A Feasibility Study of Solar Energy Development for the Otwetiri Community of Ghana

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Executive Summary

The purpose of the Otwetiri feasibility project was to find a sustainable energy solution for the community of Otwetiri in order to most appropriately address their energy needs for educational opportunities and cell phone charging. The Otwetiri community is located in Southeastern Ghana, and is an agricultural community with an average income of $1 a day. It is expected that access to electricity will provide increased educational opportunities through internet access and lighting in the new school building constructed in 2011, in addition to business opportunity with the creation of an internet cafe and cell phone charging.

Since the services are centrally located the benefits are distributed equitably. The two greatest gains from the system design are increased educational and economic opportunity. Students will become computer literate and will get the chance to connect to peers internationally to learn about other cultures. There will be internet cafe hours so that adults can benefit, too.

The project will directly hire at least 3 people within the community: an accountant and monitors for the internet cafe and cell phone charging. Through cell phone charging, entrepreneurs will be able to more reliable coordinate selling goods through distribution channels.The electrification of Otwetiri will attract more people to the bi-weekly farmers markets, drawing in more potential consumers for electric services and other locally produced goods.

Building on the enthusiasm and highly organized nature of the community the formation of community infrastructure to handle the various transactions associated with installing, using, and maintaining an off grid photovoltaic system. The revenue generated from the internet cafe and cell phone charging will be sufficient to hire an accountant and monitors for the aforementioned services. The accountant initially will focus on managing incoming money raised for the installation of the project and will then transition to collecting revenue from the monitors, paying salaries, paying back loans, and reporting to the project team savings accumulated. The team can then organize meetings with the community, the accountant, and the initial photovoltaic system installers to plan for any future system changes.

A baseline scenario was created that centers on a 5kW photovoltaic system. Together with a battery array backup, this system can produce enough to cover the loads for a computer-internet room and for a cell phone charging station. The revenues and costs align so that a payback period of less than a year is possible with a 19% interest rate.

In conclusion, due to the 9 month payback period, opportunity for business, and community support for solar electrification, we expect the project to be feasible if financial support is received for upfront costs.

Otwetiri Feasibility Study

Background

Problem Statement

The goal of this project is to develop a feasible plan for electricity in the community of Otwetiri in order to appropriately address the community's energy needs, amounting to 7.78 kWh/day for increased educational opportunity and cell phone charging with the potential to scale up in the future. The community of Otwetiri constructed a school in 2011 with assistance from the Otwetiri Project with three classrooms and a computer lab wired for electricity. The scope of the project is dependent on the services desired and the willingness of the local community to pay for solar expenses. Current energy expenditures are $1.26 for cellphone charging per person/day, not inclusive of kerosene lighting, and $1.41 with kerosene lighting.

It is expected that a wide range of community members, both within and outside of Otwetiri will benefit from the project. The community exists as an education hub for the surrounding area and contains a market which members of surrounding villages visit twice a week. Once wired, the computer lab will provide students with an IT education, and allow access to information and communication globally. Thus, the computer lab will help expand opportunities for employment and prepare students for using computers in higher education. Additionally, phones could be charged locally. Currently, community member pay a motorbike driver to taxi their phones to town 7-8 miles away for charging. Looking into the future, desired services include cold storage for medicines which would allow the development of a community health center.

With these considerations in mind, we developed multiple potential energy grid scenarios which would allow for revenue generation and increased educational opportunities. Energy demands were set at a variety of scales including a 5 kW PV system with a 9 month payback period, a future 7.5 kW PV system, and baseline 2.5 kW PV-diesel generator hybrid. We also suggest a potential computer lab and cell phone charging business for generating annual revenues of $75000 that would aid in funding the project and help achieve next steps towards a bigger system in the future.

The Community of Otwetiri

The community of Otwetiri is located in Southeastern Ghana, approximately 40 miles from Ghana's capital, Accra (Figure 1). The climate is tropical, with a mean average temperature of 80F and a mean high temperature of 90F. The rainy monsoon seasons last from April-July and September-November. These rainy, cloudy periods were taken into account with our HOMER analysis. Temperature and solar irradiance data was obtained from the National Renewable Energy Laboratory's Solar and Wind Resource Assessment (www.nrel.gov). Data is from Adawsa, the nearest town with accessible information. The average annual irradiance for this area is 4.24 kWh/m^2/day, ranging from 3.09 kWh/m^2/day in September to 5.35 kWh/m^2/day in January. The average annual temperature is 25.2°C with a range of 23.9°C in August to 26.1°C in February. The community also is free of trees which would obstruct a solar system.

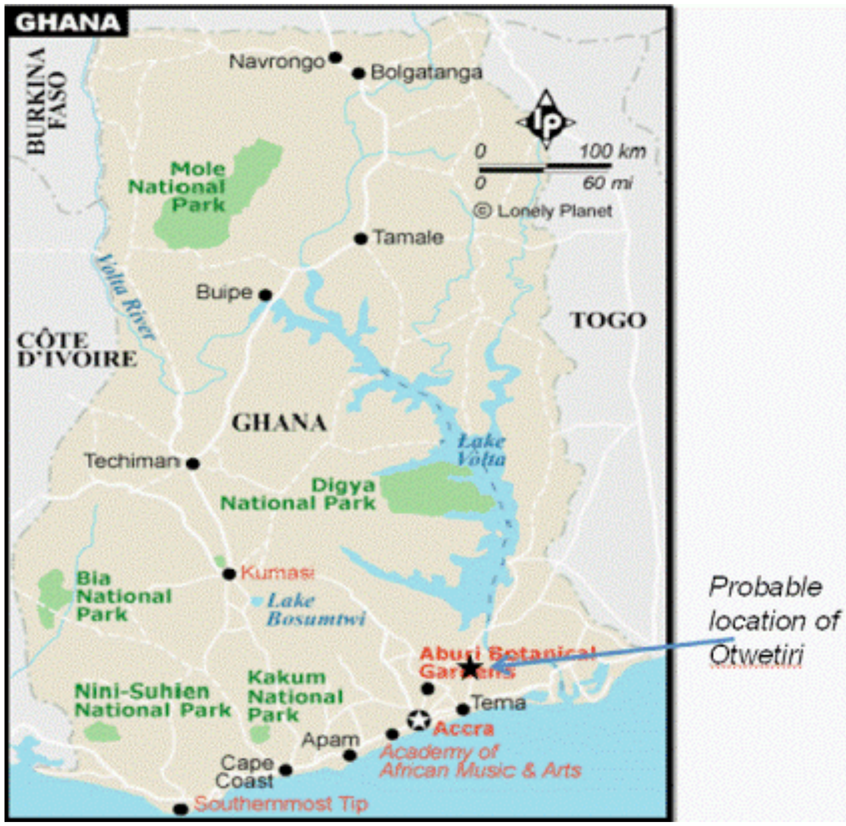


Figure 1. Probable Location of Otwetiri (www.otwetiri.org)

The community is primarily agricultural, with small scale farmers cultivating corn, cassava, yams, plantains, cocoyam, and other food crops. Otwetiri is comprised of approximately 2,000 residents living in family compounds of several homes with a common yard in the middle (Figure 2). Lighting is provided by kerosene lamps and is purchased from a salesman within the community. A market is held two nights a week across from the village, and is visited by people from surrounding communities. Otwetiri also exists as an educational hub. Four school buildings exist in Otwetiri for 650 students, and In 2011, a new schoolhouse was constructed with 4 rooms and a computer lab (Image 1). The new schoolhouse was built with the assistance of our project partner, Dr. Tometi Gbedema and the Otwetiri Project.

Figure 2. Community Map of Otwetiri

Dr. Gbedema currently works for the University of California, Davis where he received his Phd in Geography. He grew up in Otwetiri and has been very proactive in fundraising efforts within Davis for community development in Otwetiri. Through a fundraising process, capital was acquired to build the new school building in 2011, and we are confident that Dr. Gbedema's dedication to the project and enthusiasm will facilitate more successful fundraising endeavors. The computer lab was particularly important to Dr. Gbedema, as he noted the technology education gap that had to be overcome when continuing his education, and he believes internet will allow students to utilize educational resources and participate in global communication.

Energy Context of Otwetiri

Currently, Otwetiri does not have access to electricity, running water, or telephone lines. The closest electrified town is 7-8 miles away. About half of the population in Ghana currently has access to electricity as described by the World Bank (Eberhard 2011). However, there is a significant disparity between access to electricity in rural and urban areas. Currently, 80 percent of the population living in urban areas is electrified while only 20 percent of the rural population is electrified. Ghana's level of electrification is greater than the average electrification rate of Sub Saharan Africa which is around 25 percent. Expansion of electrical access in Ghana was largely a result of intensification under Ghana's National Electrification Scheme of 1989 when electrification was at a level of approximately 20 percent. This scheme was also aimed at urban areas with hopes of connecting all communities with a population of over 500 to the grid by 2020 (2011). The two state owned electrical companies in Ghana are the Electrical Company of Ghana and Volta River Authority, and they have been leading the implementation of energy infrastructure.

Despite the promises of electrification, our project partner stresses the importance of developing an independent electrification plan for reliability and because of a distrust in governmental claims. During our meetings, Dr. Gbedema mentioned the problem of reliable grid electricity within Adawsa 8 miles away, and how business is regularly haulted as a result of power outages. Additionally, he was not convinced by the governmental plan for electrification by 2020. Other such promises have not come to fruition. For example, the power lines seen behind the new school build were built with the assistance of local politician with the intention of providing electrification, but the politician was unable to fulfill this task and is no longer in office. Additionally, the nearby Volta River is the location of the Akosombo Dam on the Volta River. While the dam provides a majority of the electricity in Ghana, 80% of the electricity produced by this dam is provided to an American aluminum company (Kwame 2007) and Otwetiri has not benefited despite its close proximity to the Volta River. For these reasons, Dr. Gbedema would like to develop a grid-independent electrification plan for Otwetiri.

Image 1. The recently-built primary school building (4th-6th grades with computer room inside).

Stakeholder Analysis

An important goal of this project is to make sure that gains in human capital and local economies remain within Otwetiri. All community members will have better access to education. Children that attend the Otwetiri school live within the village and the surrounding area. As soon as electricity powers this school, Mr. Ebenezer Nyampong Offei the Designated Information Technology teacher will be able to instruct students on how to use and gain information from a computer. These students will have an easier time acclimating to higher education with the research skills gained. Project Director, Tometi Gbedema, was born in Otwetiri and said that is was a difficult road to becoming a PhD candidate with low computer literacy. Now he is able to give back to the community he loves. Residents of Otwetiri and people that come to the regional farmers market in Otwetiri will be able to have the same experience during internet cafe hours.

The internet cafe and cell phone charging hub will directly spur economic activity. At least three people will be directly employed through the solar energy project: an accountant, an internet cafe monitor (1 full time or a few part time positions), and a cell phone charging hub operator (1 full time or a few part time positions). An electrician could be trained and hired within the community as needed. Otwetiri subsistence farmers will be able to communicate better with local distributors and markets to more reliably sell agricultural goods. Women, by the same token, will be able to increase sales of artisanal goods. Otwetiri entrepreneurs can communicate and advertise to attract potential consumers in the area to the bi-weekly farmers market.

Figure 3 illustrates the full stakeholder analysis. The Otwetiri based project organizers within the community will be responsible for overseeing the construction, use, maintenance, and future expansion of the electrification project. They are:

- Bossman Kwapong - Elder
- Elders of Otwetiri Village
- Yaw Kuma Manase Agbleta - Retired Chief Registrar
- Anthony Gbaba - Headmaster of the school
- Mr. Ebenezer Nyampong Offei - Information Technology Teacher

Tometi Gbedema now works at the University of California, Davis. He started a fundraiser to help pay for the new school building that exists today. The Davis based team is:

- Tometi Gbedema (Tim) - President and Director
- Leslie Buhlman - Vice President
- Dorie Mellon - Vice President
- Belinda Kesser - Treasurer
- Jan Poole - Principal Secretary
- Martha Gegan – Secretary
- Bob and Toni Smith - Advisers

The only person who may not benefit from the current system is a local man who uses his motorcycle as a taxi. Part of his business, aside from taking people to Adawsa, is gathering cell phones to charge in town.

The community wants to expand services in the future for additional benefits such as: a community educational video library (DVD player, TV), a small health center (lighting, refrigerator for inoculations), and new economic enterprises.

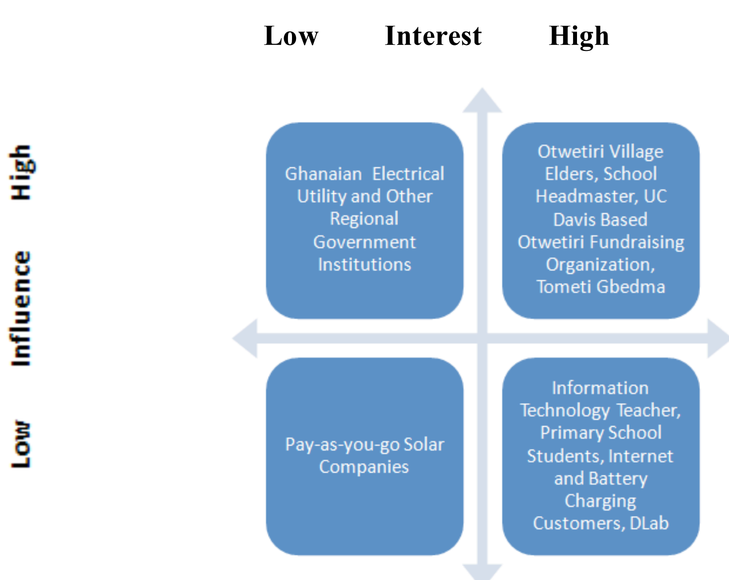


Figure 3. Stakeholder Analysis for the Otwetiri Off Grid Solar Electrification Project

Sector Papers - Literature Review by Topic

Sector 1: Off Grid Photovoltaic

The focus of this research paper is narrowed to current and possible solar projects providing energy for multiple uses while being isolated from outside sources. Otwetiri has about 2,000 people (not including market days which attract people from nearby) with the following expectations for energy: an IT lab with 10 computers, lighting room within the school, cell phone charging (with in homes or at a station, to be determined), a refrigerator for a health clinic to store vaccinations, and potentially community services for meat freezing for vendors in a nearby market and residential utility (not yet factored in). For these uses, energy must be available 24 hours a day though at varying loads.

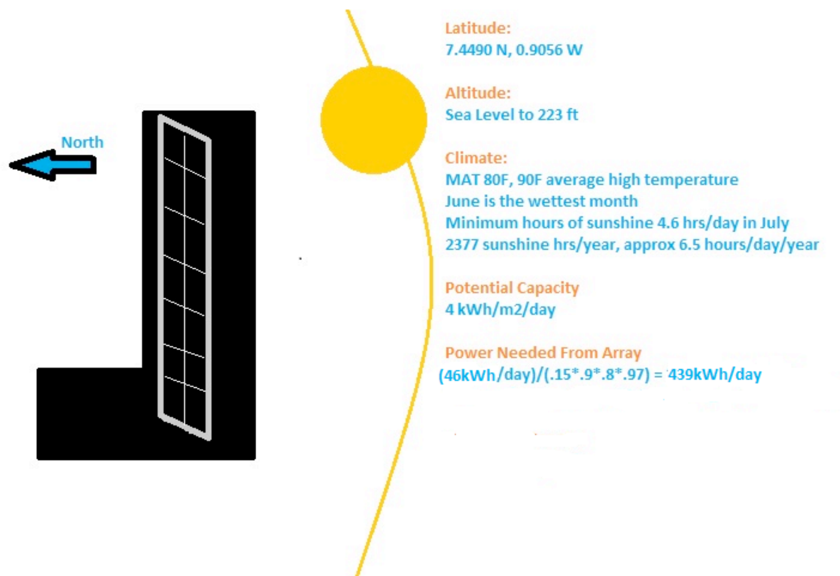


Figure 4. Proposed school project – an example of our scale

To determine the power needed from the photovoltaic array (Figure 4) as mentioned by our guest speaker, Matt Seissler, I divided the total load by the efficiencies of the constituent parts of the system (Figure 5).

Components of the system include: a number of solar panels fixed to the school roof, a charge controller that keeps peak energy flowing to the battery/rest of the system, a number of deep cycle lead acid battery, an inverter to change to incoming power from DC to AC so that certain appliances can be used, wiring/cables, and circuit breakers/fuses. There are optional parts that can be incorporated to get more out the PV array. One example is a 1 or 2-way tracking systems that pivots the panels to maintain a perpendicular irradiance angle throughout the day, however, this would mean that moving parts could wear quickly over time. I doubt because of cost and alternative methods that this will be used in our system. Without the tracking system the lifetime of such a project is roughly 11 years, not including the batteries which will need replacing 2-3 times during that period. Most of the projects I've researched resemble to some degree the following illustration.

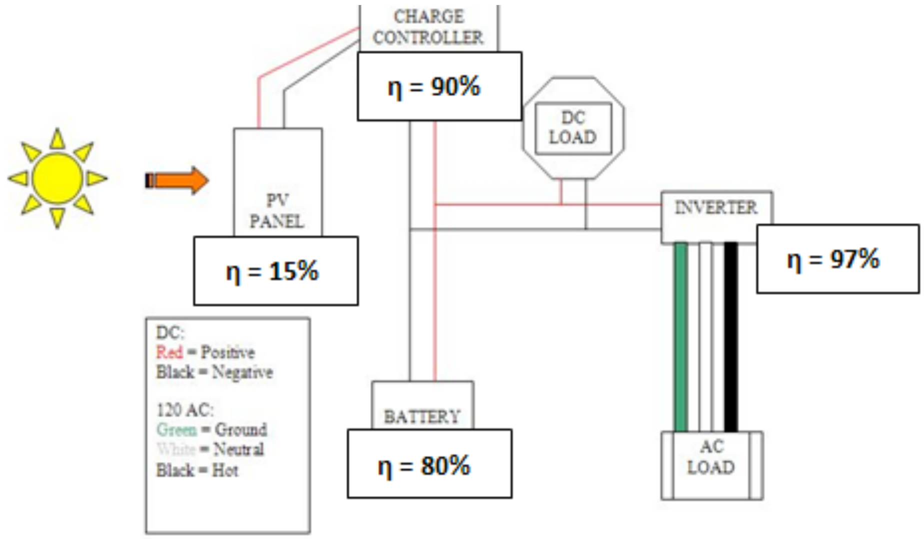


Figure 5: General Photovoltaic set up with Efficiency Range (Grafman, 2013)

<u>Types of Systems</u>

Many off grid solar projects range in size. Some systems are designed for a single purpose, like running a pump, to full systems set up for multiple uses. Here we discuss only PV arrays that would meet the needs expressed by Dr. Tometi Gbedema.

Combined Heat and Power

Projects I have read about seem to be a variation on the above theme. There is solar thermal technology where you can include combined heat and storage. My understanding is that you would concentrate thermal heat to vaporize water to turn a turbine that will generate energy. The warm water can then be diverted to warm a home.

Battery Station

Moving on, you could choose whether or not to have a DC load as pictured above. Since the energy being harnessed comes out as DC you can store or use it as is. Some practitioners set up a charging station. People would then bring their car batteries in if they could not afford unsubsidized wiring of their homes. This would be beneficial since the costs and vulnerability to the system could be decreased by keeping the wire length short. I also thought this might be a good idea because it is hard to estimate the latent demand out there. This could help us plan for community use without needing to dramatically scale up the solar arrays.

Hybrid

There are ways to overcome some of the shortcomings of relying only on solar. Sub-Saharan Africa is a hot spot for companies interested in promoting solar because of the capacity for energy production; however, with cloudy and shortened sunny days there could be a strain on the system.

Furthermore, in certain situations, scaling up the amount of panels you have to be able to satisfy demand on those days can exclude this as an option. There are a number of projects that take advantage of other energy sources such as hydro, wind, and gas generator. These configurations are site specific (i.e. if you have enough wind and/or water power nearby to use and if gas/diesel is available and is not too costly).

Lunar Solar Radiation

While looking at Appopedia, I came across another off grid solar solutions, lunar solar energy. Obviously for the purpose of the project it won't work, but what they are proposing is collecting 1% of the solar irradiance that strikes the moon's surface. The energy would be collected and sent as microwaves back to the Earth were many "rectannas" would receive and transmit the energy. My first thought was, "Wouldn't you cook the planet?"

<u>Oversizing</u>

All systems appear to be oversized to account for other factors such as demand or loss in the system. I used the conservative estimate for calculations where possible. According to Mark Seissler, photovoltaic power is dependent on global horizontal irradiance, incident angle, ambient temperature, latitude, time of year, efficiency, and soiling (one might include shading here). Efficiencies have been factored into the demand (Figure 4). The incident angle could be adjusted through tracking device or manually during the winter and the summer to compensate for the Earth's tilt. Additionally maintenance will be required to clean panel surfaces to prevent shading and soiling losses, though it should be mentioned that upkeep of this system after installation seems very low. The Ghanaian mean annual temperature varies little seasonally with an average high in the 90's (Figure 6). The voltage is decreased by high temperatures so I am not sure if a cooling system of some sort will need to be added or if the loss of voltage will be another reason to scale up the number of panels and batteries in the system.

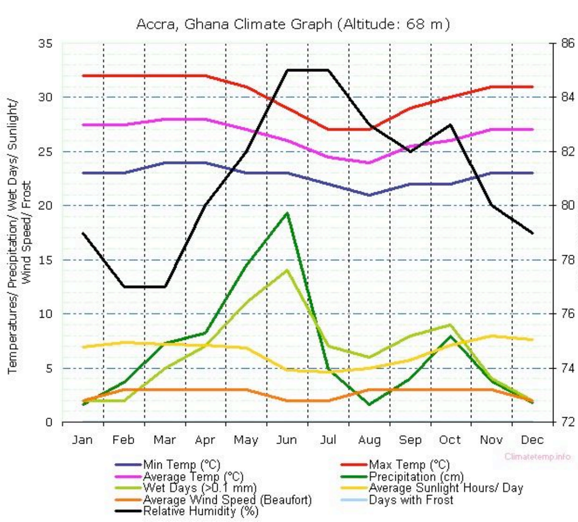


Figure 6: Climate Information for Ghana (Ghana, 2013)

Ghana's solar insulation produces between 4-6 kWh/m2/day depending on location (Essandoh). I used the low end of that range. There are about 1900-3000 hours of sun/year. With these figures one can begin to piece together the type of system desired (hybrid or otherwise) and the size of the system (number of panels, batteries, etc).

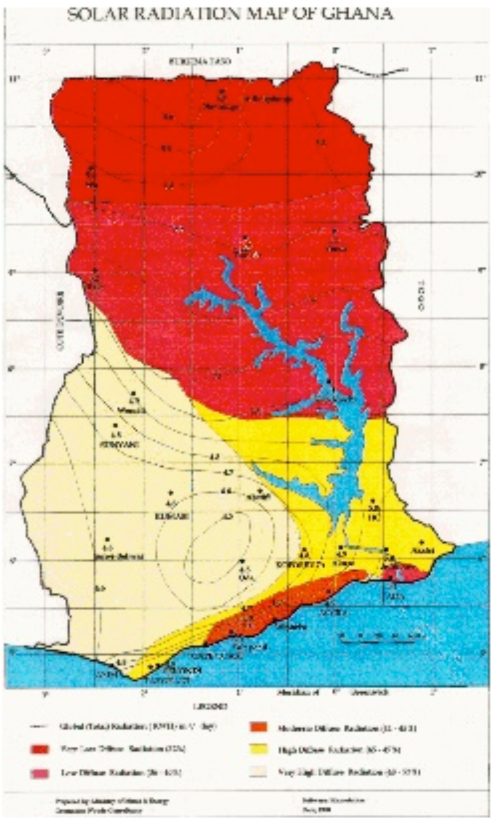


Figure 7: Solar insulation dispersion over the country of Ghana (Solar GIS)

Conclusion

It would seem there is a sea change of how off grid systems are viewed. Governments and companies are realizing that extending electrification long distances away from the power plant or energy source may be unnecessary to meet the demand of users. There are applications for this in rural and urban settings, developed and developing contexts. Today, investors look for incentives and appropriate fitting solutions for the task at hand. Looking broadly at what a region energy production potential is, one can piece together available sources. Hybrid systems that take into account the multiple assets of a site: wind, solar (electric and thermal), hydro, and access to gasoline. Knowing that each energy source has its own constraints, practitioners then calculate the energy demand. It is imperative to account for periods in which energy production will be at a yearly average low. You then build a system designed for this worst case scenario. Oversizing a system can help insure constant electrification of a site, however, this activity should be reigned in somewhat to keep the cost low.

If off-grid systems are going to be the wave of future development, governments should consider building these to take advantage of economies of scale. For now, as communities look for outside help to start their own electrification projects, consultants should try to fit demand so that it is financially feasible. Photovoltaic systems should be designed in a way that accounts for the latent demand of energy.

Working closely with the community to assess population dynamics, discuss current and projected utilization of the system, and creating a payment structure will inform the design process.

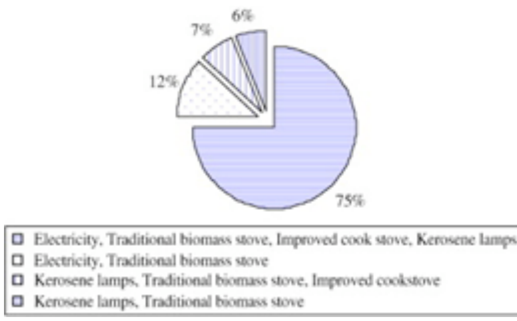
Sector 2: The Context of Energy and Microgrids in Ghana

Ghana is currently the most electrified country in Sub Saharan Africa, yet only 20 percent of people living in rural areas have access to electricity from state owned electrical centers. Additionally, communities are limited in their energy consumption by the high costs of electricity. A variety of off-the grid energy solutions are being made available to communities for the small scale use of electricity at affordable rates. Among these energy strategies are the creation of community microgrid systems which can use solar in conjunction with storage batteries and other renewable energies to produce electricity locally. Diverse social, economic, and environmental implications require site specific evaluations before implementation. However, studies have demonstrated that access to electricity leads to increases in educational opportunities, and the success of microenterprise.

Within Ghana, access to energy is expanding; however, rural settings continue to be characterized by the use of unprocessed biomass energy. About half of the population in Ghana currently has access to electricity as described by the World Bank (Eberhard 2011), but a significant disparity exists between access to electricity in rural and urban areas. Currently, 80 percent of the population living in urban areas is electrified while only 20 percent of the rural population is electrified. Ghana's level of electrification is greater than the average electrification rate of Sub Saharan Africa which is around 25 percent. Expansion of electrical access in Ghana was largely a result of intensification under Ghana's National Electrification Scheme of 1989 when electrification was at a level of approximately 20 percent. This scheme was also aimed at urban areas with hopes of connecting all communities with a population of over 500 to the grid by 2020 (2011). The two state owned electrical companies in Ghana are the Electrical Company of Ghana and Volta River Authority and they have been leading the implementation of energy infrastructure.

In addition to electrification being skewed more heavily towards urban populations, as might be expected, inequitable access also resonates with income levels. In Ghana's region, Sub Saharan Africa, a vast majority of people with electrical coverage belong to the more affluent 40 percent of the population, and in most countries, inequality of access has increased over time. Additionally, in urban populations the power lines are physically close to 93 percent of the population, but only 75 percent of households connect to these services (Eberhard 2011). Therefore, about half of the population without access to power resides close to electrical infrastructure in Sub-Saharan Africa. Coverage, therefore, is also highly dependent on demand, not just supply. The services of centralized energy providers are currently not meeting the needs of many rural, lower income people.

The way energy is being utilized currently differs depending on access and income. A study by Kankam and Boon (2009) examined energy delivery and use within Northern Ghana. The primary occupation of residents within the village is primarily farming and small and micro enterprises with most inhabitants involved in the production of yams, rice, and groundnut for markets and sustenance. This study examined energy uses from a variety of energy access programs within the area including projects with installed photovoltaic systems and beneficiaries of the governmental program on rural electrification in Ghana. Interestingly, despite access to electrification, surveys described multiple fuel use in most households. 71% of households reported the use of traditional biomass stoves and kerosene lamps, and remaining households reported dependency on two or more energy options (Figure 8.). This is in contrast to nonelectrified communities which generally use wood and kerosene as dominant fuels (Figure 9). End uses of energy options were identified by those surveyed. Major energy uses included cooking, lighting, heating, and motive power for agricultural processing, though kerosene provided lighting within households and fuel wood and biomass were predominantly used for cooking. Solar home systems were typically used within the household level for lighting, radio, and television, and at the community level for lighting and megaphones within mosques. The trend implies that electricity access within the household does not replace traditional sources of energy from fuel wood and kerosene for cooking and heating (2009).



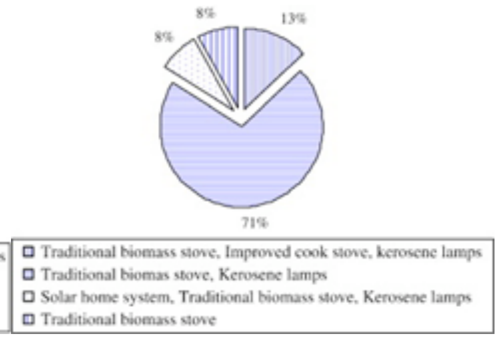


Figure 8. Household energy options utilized in two electrified communities
Figure 9. Household energy options utilized in two non electrical communities
Source: Eberhard 2011
Source: Eberhard 2011

These findings are important to the feasibility of solar for several reasons. Supplying energy at the community level does not ensure its use in the household to replace all energy services. Economically, it would be important to consider the cost of solar or electricity as a supplement for kerosene and biofuel versus a replacement. Understanding the primary uses of electricity and whether it is a service more households are willing to pay for is important for understanding the feasibility of a project. Contrary to previous conceptions that electricity is a precursor to development and grid services should rapidly be extended, as described, demand has only conditionally followed infrastructure (Kirubi et al 2008). As described by The World Bank (1995):

"One of the most persistent claims for RE is that it can induce industrial growth in otherwise lagging low-income rural economies. The evidence from developing countries does not support this claim; RE has not, by itself, triggered industrial growth or regional development...The study found that where other prerequisites of sustained development were absent, demand for electricity for productive uses did not grow. . .RE is economically justified only when the emerging uses of electricity are strong enough to ensure sufficient growth in demand to produce a reasonable economic rate of return on the investment (p. 2)."

Additionally, these results are important to social feasibility studies when addressing the benefits of electrical access within communities. The use of cook stoves and solar lighting in lieu of burning fuels is often a motivation for the implementation of solar systems due to the negative health and environmental impacts of emissions. If biomass and kerosene continue to be used with solar, this may negate some of the associated benefits of solar. Related to social implications of general energy access, 98% of those surveyed in electrified households during this study expressed that energy contributed to education very positively as compared to 80% in nonelectrified households. During discussions, the details of educational opportunities were found to include the ability of students to do their homework, but also adult education programs. This is particularly relevant in settings where photovoltaic lighting systems are included not just in individual households, but also in public places such as mosques, where many people can benefit.

As discussed, issues related to access and cost limit participation in centralized electrification systems within Ghana. A publication by the Energy Sector Management Assistance Program of the World Bank (2007) describes renewable energy options which can be applied in off grid systems as an alternative to state electrical systems. Looking strictly at generating costs inclusive of rated output (kW), levelized capital cost, fixed operation and maintenance costs, and fuel costs, ESMAP ranked renewable energy sources according to cost efficiency. The lowest generating costs for mini grids are bio-digesters and biomass gassifiers at 6-15 cents per kW/hr. While geothermal is also economical, it is limited to very geologically specific locations. For stand alone, off the grid systems, pico hydro (12 kW/hr), PV systems, and wind are able to be used, at 30-50 cents per kilowatt hour. Additionally, installations of wind and pico hydro are dependent on environmental conditions. This is also economical when compared to the generating costs of a small stand alone generator which ranges from 45-60 cents per kW/hr. As discussed in the article, figures are dependent on changing fuel costs and the cost of technologies which are becoming increasingly less expensive. Additionally, environmental and social considerations are important aspects of sustainability and were not addressed in this analysis by The World Bank.

Incentivizing the use of renewable energy sources in rural developing areas, the government of Ghana has set goals for renewable energy installations. The Renewable Energy Bill, which passed in 2011, aims to have 10% of Ghana's energy provisions produced with Renewable Sources. Large strides are being made in this commitment through centralized utility systems, but there are few incentives for small scale solar producers not applied to the grid. The Nzema Project was recently devised by a private British asset development group, Stadium, and aims to provide electricity to 100,000 homes, and will increase Ghana's power generating capacity by 6 percent. 630,000 photovoltaic panels will begin installation by the end of next year (McGrath 2012). The project is the largest in Africa and functions off a feed in tariff. Other countries where centralized electrical access to the electrified system is limited, such as Uganda, Kenya, and Tanzania,, have passed legislation for operations under 3MW to operate with no regulation and for investors to charge tariffs which act as a return on investment and cover operating costs (Kirubi 2008). However, Ghana does not currently have meaningful incentives for small scale off the grid systems.

One renewable energy solution to electrical access that has been met with success in rural low income areas across sub Saharan Africa is distribution of electricity through microgrids. For reasons of access and affordability, The World Bank suggests microgrids where feasible, especially combined with hydropower facilities (Eberhard 2011). Microgrids can be used as small scale versions of electrical utilities, producing energy renewably on local scale and then distributing it to local peoples. Some microgrids include hybrids which utilize multiple energy sources such as PV, wind, battery storage, and a generator for backup. Successful projects include that of the Bulyansungwe, Uganda which provides electricity from a photovoltaic microgrid producing 485 kWh per month to provide electricity for a school within a primarily subsistence community. Numerous photo voltaic energy projects exist within Ghana, and access to materials can occur through regional suppliers operating within the area. DENG is an example of one company operating in the area that markets a variety of solar technologies including panels, batteries, and inverters (http://www.deng-ghana.com). Demand and willingness to pay is essential to sustaining community microgrid projects. The World Bank characterizes successful projects from their

2004 study as being first, largely dependent on the cost recovery of a program which they suggest covering with tariffs that cover operation and maintenance costs at the least. They also recognize successful projects as having effective agencies coordinating and implementing projects. The form of this agency may be different. Examples include rural electrification authorities, rural cooperatives, and utility companies. Additionally, programs have considered schedules and required infrastructure for electrification. Lastly, community participation and the use of locally sourced resources has been key (World Bank 2004).

The implications of providing electrical access to rural communities in Ghana are likely to be diverse. In a case study in Mpeketoni, Kenya installation of a micro grid which supplied electricity, though not solar, was able to assist small microenterprises by allowing for the use of tools. Productivity within tailoring shops also changed substantially. Worker productivity increased by 50-170%. As supply increased, prices dropped, resulting in revenues that ranged between 20 and 70%. Other results included increased availability of tractors for hire. As welding services were able to develop in the community through electrification services, tractors for hire were more comfortable entering the area from the larger nearby town, as they did not have to fear getting stranded due to lack of repair facilities in the area. Local trade and commerce were spurred with the addition of a bank and post office, and internet access was able to be provided at the local post office. Further, educational opportunities were expanded therefore and became more level with those of nearby urban areas. Previously, students had to spend 2-3 hours every evening hauling water. The purchase of an electrical pump was able to eliminate this time requirement. Thus, the students were provided with more time and lighting to study. The project was later taken over by the government utility company, but had the infrastructure and customer base to successfully enter the centralized utility system.

On a smaller scale, and within Ghana, other studies have shown the impacts of small scale energy systems to vary. In a survey of four agricultural communities in Northern Ghana, energy contribution to education was significantly higher in electrified homes compared to homes using biomass and kerosene fuel sources. However, in the survey, improving gender roles, the creation of job opportunities, and reducing indoor air pollution were not viewed as being substantially different. During discussions, significant improvements were also made in adult education. This was particularly relevant to PV systems, as discussed (Kankam 2009). An additional study found that the use of solar in off grid microenterprises, in this case fruit vendors, was able to increase the work hours of vendors and increase income while and solar was found to be more cost efficient than their previously used kerosene lamps. Newly generated incomes also meant that night vendors could afford repair costs of Photovoltaic systems (Obeng and Evers 2009).

In conclusion, centralized electrical systems in Ghana, while expanding, disproportionately benefit people of higher incomes in urban areas. Studies related to the benefits of solar have shown improvements in education and microenterprises, demonstrating the feasibility of energy projects for bringing real improvements to communities. There are a variety of renewable energy sources that can be utilized in microgrid systems in order to distribute affordable and small outputs of energy. This been achieved with previous energy development projects. Implementation is dependent on costs and willingness to pay. It should be noted in economic and social analyses that electricity does not eliminate the costs of kerosene and health implications from burning biomass, as surveys revealed electricity to be used as a supplement for these energy sources in rural settings, not replacements. Additional research will need to look at environmental sustainability differences between technologies and site specific affordability and availability of technologies prior to implementation. Understanding the context of energy in Ghana, particularly the impacts of microgrid installations, allows for an understanding of resources available for communities desiring to obtain electrification and examples of previous projects and their impacts. These are important components related to feasibly of energy installations in Ghana.

Sector 3: Energy Sub-Sector - Diesel Generators

The feasibility of a new electric energy source (possibly using photovoltaics) is to be determined at the Otwetiri Village in the Eastern region of Ghana. While looking into this viability, it is important to assess and analyze the energy sector in Ghana and how it compares with other rural, developing areas of the continent and world. Within this energy sector, there is value in discussing the role that diesel generators have played in Ghana and elsewhere and the role that they could play in the future. This paper will focus on this generator issue.

It is important to give context and an overall view of energy consumption in Ghana and Sub-Saharan Africa. In 2006, the entire country of Ghana had the capacity to produce about 65 MegaWatts (MW) per million people (Eberhard, Vennemo, Shkaratan, & Rosnes, 2011). Also in this year, fewer than 30% of Sub-Saharan Africa households were electrified. Sub-Saharan Africa has a relatively low electrical consumption rate in comparisons with other areas in the developing world, and this rate drops even more when South Africa is not included. Including South Africa, the annual electrical consumption per capita in 2008 was 457 kWh and excluding South Africa, it was 124 kWh. Yet the average annual electrical consumption per capita for other parts of the developing world was 1155 kWh. However, Ghana itself does have 80% of urban areas electrified and 20% of rural areas electrified.

Delving into the type of energy production, there are the categories of own generation, such as with renewable sources or diesel generators, and centralized generation, such as with utility grids. About 19% (much higher than other parts of Africa) of West Africa's consumption was off of own generation (Eberhard et al., 2011). Backup diesel generators are more desired in areas where power is unreliable. In particular, Ghana averaged 60 out of 365 days of power outages in 2008. Ghana has also faced numerous electricity generation challenges over the years. In recent years, Ghana's lessening water supplies due to drought have diminished the capabilities of its hydropower plants. As a result, Ghana has looked to oil for its diesel fuel, which has had high prices as well. By using diesel generators for off-the-grid reliable power, costs for electricity are relatively much higher than typical local grid power and international grid power.

Analyses have been done comparing off-grid photovoltaic and diesel generator costs throughout Africa (Szabó, Bódis, Huld, & Moner-Girona, 2011). The mapping of these costs gives a good picture as to the best localized electrical production option, given certain assumptions. In areas where grid extension would be cost-prohibitive and load demand is relatively low, off-grid options are necessary. The maps created by Szabo et. al. relied on approximated renewable potential energy, geographical information, and the cost and transportation of oil/fuel. The focus was on the cost differences between photovoltaics and diesel generators (and also the differences to grid extension where possible/borderline) since the cost similarities would not give any useful information towards picking a power source. The costs were also standardized in order to be comparable. To create the solar aspect of the maps, simulations were run that included solar irradiation data, system size minimization based on necessary demand, inefficiencies, system lifespan, and module/components/installation costs. The overall costs of PV systems can land anywhere between .2 and .55Euros per kWh, depending on the location/situation. As for the diesel generator part of the maps, fuel consumption, engine maintenance, and transportation costs affected the total costs. A major difference in the type of costs is that PV has a greater initial investment requirement and diesel generators have large and variable long-term fuel and transportation costs. Figure 10 shows the different areas where either PV or Diesel is financially preferable. The Eastern region of Ghana appears to mainly have a Diesel preference with sprinkled-in PV locations. However, even if the Otwetiri Village was in a purely Diesel-preferred area, other factors have to be taken into account to determine what will actually be possible to bring electricity to the area. By incorporating either system into Otwetiri, analysis would have to be done that checks the proportion of average worker's earnings that power would become once installed.

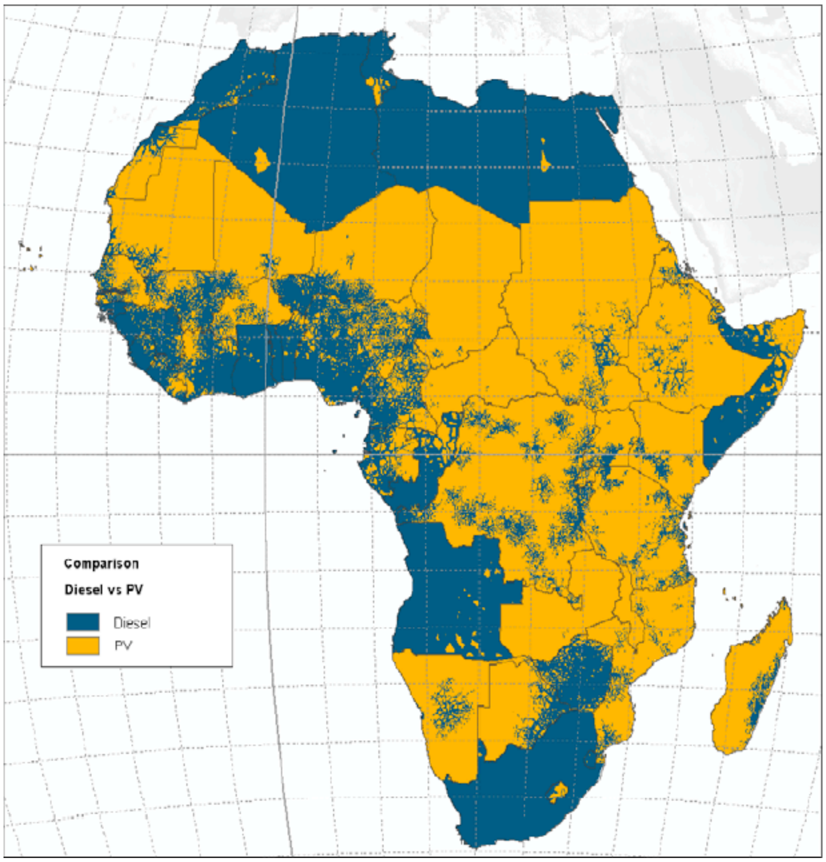


Figure 10. Least-cost option - Diesel Generator vs PV

Another method of bringing PV in as a renewable energy source is to pair it with a diesel generator (Yamegueu, Azoumah, Py, & Kottin, 2013). Using diesel as a complement to PV allows for unpredictable weather conditions that would otherwise lead to unexpected power downtime. Yamegueu et. al. specifically discussed this hybrid situation without battery backup. The authors cited research showing that battery systems were 8% less efficient than battery-less systems. The authors also discussed a "flexy" system that would allow for either gasoil or biofuel to be used in the generators. An experiment was performed in Burkina Faso using a 2.85 kW PV array and a 9.2 kW diesel generator. This setup was based off of grid-integration rather than as a stand-alone system. Potential issues that came up were voltage imbalance, current imbalance and harmonic distortion. These could be mitigated, however, through the use of a proper inverter.

Researched at the same University in Burkina Faso, hybrid system s were also tested for off-grid purposes (Yamegueu, Azoumah, Py, & Zongo, 2011). The financial cost issues were discussed earlier –

however, there are also the environmental and climate change concerns to take into consideration when looking into PV, diesel generator, or hybrid systems for power generation. Several factors affected the dominance of diesel in certain areas on the Figure 1 map and yet, there still remains a strong case for PV installation in West Africa, where solar irradiance can be between 4 to 6 kWh/m^2/day. On the other hand, the peak demand period and peak production for solar are not aligned, making the case for a hybrid system with diesel. There are several drawbacks to using battery storage: recycling issues, power loss, lifetime shorter than that of the PV array by several times and additional cost (significant fraction of total cost). The authors therefore experimented without a battery backup. Again the test was set up with a 2.85 kW PV array and a 9.2 kW diesel generator and the two were in parallel. The diesel generator was at optimal fuel efficiency when it ran at 80% of the rated power and a minimum of 0.324 liter/kWh. The PV inverter could reach 95% but was at a much lower value when the array was producing a relatively low amount of power. Different levels of loading were tested on the hybrid system. For the lower loads, the diesel generator works less efficiently since it needs a certain amount of loading to be most efficient (around 80%) and the PV production efficiency also suffers. At higher loads, demand may not be met all times, but the diesel and PV are able to run more efficiently.

Similar studies were run on diesel, hydro-diesel, and photovoltaic-diesel systems in a rural section of northwest Argentina (Díaz, Arias, Peña, & Sandoval, 2010). In addition to some previously mentioned disadvantages regarding diesel generators, there are also the cases where tough-to-transport areas force lots of fuel to be stored, requiring lots of money to buy all at one time. This particular study involved 16 diesel generation systems, 5 hydro-diesel systems, and 7 photovoltaic-diesel systems (each system was at a separate location in Argentina) between 2001 and 2008. Energy consumption hour limitations were needed at all but one site. As Figure 11 shows, energy demand seemed to have a direct relationship with system sizes – larger systems have more economic development in place and so there is more built-in demand (as one possible explanation). Growth in demand over time also relates to the Figure 11 information in that the rate of growth was higher for the larger systems and lower for the smaller systems. Hybrid PV/diesel systems started off in this study as PV-only and then became hybrid to compensate for increase demand, but the demand still grew at a slow rate. In addition to diesel generators being more efficient due to higher consumption/load, the generators are also more efficient the larger in size they are. In the hydro-diesel systems, hydro had the biggest production ratio at about 80-90% and the smallest production ratio at about 10%. As a point of comparison, Uganda's primary power source is hydroelectric and it is supplemented by diesel, but generally not as part of hybrid systems (Twaha, Idris, Anwari, & Khairuddin, 2012). Local conditions would affect the results from this study and so one would need to model the site-specific situation in Ghana (Díaz et al., 2010).

Energy demand by type of system (year 2008).

Type of system	N systems	N users (clients)	Total energy demand (kWh per day)	Energy demand, per client (kWh per day)
Large-diesel (24 h)	1	283	2054	7.25
Small-diesel (8 h)	15	873	853	0.98
Hydro-diesel (18 h)	5	811	1084	1.34
PV–diesel	7	358	128	0.36

Figure 11. Energy Demand By Type of System

An implementation plan was created as part of a thesis to sustainably electrify a northern Ghana village, a similar situation to that in Otwetiri (Bailey, Chotimongkol, & Isono, 2007). As some background, about 10% of rural areas in Ghana are electrified. It is important that the feasibility of different power sources is determined so that precedent can be set and copied in other similar situations. Also, it is important to note the work done in the past towards off-grid generation: solar home systems were installed in the 90s in areas that were close to enough to the grid that they eventually were connected to the grid. The power from the grid circumvented the usefulness of the solar arrays since the latter is much more limited. Success for either PV or diesel generator systems would require that consumption demand is estimated appropriately, a fiscally sustainable arrangement is possible, and that the generation system cost is minimized. HOMER software, from the National Renewable Energy Laboratory, was used as part of this implementation plan to simulate an optimal generation system based off of parameters such as resident surveys. One selection from the plan/model was to use a DC generator instead of AC in order for it to be properly sized and not running at low load inefficiently. Results from the HOMER model showed that the hybrid system would be best. Part of the model's input conditions involved consumption limitations and annual financial obligations for the residents. Limiting consumption would require some type of administrative setup.

The different chances renewable energy/generators have in the grid-connected city parts of Sub-Saharan Africa rather than the off-the-grid rural parts was discussed from the economic point of view (Deichmann, Meisner, Murray, & Wheeler, 2011). With great capacities for renewable energies across Sub-Saharan Africa, the obstacle to its quick spread is on the finances. As part of the economics analysis, the costs were contrasted between a theoretical grid extended everywhere versus the costs of either each home producing its own power or all homes having access to decentralized mini-grids. For the decentralized possibilities, diesel generators, PV, wind and biodiesel were all included as options. Different algorithms and cost estimations were used to come up with the models. The results from the modeling suggest that localized information about the allocation of people and resources and all the different associated costs make for very specific feasibility determinations – it cannot simply be generalized.

Another case regarding diesel generator/photovoltaic hybrids in a different part of the world is in East Malaysia (Ajan, Ahmed, Ahmad, Taha, & Mohd Zin, 2003). Like the previous Ghana example, this situation was off-grid. The difference in this situation is that the existing setups had diesel generators to begin with and the proposal was to supplement them with PV. This was proposed because of the high prices of fuel; however, PV would not have been stable enough to be the sole generator. The path to determining the PV feasibility consists of checking the average demand loads, dividing up the loads onto the PV and diesel, calculating daily production, calculating daily fuel cost, and comparing life cycle cost of the original diesel system and the latest diesel plus PV system. With the battery back-up added to the hybrid mix, the demand loads are covered by a combination of the three power sources (with priorities given to each to make the most efficient system possible). The conclusion from this case study was that adding a 35 kW PV to the 150 kW generator would only slightly yield savings over the long run.

Another example can be made of Nigeria's possible transition from diesel to hybrid systems (Oparaku, 2003). At the time of this paper, PV systems were viable for smaller loads (up to television) but became expensive once refrigeration or a similar load was needed. Life cycle cost comparisons were done to show this. Major factors in the comparisons that were done were the ever increasing price of fuel and the decreasing price of PV modules. The conclusion for this situation was that the centralized PV system was not feasible at that time. Being that this paper was from about ten years ago, there could be an update in these calculations that would reverse this conclusion.

As was shown in several examples, diesel generators are constantly being assessed for their potential as power sources. Increasingly, these generators are found not to be sufficient as sole supplies of power in terms of cost and environmental effects. Instead, the right balance has been found sometimes to be pairing the generators with renewable energies. As electrification projects are assessed and implemented, it will be essential to know what is working and not working for sustained electrical production growth.

Methodology

Multiple possible energy production options were specifically considered for the Otwetiri village. A photovoltaic system was immediately considered due to the high solar irradiance for the area and the available roof mounting areas that came as a result of the newly-built primary school building. However, other sources of power were also proposed. There is no major water flow in the area that could have been used for hydroelectric power. Ghana has moderate to excellent wind coverage for .5% of the land area of the entire country [National Renewable Energy Laboratory 1]. Within the Eastern province, there are 285 km^2 of moderate class wind and 26 km^2 of good class wind (no areas are captured in the excellent class). To get a more specific estimate of Otwetiri Village, Figure 12 shows a wind map from the National Renewable Energy Laboratory (working in conjunction with the United Nations). The estimated location of Otwetiri is marked by a red x near 0° longitude and 6° latitude. This area is has either Poor or Marginal wind classification and so would not make for a good environment to install a micro-wind power generator.

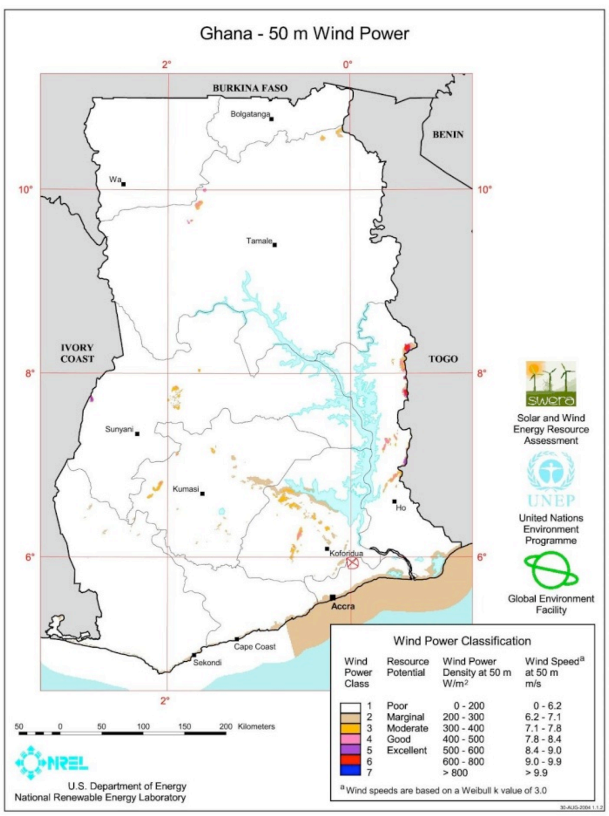


Figure 12. U.S. Department of Energy NREL Wind Classification Map

Testing the feasibility of a solar photovoltaic system was the logical next step for an area so rich in solar potential. First steps in checking the possibility of a PV system involved scoping the area of possible installation. An aerial view of the village was not possible because the exact location could not be pinpointed within mapping programs. As a result, photos and information from Tometi Gbedema were gathered to get an idea on the orientation of the schoolhouse and its proximity to trees. It was assessed that shading would not be an issue on the school roofs and that there were south, east, and west mounting planes (pitched at approximately 9°) available for a photovoltaic system. For the sake of the feasibility study, the south roof mounting plane was used in the calculations for best production and for practicalities. As opposed to a ground-mounted system, this would be easier on installation, security, placement, and materials. Additional components need to be added for ground-mounted systems and a soil sample may be needed, depending on the type of mounting equipment installation. Having a system on the roof makes security easier, but still requires some kind of protection. The community will be involved in the watching of the system so that it stays safe.

To proceed to sizing the system, potential electrical loading had to be determined. The powering of computers, lights, televisions, freezers, cell phones and radios were listed as desired goals for the community. Being that all these electrical products would add up to a sizable load, priorities were determined to decide which loads should be modeled. HOMER, an energy modeling software for hybrid renewable energy systems, was to be used to simulate the optimal renewable energy production system and figure out costs.

The Otwetiri Village has already installed power lines and electrical wiring in certain buildings. Specific information on how and where the wiring was exactly set up was not available for this report and therefore only assumptions could be made. However, this would only affect the distributed generation scenarios. If all of the power consumption occurred at a central hub (such as the schoolhouse) for a particular scenario, then the only installed wiring of relevance would be that found in the school building.

Modeling also required cost information for the various aspects of a potential hybrid or non-hybrid renewable energy system. Prices were obtained in both Ghana Cedis and US Dollars and are set at USD in this report for the purpose of comparison. The PV components (modules, voltage controller and mounting hardware) and installation were estimated to cost a total of $4.50/Watt (based off about a $2.25/Watt cost for modules and the rest for the other $2.25/Watt). A local Ghana PV installer was contacted in order to get general estimates on prices. Operations and maintenance were estimated at $150/year. The inverter was estimated at $1.21/Watt based on the locally available Studer inverter line [Studer XPC-1412]. The lead acid batteries were also selected based on what appeared to be available relatively nearby - sizing was determined by cost-effectiveness. Cost was assumed to be $700 per 2V, 1500 Ah and 3 kWh Hoppecke battery [Hoppecke OPZS Series]. As a result, the cost per watt for batteries was $1.4 (and operations/maintenance at $20/year). Also, for the diesel generator hybrid scenario, the average diesel fuel cost in Ghana was $.83/liter at the time of this report.

After modeling with a variety of the loads desired by the community, it became evident that a baseline scenario with only the most important loads should be simulated. The reason for this was that the PV system size could not get too large without greatly increasing the capital cost. A base scenario with only cell phone charging and computer usage was created. Computer loads are significant to the community because of the educational potential for students (as well as connecting them to the world through the internet) and they can also bring revenue back to the project if used as an internet cafe after school hours. Cellphone charging has the potential to bring in significant revenue while also meeting the demand of the people of Otwetiri as well as nearby villages. Currently, if a community member wants to charge a cellphone, they must either travel a long distance or send the phone with a taxi to be charged at a station. These charging stations also have long delays due to high demand and an increased charge time that is an effect of too much simultaneous loading. The cost plus the inconvenience lead to the opportunity available for a neary charging station.

The base scenario modeling yielded a 5kW system as the least Net Present Cost solely-PV energy system. The initial capital required is $32,880, with an operating cost of $515/year, total Net Present Cost of $39,461 and cost of energy at $1.088/kWh. The HOMER software ranks scenarios by the Net Present Cost because it deems this value as more reliable than the cost of energy value. In order to achieve these values, a specific loading schedule was creating to synchronize with the PV production. Cellphone charging (15 cellphones at a time) at .004 kW each would occur throughout the day (from 7am to 8pm) and computer usage (5 computers) at .2 kW each would occur from 11am to 5pm (the hours could, for example, be split into 4 hours for school and 3 hours for internet cafe). The total kWh consumed per day in this scenario is 7.78. In comparing the costs determined by HOMER with the revenue coming in from the PV-related businesses, some additional costs had to be taken into account. The cost of the technician who will look after the technical aspects/monitoring of the PV system were included in the HOMER software values. The annual salaries of the employees in charge of the phone charging, internet cafe, and the accountant are assumed to add up to $5,800. The estimated internet cost for the year is $1492. Figure 13 shows more details about the different cost and revenue components that yielded the 9 month payback period for investors. A 19% interest rate was used to be conservative based on the high side of the Ghana benchmark interest rate of the last seven years. The business capacity was assumed to run at 75% efficiency (multiplying the total potential revenue by 75%) to take into account possible longer charging times, malfunctions, power outages (this should be very rare since system was designed for excess of 2,663 kWh/year), and demand slowness . The internet cafe would be open for 29 hours a week (with 5 computers available) and cell phone charging is assumed to be 15 phones at a time for a charge time of 2 hours. The computers would be used for free by the school for 20 hours a week.

kW	Capital Cost	Total Net Present Cost	Total cost per watt	PV production/year (kWh/year)	Excess electricity (kWh/year)	Total annual cost	Scenario	
5	32880	39461	7.8922	5816	2663	3087	1C	
	Operating Cost/year							
	515							
Internet Connection Monthly Cost (24GB)	Yearly Cost (GHS)	Yearly Cost $	Yearly Salaried Phone Charger Emp	Yearly Salaried Internet Café Emp	Yearly Salaried Accountant Emp			
240	2880	1492.227979	$1,000	$1,800	$3,000			
								$ Assuming 75% of Capacity Being Used
Internet Café Price (GHS per hour)	Number of Computers	# Hours Available Weekday	# Hours Available Per Weekend Day	Total # Hours available	Revenue Per Week (GHS)	Revenue Per Year (	RPY in $	
2	5	3	7	29	290	15080	7813.47	5860.103627
Charging Phone Price (GHS)	# Sockets Used	# Hours of Charging Per Day	Revenue Per Day (avg. 2hrs per phone)	Revenue Per Year			RPY in $	
5	15	13	487.5	177937.5			92195.6	69146.69689
Paying Off Total Costs In First Year (NPC used instead of capital cost):	Total Revenue for First Yr		Interest Rate (more conservative):	Payback Timeline (Months):				
$46,753	75006.80052		0.19	9				
			Total Costs Plus Interest:					
USD	GHS		$55,636.34					
1	1.93							

Figure 13: Costs and revenues used to determine 9 month payback period.

It is important to note that HOMER had the best energy production estimate of the software used. PVWATTS is also commonly used for solar radiation estimates, however, only had an Accra data station available in Ghana. Even though Accra is only about 45km away from Adawsa/Otwetiri, there is a significant enough difference in production potential. Accra has an annual average of 5.22 kWh/m^2/day. For a 5kW system under the same conditions as in Otwetiri, the production would be about 6573 kWh under a .77 DC to AC derate. This value is about 750kWh greater than what was estimated by HOMER based on the Adawsa weather and solar irradiance data and therefore, only HOMER production estimates could be used.

As the diesel energy sub-sector section showed, a hybrid diesel-PV configuration can lower capital costs so that financing barriers can be further broken down. In a hybrid system, there is the issue of access and cost of fuel. While it is possible to get diesel fuel to Otwetiri, there are multiple issues that need to be taken into consideration for the overall system. These issues include transporting and refilling the generator fuel on a constant basis, the cost of the fuel (this is included in the HOMER simulation), maintenance (also included in HOMER), environmental emissions, require replacement (also included in HOMER), and noise pollution. As referred to earlier, fuel was assumed to cost $.83/liter. A 6 kVA generator (among others) was found amongst local prices in Accra in order to determine cost/watt ($.23/W) for the generator [Google Trader]. The consumption loading remained consistent with the first HOMER scenario. Figure 14 demonstrates how there would be a six month payback (as compared to the PV-only 9 month payback) and also a $16,669 initial capital investment, contrasting with the $32,880 initial capital investment for the first scenario. In this case, total fuel costs would approximate $213/year and only 5 batteries would be needed (10 are used in scenario 1). Cost of energy is $.631/kWh. In terms of emissions, 676 kg of CO_2/year would be predicted to enter the atmosphere, along with 2 kg of CO/year, and 15 kg of NOx/year. If capital raising efforts can bring in the amount needed for the hybrid system but not for the PV-only system, then this is one method to bringing an energy source to the community.

kW	Capital Cost	Total Net Present Cost	Total cost per watt	PV production/year (kWh/year)	Excess electricity (kWh/year)	Total annual cost	Scenario		
2.5	16669	22902	9.1608	2908	451	1304	1D		
	Operating Cost/year								
	488								
Internet Connection Monthly Cost (24GB)	Yearly Cost (GHS)	Yearly Cost $	Yearly Salaried Phone Charger Emp	Yearly Salaried Internet Café Emp	Yearly Salaried Accountant Emp				
240	2880	1492.227979	$1,000	$1,800	$3,000				
								$ Assuming 75% of Capacity Being Used	
Internet Café Price (GHS per hour)	Number of Computers	# Hours Available Weekday	# Hours Available Per Weekend Day	Total # Hours available	Revenue Per Week (GHS)	Revenue Per Year (	RPY in $		
2	5	3	7	29	290	15080	7813.47	5860.103627	
Charging Phone Price (GHS)	# Sockets Used	# Hours of Charging Per Day	Revenue Per Day (avg. 2hrs per phone)	Revenue Per Year			RPY in $		
5	15	13	487.5	177937.5			92195.6	69146.69689	
Paying Off Total Costs In First Year (NPC used instead of capital cost):	Total Revenue for First Yr		Interest Rate (more conservative):	Payback Timeline (Months):					
$30,194	75006.80052		0.19	6					
			Total Costs Plus Interest:						
USD	GHS		$35,931.13						

Figure 14: Costs and revenues for a 6 month payback period on a PV-generator hybrid.

Being that the base scenario, either with or without generator, emphasizes a revenue stream for further capital investment in the future, a multitude of combinations of new loads could be configured. Based on the updated priorities set by the community, a new system could be added to the school roof to allow for more loads and also distributed to power lights at other homes. The distribution of power relies on the power lines that have already been installed by the community. Since information on the wiring is unknown at the time of this report, an assessment would have to be made a later time to see whether any additional infrastructure would need to be constructed or if the infrastructure was ready. One example of a future system could be 5 additional computers, 14 lights, allocation for an additional 15 cell phone chargers, and a television. It is important to note that the baseline 5kW scenario will most likely cover the sole south-facing mounting plane roof. As a result, a west orientation at the same roof pitch was inputted into HOMER to accurately predict annual kWh production. HOMER simulated the most cost-efficient system to be based off of a 7.5kW PV system, (24) Hoppecke 20 OPzS 2500 batteries, a 4.2kW inverter and 13.5 kWh/day of loading. This yielded a $67,620 initial capital cost, $82,301 total net present cost, and $1.307/kWh cost of energy.

The Four Lenses of Sustainability

Financial

No doubt there are many benefits to rural electrification. Education and economic enterprise can be extended beyond daylight hours. New and more reliable business can be conducted through enhanced cell phone communication.

Potential payment schemes with the current baseline scenario will be fairly easy to delegate. The revenue generated from internet cafe and cell phone charging are projected to have a short payback period and will be able to cover the hiring an accountant and monitors for the internet cafe and cell phone charging hub. The project team can hire qualified people for these positions. The accountant will collect revenue from electrical services, pay back loans, pay salaries, and coordinate with the project team on future expansion of the system. Additional loads will need to be prioritized and the team will have to maintain equitable access to energy. They will meet with company that installed the system to see what additional system elements (panels, gas generators, batteries) will need to be installed and at what cost. Revenue less expenses should be saved for this purpose.

Power can be extended to residential areas, however, equitable access should be a high priority. The upfront costs just to wire a home could mean that some won't be able to connect to energy even if their neighbor has it. There are two methods of payments for these kind of situations: meters or pay-as-you-go. Meters would be required if the proposed system is going to be connected to homes/compounds. Fundraising will be required to insure all families have access.

Some pay-as-you-go solar microgrid companies are:

- Simpa: simpanetworks.com
- Shared Solar: sharedsolar.org
- Azuri / Indigo: www.azuri-technologies.com
- Echelon: microgrids-india-south-africa.htm
- Angaza: www.angazadesign.com

These companies are able to extend the upfront costs of installing a single home-sized solar array payments. Users gain access to electricity from the system by making a payment by cell phone that is linked to a personal bank account. Feasibly these companies may not operate in Ghana yet and villagers may or may not have personal bank accounts, but it would be unwise to rule out this option. It allows the community system to avoid the technical problems grid extension experience. ·

EG's analysis shows that the number of enterprises grows as a result of electrification and that these enterprises operate for more hours.Therefore, a positive impact on household income accrues. Project design options that have been uncommon would enhance project benefits include financing schemes for connection charges, consumer education, and support for productive uses.

Technical

While many technical aspects of the project have been covered in the methodology section, there are still others to be discussed. The actual installation of a photovoltaic system would require someone or a whole installation crew with experience in the field. The community previously contributed in the construction of the school building and so it may be possible for the community again to help build the project alongside a solar contractor. When performing a roof- mount, structural integrity of the roof has to be confirmed and the mounting hardware has to be properly attached to the roof. There are two forces that a proper installation can battle back against: the wind uplift pulling the modules up and the weight of the modules and mounting hardware pulling down into the roof. An evaluation of construction drawings (and a validation that the installation matches the drawings) could determine the assumed suitability of the roof for solar.

On the electrical side of the installation, the wiring and hardware have to be properly sized and connected. The gauge of wire has to be calculated so that it can handle the short-circuit current (dependant on the number strings of modules in series and the rating of the modules used) that would flow through. The connections from modules to wiring to charge controller to batteries to inverter to AC tie-in and possibly to generator have to be firmly set to avoid short circuits and wear on the wiring.

If the community does eventually get to a distributed power generation setup, there will be further challenges to contend with. There will need to be some type of mini-utility created (as long as the Electrical Corporation of Ghana utility doesn't become involved) to manage the wiring from the generation center to the compounds. Balancing the voltage could be a project in itself and appropriately separating out the power would be a new difficulty.

Environmental

While the potential diesel generator emissions were covered in the methodology section, there are several other environmental facets that need to be taken into consideration. A lead acid battery is composed of lead/lead compounds and sulfuric acid - lead is possibly a carcinogen and can cause other health problems [Quansah, David A]. The sulfuric acid can lead to acid rain and damage the soil (especially important for a rural society). Over the lifetime of a photovoltaic system, there will be battery replacements and old batteries will need to be disposed of properly. Failing to do so could become problematic for the environment as well as to humans.

If a diesel generator was implemented, the fuel source, emissions and the disposal have to be considered. Having a fossil-fuel based source of energy brings with it many issues. Obtaining diesel fuel adds to the demand (although one relatively small generator does not have a great effect on fossil-fuel demand, it continues on the cycle of dependancy). Emissions were discussed previously in the methodology section. As many scientists believe CO_2 emissions have an effect on global climate change, adding a generator to the equation brings additional probability of future harsh weather conditions that could especially affect a rural/agrarian community. Disposal is another challenge with diesel generators. It would be extremely difficult to find a plant that would be able to recycle a small-sized generator and so the end of its lifecycle would carry a difficult disposal question.

Social

It is expected that there will be multiple social benefits to Otwetiri with the installation of solar, and it was social considerations motivated Dr. Gbedema to request the development an energy plan. As discussed, educational opportunities are projected to be greatly expanded. With access to computers, students can gain valuable technical skills for future employment and education. They will also be equipped with access to extensive information and communications via the internet. Additionally, lighting would facilitate evening classes for both children and adults and provide the option of a community gathering space. With electricity, the technical educational gap between Otwetiri and surrounding urban areas will decrease.

Additionally, farmers may benefit from having more dependable charging. More regular cell phone access will allow for discussions between farmer, and potentially allow markets to be accessed. Having internet and phone charging in Otwetiri may also increase traffic in the town on market days, thus further benefiting farmers and other vendors. Additionally, employment opportunities outside of farming may develop with the introduction of the internet cafe and potentially business development if the solar project is eventually scaled to support shops.

Previous studies have shown varying social results from micro grid installations regarding business opportunity and social roles. Education, however, has consistently displayed improvements with solar installations. See sector paper 2 for case studies related the social impact of rural electrification in Ghana.

Results and Recommendations

Suggested Next Steps

Based on our feasibility study and analysis we suggest that the 5 kW energy scenario with a 9 month payback period is a "go". The community is very enthusiastic about receiving electricity and the model we have suggested would provide beneficial business and educational opportunities. The revenues from cell phone charging and computer use would pay back the net present costs of $39,461 (plus additional costs and interest) within a reasonable amount of time to be attractive to investors and community members.

These upfront costs, however, are limiting to the community of Otwetiri. It is likely that some of the costs can be relieved by fundraising efforts. Dr. Gbedema remains engaged in fundraising efforts within Davis California, and his efforts have been met with great success in the past, resulting in the new school building. We also suggest, that the Otwetiri actively looks for assistance from grants and investment. Organizations that may be of assistance include KIVA, National Collegiate Inventors and Innovators Alliance (NCIIA), and Access2Innovation. KIVA provides small loans to community members and will not cover the expense of solar installation. However, KIVA could be of assistance with business costs in the internet cafe for needs such as internet infrastructure, power strips, and parts of the solar installation such as batteries. The loans KIVA provides average $403.98 (www.KIVA.org). NCIIA provides up to $50,000 worth of grants for sustainable technologies and business development at the highest level of funding, but it is highly competitive. They also provide $5,000 grants for sustainable technology solutions (www.nciia.org). Davis is a participating institution with NCIIA, and therefore, it would be possible to apply with the partnership of faculty and students. Access2Innovation is a Danish organization which bridges connections between NGOs, universities, and businesses to formulate sustainable energy solutions. Contributions can be as large as $40,000 and Access2Innovation is interested in market solutions to renewable energy demands. In order to apply, communication would need to be made with a Danish company or organization (www.access2innovation.com).Seeking assistance from organizations such as these and fundraising efforts would help with solar installation costs and allow for the feasibility of a solar microgrid system in Otwetiri in order to address their energy needs for increased educational opportunities and cell phone charging, with the potential to scale up in the future.

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Energy Sub-Sector - Diesel Generators

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Appendix 1 - Annotated Bibliographies

Solar Energy

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Brandt, Dana. "The Future of Community Scale Renewable Energy." *Homepower.com*. N.p., 2006. Web. 11 Feb. 2013. <http://www.homepower.com/article/?file=HP109_pg48_Brandt>.

This article describes the set up of an AC solar photovoltaic system built on the roof of a school in Uganda. The PV array "micro-grid" produces 3,600 watts. I actually got this source from Megan who is doing a paper on the current energy provisions in Ghana. Reading through it, this article seems like a comparable system for what may be good for the Otwetiri Project. With an AC coupled system you can fit in multiple sources of energy production instead of having everything based off a DC system. This may be ideal since it seems like the community is expecting to run other things off of this source beyond the needs of the school. Since they are not connected to the grid having multiple options could compensate for lack of sun or other issues.

Essandoh Yeddu, J. (1997). "Current solar energy utilization in Ghana." Renewable Energy 10(2-3): 433-436.

This paper was produced by the Ghanaian government back in 1997 describing why people were starting to look at solar PV as a viable energy solution. The author sets forth the limitations up to that point namely the high cost of installation at the time and the lack of government support. At the time there was no governmental entity handling renewable energy; there was only the Department of Mines and Energy. Also, at the time there were no incentives to entice companies to start solar projects in the country. It is neat to see that since the publication of this paper there have been major proposed solar projects due to rectifying these setbacks.

Evers, G. Y. O and H. D. (2010). "Impacts of Public Solar PV Electrification on Rural Micro-Enterprises: The Case of Ghana." *Energy for Sustainable Development* **14**(3): 223-231.

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McGrath, Matt. "Ghana Solar Energy Plant Set to Be Africa's Largest." *BBC News*. BBC, 12 Apr. 2012. Web. 10 Feb. 2013. <http://www.bbc.co.uk/news/science-environment-20583663>.

This is an article about a very large project in the works. Thanks to Ghana's renewable energy law, incentives like the Feed-In Tariff bring in companies willing to seriously investing into solar PV in countries like Ghana. The tariff system insures prices that reflect the cost of installation. Wind projects receive price contracts commensurate with the relatively cheap start up costs. Solar still being high cost initially receive a high guaranteed price that continues to "ratchet" accordingly for the duration of the contract.

Seissler, Matt. "Feasibility of Renewable Energy." D-Lab, Davis. 14 Feb. 2013. Lecture.

Nassen, J., et al. (2002). "Distributed power generation versus grid extension: An assessment of solar photovoltaics for rural electrification in Northern Ghana." Progress in Photovoltaics 10(7): 495-510.

This paper points out the failures of large grid systems. The length of the power lines away from the "power plant" constitutes the majority of costs and power failures making them. This paper makes the case for micro-grid or more autonomous energy applications for rural electrification.

s.r.o., S. G. S. (2011). Solar Radiation Map: Global Horizontal Irradiation for Africa and Middle East. GIS. http://solargis.info/free-solar-maps. 663 KB.

This source gives important information about the capacity for solar photovolatics by region. I used this resource in particular, but there is much to be found in the way of logistics that will help me understand perhaps why, along with incentives, solar PV is appropriate for sub-Saharan Africa.

The Context of Energy and Microgrids in Ghana

Bank, T. W. (2007). "Technical and Economic Assessment of Off-grid, Mini-grid, and Grid Electrification Technologies." E. S. M. A. Program. Washington D.C. , The World Bank.

This report provides a comprehensive evaluation of diverse alternatives for burning biofuels. Off-grid, mini-grid, and grid systems are examined within the context of use in developing countries. Economic feasibility and power generating capacity of diverse systems ranging from bio-gas, battery power, generator power, geothermal, solar, and coal were analyzed. Additionally, future expectations for technology and fuels costs are addressed, and the efficiency of systems is described depending on the scale of application. Long term sustainability will be an important consideration for the system installed in Otwetiri. Information on alternatives to solar, also provides context for alternatives or combinations to consider while looking to power Otwetiri.

Boon, S. K. and E. K. (2009). "Energy Delivery and Utilization for Rural Development: Lessons from Northern Ghana." *Energy for Sustainable Development* **13**(3): 212-218.

This article provides a site specific example of the how energy is being distributed in Ghana, infrastructure, and governmental involvement. Additionally, it examines energy use patterns in in different electrified and non-electrified systems. Importantly, the article discusses the correlation of energy introduction with increased educational and job creation opportunities. Relating to the Otwetiri Project, the article addresses the social context of energy projects, will help us understand how energy is allotted in daily living, and provides support for Tometi's thinking that solar can increase educational opportunities and provide opportunity for local business.

Brandt, Dana. (2005). "AC Mini-Grids: The Future of Communityscale Renewable Energy." *Home Power* **109**: 48–54.

This article explains the application of mini-grids inclusive of a detailed description of a recent project in Uganda. The project includes the use of a mini grid system to power a school, similar to the Otwetiri project. Additionally, a benefit of this system, as described in the paper, is that it can easily be expanded and scaled up. This would be important in Otwetiri since the energy needs are diverse, and business may expand because the town is a center for marketing produce and for education. Additionally, the micro grid system can be connected to utility grids at any point, which is relevant as utility access spreads in Ghana. The needs of the community involved in this project are similar to Otwetiri, and many technical methods described in this article seem applicable.

Eberhard, A., Orvika Rosnes, Maria Shkaratan, Haakon Vennemo (2011). *Africa's Power Infrastructure.* Washington, D.C., The World Bank.

The first chapter of this book, published by the World Bank, is particularly helpful for understanding the current energy situation in Africa and the services people are currently paying for. Additionally, the unreliable energy supply can be costly to many businesses as they lose operating hours during outages and emphasizes provides information on less favorable aspects of generators. Additionally, other energy sources such as hydropower in Ghana are discussed and the environmental context of problems concerning drought and conflict are mentioned. This helps justify solar as an energy option, as it is immune to governmental and climactic instabilities when installed on the local scale and is said to be more reliable.

Evers, G. Y. O and H. D. (2010). "Impacts of Public Solar PV Electrification on Rural Micro-Enterprises: The Case of Ghana." *Energy for Sustainable Development* **14**(3): 223-231.

This reading provides an example of solar as a contributor to the success of local small businesses and thus local economies. The study shows an increase of sales after sunset, in groceries, specifically. This is particularly relevant to the project, as Tometi mentioned that Otwetiri is the center of food sales for the surrounding community on market days. Savings from solar would allow local vegetable salesmen to extend their sales time and receive a higher profit. It would also allow more people more time to access the market. Additionally, the article mentions that creating micro-enterprises makes it more likely that maintenance of solar can be afforded by the owners of solar panels, and solar becomes more sustainable. This may be important in Otwetiri when planning a solar system with the potential to be utilized by local businesses or expanded in the future.

Fath, H. E. S. (1998). "Technical Assessment of Solar Thermal Energy Storage Technologies" *Renewable Energy* **14**(1-4): 35-40.

Energy storage is a concern in solar systems, as energy can only be harvested from the sun during daylight hours. In this article, Fath describes the advantages and disadvantages of various solar storage systems. This is an important consideration when thinking about appropriate solar system installations for Otwetiri School. Additionally, the technical process of energy storage is described, which is helpful to becoming familiarized with solar.

Obeng, George Y., H.-D. E., F.O. Akuffo, I. Braimah, A. Brew-Hammond (2008). "Solar Photovoltaic Electrification and Rural Energy-Poverty in Ghana." *Energy for Sustainable Development* **12**(1): 43-54.

This survey, which is specific to Ghana, surveyed households in order to assess what was described as an Energy Poverty Index Score. As described in the article, important variables included monthly savings in lighting, the amount paid to obtain the electricity system, and the number of children who can sit around lighting. The study concluded that investing in more reliability and quality in energy sources can help improve quality of life related to social, economic, and environmental factors. This allows for an examination of the economic feasibility of solar on a household level, and will be helpful with communicating long term benefits. Additionally, the article is helpful for understanding the social benefits of solar.

Energy Sub-Sector - Diesel Generators

Bawakyillenuo, S. (2012). Deconstructing the dichotomies of solar photovoltaic (PV) dissemination trajectories in Ghana, Kenya and Zimbabwe from the 1960s to 2007. Energy Policy, 49, 410–421. doi:10.1016/j.enpol.2012.06.042

The author contrasts Ghana's relatively low photovoltaic installation numbers with the higher numbers for Kenya and Zimbabwe. The author addresses Social Construction of Technology Theory as a hypothesis as to why Ghana has lagged behind in solar. This theory draws on the complexity of social interactions and how different social groups exist that interpret technologies different and decide which technological issues need to be addressed. Economic growth was overall more stable for Kenya and Zimbabwe between the 1960s and 2007. Also, much stronger PV investment was done in Kenya and Zimbabwe. With regards to governmental policy, proportionately, solar generation was on even footing with grid-delivered electricity in Kenya and Zimbabwe while Ghana had much higher absolute and proportional leveles of rural electrification through the grid. The Ghanaian government also incentives grid use through tariffs and imposes duties on PV components. Demand for solar in Ghana increased in the late 90s due to a power crisis in the grid-connected areas, however, it lessened once grid-delivered electricity became stable again. Another significant difference between Kenya and Zimbabwe and Ghana was in the varying solar panel wattages. Kenya and Zimbabwe had more of a range to work with to give more financial flexibility while Ghana panels mainly were on the high-wattage end, intended more for the affluent.

Brass, J. N., Carley, S., MacLean, L. M., & Baldwin, E. (2012). Power for Development: A Review of Distributed Generation Projects in the Developing World. Annual Review of Environment and Resources, 37(1), 107–136. doi:10.1146/annurev-environ-051112-111930

The authors discuss the transition from centralized power generation to distributed, local generation in the developing world. A microgrid consists of two or distributed generation (DG) units, transmitting via low voltage lines. Besides pollution, diesel generators also have noise, high fuel costs, and lack of consistent fuel sources. DG is commonly done in areas where grid extension is prohibitively expensive. The authors discuss 60 case studies to see how DG failed or succeeded based on on-the-ground results/experience. Discrepancies were found between similar situations (e.g. one study found solar to average out as cheaper than using kerosene for lighting while another study contradicted this but stated better quality lighting with PV). The authors were surprised to find many of the case studies did not discuss environmental results from DGs (as well as educational and health-related results). The big hurdle of financing initial capital costs most often came from loans and donor funds. The authors found that it was critical for the end users to be involved in the planning, finances and multiple stages of the DG installation and maintenance. The authors' summary showed the great variance across projects: some were sustainable for years, some were only checked on after a few years, and some failed (not maintained) within a few years.

Essandoh-Yeddu, J. (1997). Current solar energy utilization in Ghana. Renewable energy, 10(213), 433–436. Retrieved from http://www.eng.stu.edu.cn/interior/Attachments/2010-3-5-18-7-50-671-%E9%99%84%E4%BB%B6%E4%B8%80.pdf

The author discusses the increased demand so solar power generation as a result of an energy shortage, partially caused by draught. About 30 solar thermal systems had been installed by about 1996. Solar electric production had mainly been used by large commercial companies. About 700 PV systems had been installed in Ghana by 1994. A smattering of solar cookers had been tested. The author listed several deterrents to solar: high duties on solar products, lack of credit systems, no installation codes, domestic energy consumers that exclude the solar generators got tariffs, and the government/utilities were not involved in solar.

Lemaire, X. (2011). Off-grid electrification with solar home systems: The experience of a fee-for-service concession in South Africa. Energy for Sustainable Development, 15(3), 277–283. doi:10.1016/j.esd.2011.07.005

Author discusses the decline over time of PV systems that were donated and proposes using microcredit or creating utilities with a fee-for-service model in order to yield sustainable solar systems. South Africa had a particular fee-for-service plan that it experimented with. In the fee-for-service setup, a small utility is formed that receives a loan from the government so that they can provide a relatively cheap installation while charging a monthly fee for electricity use. In the microcredit system, there are maintenance companies and financing companies that work together. In both of these, electricity is disseminated to many homes. Fee-for-service is more commonly done in the rural areas that don't have access to bank institutions. For the South African program, it was much cheaper to install PV on a home in a remote area, rather than extending the grid to that area. While there were subsidies for this program, economies of scale brought the PV installation costs down relative to other African countries. The maintenance of the systems was very centralized (making it slow and challenging). Smaller scale setups have the advantage of more at-home maintenance checkups. Larger scale setups have the advantage of reaching better economies of scale.

Nassen, J., Evertsson, J., & Andersson, B. a. (2002). Distributed power generation versus grid extension: an assessment of solar photovoltaics for rural electrification in Northern Ghana. Progress in Photovoltaics: Research and Applications, 10(7), 495–510. doi:10.1002/pip.439

The authors compare the longterm costs of PV generation in rural northern Ghana to extending the electrical grid.They found that for demand of less than 140W (used for lighting, entertainment, and public facilities, PV generation was cheaper. Battery maintenance constitutes a major part of the PV generation cost. The authors use a life-cycle cost model to assess the two competing power distributions. Household consumption/demand played a major role in determining the costs (due to scaling of a potential PV system). With greater energy demands, the PV system cost/W needs to decrease to a certain point in order for PV generation to make financial sense (vs grid extension). Less dense areas make it more expensive for grid extensions while having no effect on PV generation costs. The cost of low-voltage microgrids within the communities majorly affects the overall cost of grid extension.

Obeng, G. Y., & Evers, H.-D. (2010). Impacts of public solar PV electrification on rural micro-enterprises: The case of Ghana. Energy for Sustainable Development, 14(3), 223–231. doi:10.1016/j.esd.2010.07.005

The authors studied the fee-for-service method used by micro-enterprises to obtain PV energy. The authors do a cost-benefit analysis comparing the added benefit from electrification vs the cost associated with it (the alternative being no significant electrification). Micro-enterprises generally had under six employees. The authors tested whether increased hours of lighting affected the income of these businesses. Many businesses used a combination of PV and kerosen due to fluctuations in irradiance. The study found that there was an increase in income for PV-lighted businesses.

Appendix 2: Additional Tables

Load Consumption Tables for different scenarios:

	Item	W	kW	# of units	kW	Daily kWh	Hour Of the Day	Computer	Lighting (Incandescent)	Outlets				Hourly kWh
										Cell Phone Charging	TV	Other (DVD/Radio)	Refrigerator	
	Desktop Computers (running)	200	0.2	5	1	7	12:00 AM							0
	Desktop Computers (sleeping)	4	0.004	0	0	0	1:00 AM							0
							2:00 AM							0
	Cellphone Charging	4	0.004	15	0.06	0.78	3:00 AM							0
							4:00 AM							0
							5:00 AM							0
Scenario 1c							6:00 AM							0
							7:00 AM			0.06				0.06
	Total:					7.78	8:00 AM			0.06				0.06
							9:00 AM			0.06				0.06
							10:00 AM			0.06				0.06
							11:00 AM			0.06				0.06
							12:00 PM	1		0.06				1.06
							1:00 PM	1		0.06				1.06
							2:00 PM	1		0.06				1.06
							3:00 PM	1		0.06				1.06
							4:00 PM	1		0.06				1.06
							5:00 PM	1		0.06				1.06
							6:00 PM	1		0.06				1.06
							7:00 PM			0.06				0.06
							8:00 PM							0
							9:00 PM							0
							10:00 PM							0
							11:00 PM							0
													Total kWh/da	7.78

Load consumption schedule for Scenario 1C, base 5kW PV system.

	Item	W	kW	# of units	kW	Daily kWh	Hour Of the Day	Computer	Lighting (Incandescent)	Outlets				Hourly kWh
										Cell Phone Charging	TV	Other (DVD/Radio)	Refrigerator	
Scenario 1b (potential additional system to be built after scenario 1c)	Desktop Computers (running)	200	0.2	5	1	7	12:00 AM							0
	Desktop Computers (sleeping)	4	0.004	0	0	0	1:00 AM							0
	Lighting (Incandescent)	40	0.04	14	0.56	4.48	2:00 AM							0
	Cellphone Charging	4	0.004	15	0.06	0.78	3:00 AM							0
	TV	300	0.3	1	0.3	1.2	4:00 AM							0
							5:00 AM							0
							6:00 AM		0.56					0.56
							7:00 AM		0.56	0.06				0.62
	Total:					13.46	8:00 AM		0.56	0.06				0.62
							9:00 AM			0.06				0.06
							10:00 AM			0.06				0.06
							11:00 AM			0.06				0.06
							12:00 PM	1		0.06				1.06
							1:00 PM	1		0.06				1.06
							2:00 PM	1		0.06				1.06
							3:00 PM	1		0.06				1.06
							4:00 PM	1		0.06	0.3			1.36
							5:00 PM	1	0.56	0.06	0.3			1.92
							6:00 PM	1	0.56	0.06	0.3			1.92
							7:00 PM		0.56	0.06	0.3			0.92
							8:00 PM		0.56					0.56
							9:00 PM		0.56					0.56
							10:00 PM							0
							11:00 PM							0

Load consumption schedule for Scenario 1b, additional 7.5kW PV system as possible future next steps.