When you get electricity what would you use it for or how differently would you use electricity from your current energy sources? A lot, as a fishing community, we need refrigerators to preserve our fish harvest. Often, we are compelled to sell most of the day's harvest very cheap to visiting traders and they usually decide the price they want to give to us. We have little or no option to reject their offer because if we do, the fish will spoil in few days. So light should help us to acquire fridges to preserve our harvest and decide a suitable price ourselves G2atg. We can charge our phones for cheap, use it for radio and TV for more information G3atg. Sometimes, it is very difficult to cover our diesel costs for the boat we use for fishing since the price we receive for our harvests is very low. We smoke the fish when we don't get market for it but the problem is that smoked fish does not have the same price as fresh ones. The smoke fish usually looses its market value; hence the fall in price. We hope that the solar electricity will help us so that we can sell our fishes for a better since we can acquire fridge and store the fish we catch from the lake and sell it fresh later for a good price G5ped. In this village, the only source of information is news on the radio, which is marginally insufficient. But when there is light we can have access to a variety of information because we can buy TV, computers, and advanced mobile phones that can browse the Internet. I am a teacher and in the school it will be possible to teach students how to use the computer to search for information on the Internet. This will improve our knowledge base in terms of information G2ped. When we get electricity, we can buy TV to watch, learn and know what is going on in Ghana and around the world so that it will help us to somehow change the way we think and do certain things. In fact if a natural disaster will hit the

Comment [1]: Occupation: Fishing

Comment [2]: Energy sources: Dry cell battery, Kerosene, Firewood & Charcoal

Comment [3]: Indiscriminate disposal

Comment [4]: Average monthly expenditure on energy sources GHS24 (Ghana Cedis)

Comment [5]: Bargaining power and suitable price for fish harvest

Comment [6]: Increase in information

Comment [7]: Suitable price for fish harvest

Comment [8]: Increase in information

Comment [9]: Increase in information & entertainment world and kill people, we will probably be the first to die because we would certainly not hear about it and how to avoid it if it is announced on TV G1atg. Sometimes the youth of this community travel to Big Ada to visit the cinema and watch video/movies at night, which is not even safe. If we also get light we can buy TV, video recorders and other facilities that will entertain us. We know that a lot of entertainment programmes are shown on TV but because we cannot enjoy it because we don't have electricity and TV G3ped.

6. Do you think solar PV mini-grid electricity will be better than your current sources of energy? Yes because as we told you we need quality energy to change our lives G1ped. Batteries and kerosene are expensive and don't last for long so the solar light will be better G1atg.

7. How do you think the solar PV electricity can impact your lives and the community economically/financially? As we have mentioned it will help us to store our fish harvest and decide a good price ourselves G4atg. It will help our small businesses in the community. For example, I operate corn mill and usually I work during daytime because operating a corn mill machine with lantern is very risky. But when we get access to the solar mini-grid electricity, I can connect light to my shop and also operate at night to serve those who may need services at night. Also, diesel is expensive and sometimes difficult to come by because of our location, so getting electricity will reduce my cost and help my business to grow G3atg. We have very good and spacious island communities on the Volta Lake but almost all the islands are not properly developed to attract visitors and tourists because of the lack of electricity. With the construction of solar PV mini-grid electricity in the communities, we are hopeful that it will open up to the establishment of some tourism business activities and also provide jobs for the youth in the communities G1, 3&5ped and G3&1atg. As women in this community, our main job is to smoke the fish from our husbands' daily harvest and sell them. Over the years, the harvest has been very low, which affects our income. Apart from that there is no other job we can do to earn extra income to help home finances. But when there is electricity we can engage in the selling of "pure" water and some minerals to earn extra income for our home finances. Bringing extra income to the family can boost our image and respect at home G4, 2, 1&3atg, G3, 5, 2&4ped. Light is good but paying monthly bills can be stressful since we not used to that G2ped. Electricity will not be free and if we will have pay the same bills as consumers in the cities pay, it will be make us poor. Government support will be needed G2, 4,1&3atg, G1, 4, 3&5ped

8. Think about this community and tell me how solar electricity can affect it socially. There is no school in this community so the electricity can help us to get a school G3, 1&4atg. There are no lights in our classrooms and with electricity we can connect to classrooms. Sometimes when the weather is cloudy classrooms become a bit dark to teach G3&5ped. Recently, the use of computer and internet to teach in schools has generally improved education in big cities. But how can one benefit from such advancements without electricity G5, 3&4ped. Access to electricity could facilitate our work to provide some education on basic computer literacy to students in the community G5, 3&2ped. One major challenge for this community is the lack of qualified teachers. Trained teachers are reluctant to come here and teach because it's an island community with no electricity. Teachers will be motivated to come here and teach G1, 2, 3, 4&5ped, G1, 2, 3&atg. Absence of a school in the community has caused high teenage pregnancy in this community. So the light can help resolve this issue G3, 2&1atg. Electricity in this community will do us a lot good, especially for this clinic. The number of health workers in this clinic is far less below the island population but nurses are not willing to come and work here because there is no electricity in the community Sometimes, even those of us working here feel very handicapped at work because we don't have good facilities to perform, as we ought to all because of lack of electricity G2, 4&1ped. We hope that in the immediate term, it will be possible to have a refrigerator to preserve medicine to provide

Comment [10]: Increase in information & entertainment
Comment [11]: Cost of current energy
Comment [12]: Bargaining power
Comment [13]: Prolonged business hours
Comment [14]: Business growth or expansion
Comment [15]: Prospects for tourism
Comment [16]: Potential increase in household income
Comment [17]: Dignity for women
Comment [18]: Financial burden
Comment [19]: Financial burden
Comment [20]: Educational facility
Comment [21]: Improved education
Comment [22]: Improved education
Comment [23]: Motivation for teachers
Comment [24]: Education and teenage pregnancy
Comment [25]: Improved health services
Comment [26]: Improved health services

first aid in the community as when the light comes G3&4atg. The clinic and the community can get access to clean water G3, 1&4ped, G1, 3&4atg. There will be streetlights in the community, which is safe for women and child to walk at night G5, 2, 3, 4&1ped, G1, 3&4atg

9. In the same way, how do you think solar electricity can change the social conditions in your individual lives? My neighbour's child who was about 3 years old drunk kerosene, which was in water bottle and suffered a lot of sickness afterwards. So this light can prevent this kind of accidents in our community G1ped. When we also get light we will not use kerosene any more and our children shall be protected from kerosene poisoning G3, 2&1atg. It can reduce our work of women and children in fetching water and also firewood G1&4atg G2&4ped. When we have light I think the youth will stay and help build our community G3&2atg, G5, 3&4ped

10. Do you think solar can affect your local environment and how? We will stop using batteries and also stop throwing the dead batteries in the land G2&4atg. If Pediatorkope also receives light, we will use the electricity and put away the dry cell batteries G1, 2, 3, 4&5ped. Sometimes we burn a heap of firewood to provide us with enough light. We cut trees and leave them for a longtime to dry so that we can use it as firewood and light for r certain entertainment and activities at night. So when the light comes we will not need to use such amount of firewood for lighting purposes G5&3ped G1, 2&4atg.

Sample data analysis of project expert interviews

1. Can you tell me why this project is being implemented? Well errr this project is being implemented as part of the renewable energy policy plan of the Ministry of Energy, which intends to achieve a 10% addition of electrified areas in Ghana. But this particular one is to supply electricity to island communities on the Volta Lake because they cannot be connected through the conventional grid because of their locations. It's being done as an experiment to learn lessons for future deployments e1. Oh the project is simply to provide electricity for those rural areas without access to electricity e2
2. What criteria did the project use to select the communities involved? We surveyed the island communities with populations ranging from 614 and above and in the end five communities were selected based on their sizes and urgency of need of electricity. So we decided to start with those communities and later extend the project to other island communities in the country e2.
3. What is the project suppose to deliver? In the firs place let me say that there will be electricity but at a limited capacity. Basically the project will supply the communities, first with basic electricity to ensure that every household in the communities is connected e2. The capacity is going to be backed up as time goes on and for those who would need extra energy such as small businesses. Therefore, the level of electricity to be provided is also dependent on the sizes and electricity needs of each community. The level of electricity to be provided in Pediatorkope is 50 kWh and in Atigagorme 26 kWh and these levels have factored in all existing businesses and as I said room has been made for expansion whenever demand increases in future e1. But I think the whole idea behind mini-grid is because is it scalable and it's modular if peoples demand are going up and they can afford to pay, it will be scaled up e2
4. Will the utility be free of charge for the communities? If not how much do you estimate consumers are likely to pay in a month? Definitely no, they are going to pay. But the thing is that in terms of the ability to pay we have a proxy indicator, which is what they are actually spending, unless what they are actually spending they are exaggerating. But if the revealed willingness to pay is what they are actually spending on the energy alternative, then that's a good indicator as to whether they are able to pay or not e2. We are looking at between $6-$8 for LEVEL 1, $10-12 for LEVEL 2, and $15-18 for LEVEL 3 but the last two levels are later capacity additions so for now lets think about the first one for consumers 1e. Oh the issue of financial burden will solved by the willingness to pay survey which the will conduct a second time and the electricity will supplied to all categories of consumers based on that e1

Comment [27]: Improved healthcare

Comment [28]: Access to clean water

Comment [29]: Safe for women and children

Comment [30]: Prevention of child accidental poisoning

Comment [31]: Prevention of child accidental poisoning

Comment [32]: Reduction in workload

Comment [33]: Reduction in youth migration to cities

Comment [34]: Displacement of dry cell batteries

Comment [35]: Displacement of dry cell batteries

Comment [36]: Reduction in deforestation

Comment [37]: Renewable energy

Comment [38]: Access to electricity

Comment [39]: Size of community

Comment [40]: Energy level, Pediatorkope 50 kWh

Comment [41]: Energy level, Atigagorme 26 kWh

Comment [42]: Financial burden

Comment [43]: Financial burden

5. Can the electricity supplied from the solar PV mini-grid support local businesses? Like I have said before our feasibility studies showed the main occupation on the islands are fishing and they sell their fish harvest very cheap to external buyers because of lack of storage facilities. For now I'm afraid the electricity that will be provided cannot support refrigerator but we believe as the project get implemented and capacity increases in the near future, they can buy storage facilities such as solar refrigerators to keep their harvest longer and determine a suitable price for it later e2. Those levels that are being provided can support some petty trading activities that needs only light to operate e1

Comment [44]: Suitable price for harvest

Comment [45]: Support for petty trading

6. Do you think solar PV-based mini-grid is an answer to the needs of these people in terms of electricity? There is no doubt that emm that this is a perfect solution for people living in such remote islands if I should tell you that. Successive governments have not been able to provide these places with electricity all because of the location which is very difficult to access by land transportation so off-grid and mini-grid has come as a perfect fix for these people to get electricity e2. Oh to me emm there, there is a scarce means by which electricity can reach these inhabitants on the islands. Extending grid electricity looks almost impossible considering the costs involved in doing so. So like if this project will be multiplied accelerated for most rural communities deprived of electricity because of their location, I that's better e1
7. In what ways do you think the project can affect the environmental conditions of the communities? Any environmental policy for the project? Errr oh but there is errr ok think about the batteries the people use and dispose off if you errr look at how the solar can displace such huge battery use e1. Right now well, errr I don't know of any there is no plan or policy that clearly states that the way we should discharge or dispose off the systems errr batteries and panels after its life span I mean when are no more in use. Especially, If you errr considering the communities are islands and far away access to such places are comparatively difficult, it appears certain components such as batteries are likely to be left improperly disposed or under worse situations hmm buried, which can result in high environmental damage, even a release of acidic substance to the lake e1 Errr there is one thing something called what shading of solar cell that, that which occurs when there is a stationary or or something any object like in motion blocks or intercepts the solar direction or irradiance and the surface of the cells. These can be anything a tree or any object errr blocking the sun to certain extent. Because of this definitely some objects that are which are close to some proposed sites had to be clear of the solar panels This is errr when this shading of even one cell reduces can reduce the current or voltage which that can affect the power out of errr the solar I means the system e2. We consider that well in fact if you consider the current project require what a small piece of amount of land for implementation which and that makes the proportion of the land errr space acquired needed very somewhat insignificant if we we when considering the solar PV mini-grid deployment and what errr competition for land e2. For now errr very little land was needed for the solar PV mounting However, in future projects can face be threatened since because of amount of land that errr would be essential for the the implementation e1.

Comment [46]: Battery displacement

Comment [47]: Disposal of solar panels and batteries

Comment [48]: Effect on vegetation

Comment [49]: Competition for land

Comment [50]: Competition for land

8. Will the project involve the local people in implementation and management process and how? Oh yes we cannot do this errr without the community so it's a must we have engaged them in many areas, we have consulted and dialogued with community opinion leaders to receive approval on issues such as location and land use e2. Hmmm that's an interesting but in this kind of a errr projects that you cannot succeed without the local people so throughout the project we have engaged and involved community members at each phase where necessary e1. Moreover, we have been providing basic technical skills relating to electricity and operations to the youth in the communities to handle basic operation of the systems after installation e2

Comment [51]: Community involvement

9. To what extent can solar PV mini-grid affect the economic conditions of the communities? That the electricity can support local petty trading in the communities e1 this project mini-grid by nature because the production of electricity is so limited, you can't go and promote new businesses that is not there but as capacity increases it can support storage facilities such as refrigerators for their fish harvest in order to in the near future, they can afford solar refrigerators to preserve their harvest longer and sell later for a a good price e2 As I mentioned earlier, this this project is being implemented for to errr bring some err sort of improvement to the prevailing conditions on the island communities and one of such is that that those who engage in small selling activities can possibly extend their usual business hours at night because of the access to electricity e2 Yes this issue is errr we think is important and that's why we the willingness to pay survey was conducted to to deal with any potential financial burden on consumers But we can thing of the errr about this in relation to the current energy sources and how much the people are actually spending and thing we this intervention is not provided are the people better off or not

Comment [52]: Support local petty trading

Comment [53]: Suitable price

Comment [54]: Prolonged business hours

Comment [55]: Potential financial burden

10. In relation to social impacts, how is electricity from solar PV mini-grid beneficial to the communities at large? As for social benefits we can thing about a lot. For example, improved healthcare and, education, information and entertainment but this errr one can be a snare for school children to devote time for studies during evening hours e2.

Comment [56]: Improved healthcare

Comment [57]: Improved education

Comment [58]: Access to information and entertainment