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Meeting the electricity demand with a decentralized autonomous solar PV system using HOMER PRO. A Case Study of NyongYapalsi, Karaga District, Northern Region, Ghana

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ABSTRACT: Remote communities, off-grid communities rarely have access to electricity. Renewable energy, solar PV presents an opportunity to provide power to rural dwellers. Hybrid Optimization for Multiple Energy Renewable (HOMER) computer software used in this paper provided the technical and economics of modeling an autonomous solar PV. The system comprised of 11.4 kW converter, 24.4 kW PV array and 156 acid lead batteries. The electricity generated by the system has a yearly surplus of 46.5% of the annual 53211kWh with an insignificant unmet load. The cost of energy of the proposed design was $ 0.480/kWh, with the total net present cost of $ 119,479.00. Sensitivity analysis of free solar panels projects reduced the COE and NPC by approximately 31%. Reduced discount, inflation, component cost impact on the COE ($ 0.331/kWh) is similar to the free PV panel project effect on system cost.
KEYWORDS: Autonomous, Sensitivity, Renewable, Solar PV, Remote community

I. INTRODUCTION

The world is injecting a considerable amount of investment in renewable energy resources conversion technologies. The trend is driven by the continuous changes in the climate resulting in global warming[1]. In recent years, many efforts made to increase the implementation of renewable sources of energy through researches and application is promising. The drive is not only in the developed countries but also in thedeveloping countries. Sufficient and secure energy is the leading enabler for welfare and economic development of society. As energy-related activities have significant environmental impacts, it is indispensable to provide an energy system which covers the needs of the economies and preserves the environment.Access to energy is cardinal to the achievement of the sustainable development goals (SDGs) 2030[2]. Although the government of Ghana has made huge investment in the energy sector, the reliable energy supply is challenge[3].

According to Ghana's Renewable Energy Master Plan (2019), there are several potentials, both technical and non-technical, with some challenges for renewable energy implementation similar to most developing countries in Africa[4].The Northern Region is one of the sixteen regions of Ghana. It was the largest of the ten regions, covering an area of 70,384 km^2 or 31% of Ghana's area until December 2018 when the Savannah Region and North East Regions were carved from it. It is divided into 14 districts with the regional capital being Tamale[5]. The vegetation consists predominantly of grassland, with clusters of drought-resistant trees such as baobabs or acacias[6]. The wet season is between about July and December with an average annual rainfall of 750 to 1050 mm (30 to 40 inches). The highest temperatures reached at the end of the dry season, the lowest temperature in December and January. However, the hot harmattan windfrom the Sahara blows frequently between December and the beginning of February. The temperatures can vary between 14 °C (59 °F) at night and 40 °C (104 °F) during the day[5].

Ghana has a significantly high electricity access rate in the sub-Saharan region. The National Electrification Scheme (NES) started in 1989 with the principal objective of increasing the grid electricity access rate to 100% by 2020. Although the target has not been met, a significant portion of the country is connected to the grid network. An estimated electricity access rate of 82.5% as of 2016 achieved, an improvement from the 15% access rate when the NES initiated in 1990. Other pragmatic programs, such as the Self-Help Electrification Program (SHEP) promoted the milestone[7]. NyongYapalsicommunity is among the few not connected to the national gridowing to proximity to grid lines. Illumination at night is achieved with dry cell, kerosene and solar lamps. Inhabitants of the community travel about 25 km to the nearest grid-connected communities for mobile phone charging.

NyongYapalsi is a predominantly farming community in the Karaga District of Ghana, Northern Region and 70 km away from the regional capital. According to the 2010 population and housing census, the population of the district stands at 77,706 with 37,336 males and 40,370 females[8].The settlement started like most communities, as farming landand the farmers stayed to form the community. Most of the inhabitants are from Nyong the mother community. Yapalsi means new homes, NyongYapalsi means news homes of Nyong. The village has 38 mud houses with 114 households, a mosque and primary school with minimal economic activities. They earn their income mostly from the sale of farm commodities at the end of farming season. The farming season occurs once a year between May and December. The farmers depend on rain feed crop cultivation (maize, rice, beans, etc)and free-range animal rearing (sheep, goats, poultry and cattle). Crop cultivation is semi-mechanized in this area with tractors and harvesters.

Life in the community comes to a standstill at dusk due to lack of electricity. Owing to this, none of the primary school teachers live in the community. School hours are used by teachers in commuting from their homes in nearby communities to NyongYapalsi. School contact hours is reduced and pupils cannot engage in preparatory studies at night as their colleagues. Access to potable water in the dry season is a major challenge as the only dam in the village dries up. Product hours are used in search of water.Groundwater is an alternative source of potable water which could be explored[9]. Access to electricity could address this plight of the inhabitants via electric water pumps and even present new opportunities such as irrigation farming in the dry season.

Energy system modelling offers helpful insights for exploring the potential use of renewable energy technologies[10]. Several software tools have been adopted by various authors to model and design renewable energy systems in different countries around the world. Hybrid Optimization of Multiple Energy Resource Professional (HOMER Pro) and Retscreen have been used by[11]–[15]. HOMER has used in modelling of optimal systems for rural electrification. In the Island of Gilutongan, Philippines, solar PV with a diesel generator as hybrid showed a reduced cost of energy[16]. Furthermore, rural electrification simulation studies have been conducted in Nigeria [17], [18]. These studies confirmed the technical potential of renewables in the electrification of off-grid or rural communities.

Renewable power solutions present an opportunity for rural dwellers to electrification in the shortest possible time. The high cost of grid extension to remote communities and the difficulty in revenue collection are addressed with renewable energy technologies. The renewable energy act 2011(act 832) seeks to promote clean energy in the country's energy mix. The national energy policy plan proposed 10% of renewables in the energy mix[19].Government’s commitment to achieving in electrification with solar PV technology is a step in the right direction. The free rooftop solar PV panel for residential buildings projects with the primary objective of providing 200MW peak load relief in the medium term offers an opportunity to reduce the cost of electricity form the technology[20].

The study investigated the feasibility and the cost of energy (COE) for an autonomous solar PV system to power NyongYapalsi. The system intended to provide illumination, phone charging and some form of entertainment to residents. The objective is achieved via the specific aim to determine electricity load profile of the community, cost of components for the system and economic constraints. A sensitivity analysis of the impact of the free solar PV panel project of the Energy Commission on the COE of the system. The findings of the paper provided information to promote the use of renewables to meet the energy needs of remote communities in the region and the country as a whole. The information would assist stakeholders, in the provision of electricity to bring about development, improved health and promote general well-being.

II. METHOD AND MATERIALS

The simulation process of the HOMER software intended to address the uncertainties associate with renewable energy sources, loads demands and input variables. It accomplishedthrough three folds of tasks, namely simulation, optimization and sensitivity analysis. Firstly, it determines whether the system is feasible and its total net present cost. It considers the system to be possible if it can adequately feed the load (electric or thermal loads) and meet any other constraints stated by a modeler. Secondly, it performs multiple simulations on different system configuration. It estimates the life-cycle cost of the system, as the total cost of installing and operating the system over its lifetime. The best possible, or optimal, system configuration is the one that satisfies the user-specified constraints at the lowest Total Net Present Cost (TNPC). Finally, it assesses the effect of uncertainties of variables which are beyond the designer's control such as system cost prices, fuel, a renewable resource, by performing several optimizations under given assumptions to assess the extent of the impact of changes in the designer's inputs[21].

The global trend of cost of a solar PV system has seen a positive declination and it’s expected to continue through to 2030 according to International Renewable Energy Agency IRENA [22].The study of

Feldman David,etal, illustrated that during 2010–2011, installed prices fell by $0.72/W (11%) for systems of 10 kW or smaller, $0.89/W (14%) for systems of 10–100 kW, and $0.77/W (14%) for systems larger than 100 kW[22]. For sensitive analysis on the cost of solar PV system components, a 10% decreasing multiplier used as prices expected to decrease. Figure 1 shows the installed cost and global module price index over time.

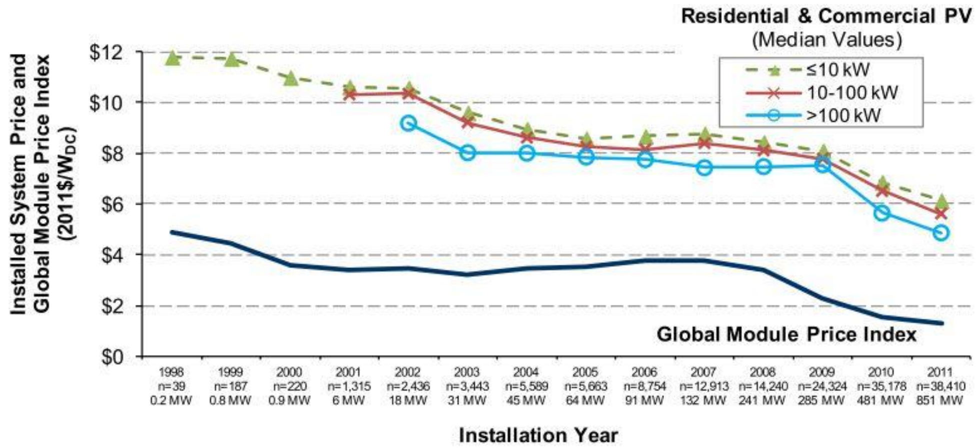

Figure 1. Installed price of residential and commercial PV systems over time[22]

2.1 Data collection

The Global Positioning System (GPS) coordinates of Nyong – Yapalsiis 9°46.601'N, 0°36.944'W.The buildingscomprised of 38 residential houses, a central mosque and primary school. A focused group discussion held with the chief, opinion leaders in the community and community members which revealed that the primary use of electricity would be for phone charging, lighting, entertainment and commercial refrigeration of water and beverages. Figure 2a and figure 2b display the study area.

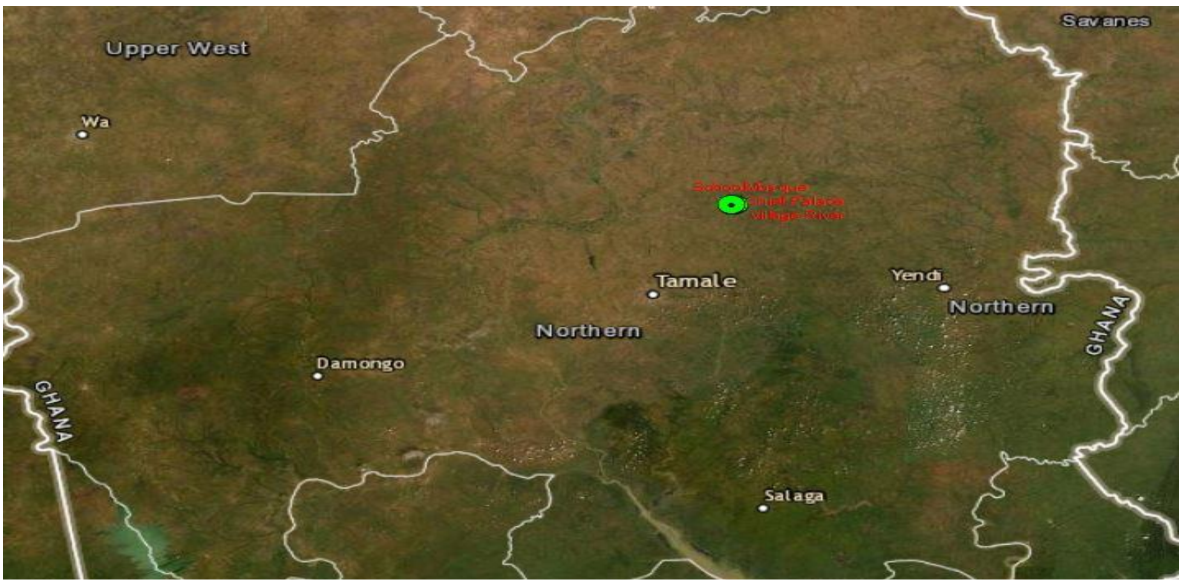

Figure 2a Map of the Northern region (Green shows village): Arc GIS

Figure 2b Map village with crucial buildings.: Arc GIS

2.2 Load Profile

Making a good load estimation is cardinal to designing the system size to meet the electricity demands of the community adequately. As aforementioned, Ghana has a significant electricity penetration rate. The few communities not connected to the national grid are usually inaccessible or expensive to extend the national grid network. The community forum provided an opportunity for chief and other opinion leaders in the community to identify the felt need of the community to be electricity. The primary use of power will be for phone charging, lighting, entertainment and commercial refrigeration of water and beverages. Table 1 below is the wattage of the expected electrical gadgets to be used in each house after the interview. Table 2 gives the detail estimation of appliance in each building to be supplied with electricity. The only provision shop in the community wanted to use a deep freezer, and the Iman (leader of Muslims) also intends to use an amplifier to call for prayers were factored.

Table 1 Power rating of gadgets

S/N	Rated power (W)
Bulbs	15
Fans	75
Television	60
Phone charging	5
Radio	5
Deep Freezer	150
PA system	600

Table 2 Estimated electrical appliance of community

S/N	Facility description	Bulbs	Fan	Television	Radio	Phone Charging
1	Residential	4	1	0	1	2
2	Residential	3	1	0	0	1
3	Residential	2	0	0	1	1
4	Residential	5	1	0	0	2
5	Residential	4	0	0	0	2
6	Residential	7	2	0	1	4
7	Residential	5	0	0	0	3
8	Residential	3	0	0	0	2

9	Residential	8	3	0	1	5
10	Residential	9	2	1	0	6
11	Residential	12	4	1	0	8
12	Residential	4	1	0	1	2
13	Residential	4	1	0	1	1
14	Residential	3	0	0	1	1
15	Residential	10	3	1	1	4
16	Residential	3	0	0	1	1
17	Residential	5	2	0	0	3
18	Residential	6	2	0	1	2
19	Residential	3	0	0	0	1
20	Residential	2	0	0	1	0
21	Residential	6	3	0	0	2
22	Residential	12	7	1	0	5
23	Residential	11	5	1	1	6
24	Residential	5	2	0	0	2
25	Residential	4	1	0	0	1
26	Residential	6	3	0	1	2
27	Residential	3	0	0	0	0
28	Residential	5	2	0	0	2
29	Residential	5	0	0	1	1
30	Residential	6	2	0	0	2
31	Residential	4	1	0	0	1
32	Residential	8	3	0	1	3
33	Residential	3	0	0	1	1
34	Residential	5	2	0	1	2
35	Residential	5	2	0	0	2
36	Residential	4	1	0	1	1
37	Residential	3	0	0	0	1
38	Residential	9	3	0	1	4
39	Mosque	6	6	0	0	0
40	School	2	1	0	0	3
41	Shop	2	1	1	1	0
	Total	**216**	**68**	**6**	**10**	**92**

2.3 Hourly load assumptions

The community is a one-season rain feed farming community usually between May to September[23]. During this period, they spend most of their time on the farm for land preparation, and harvesting of farm produces. Hourly load estimationbased on the community pattern of life and the estimates of operational gadgets of each hour. The values given may either increase or decrease dues to financial power and change of lifestyle of the community. An assumption that most room bulbs would be off by 9:00 pm and on at 4:30 am. The fans in the community mosque would be on for 15 mins for each of the 2 (Zuhr and Asr) daily prayers and for 1 hour 30 minutes with interior bulbs for the evening prayers. It would be difficult to predict the duration bulbs would be on in each house. The assumption all lamps would be on for 10 hours out of the 24 hours in a day was made. Entertainment as television and radio would work for 6 hours daily and 3 hours allocated for each phone for charging daily. The deep freezer of the shop will be on for 12 hours of the day. A tolerance margin of 10% of the total estimated load taken as provision for contingencies. The tolerance margin is assumed to be on all day. Figure 3 is the estimated load profile of the village based on the assumptions aforementioned.

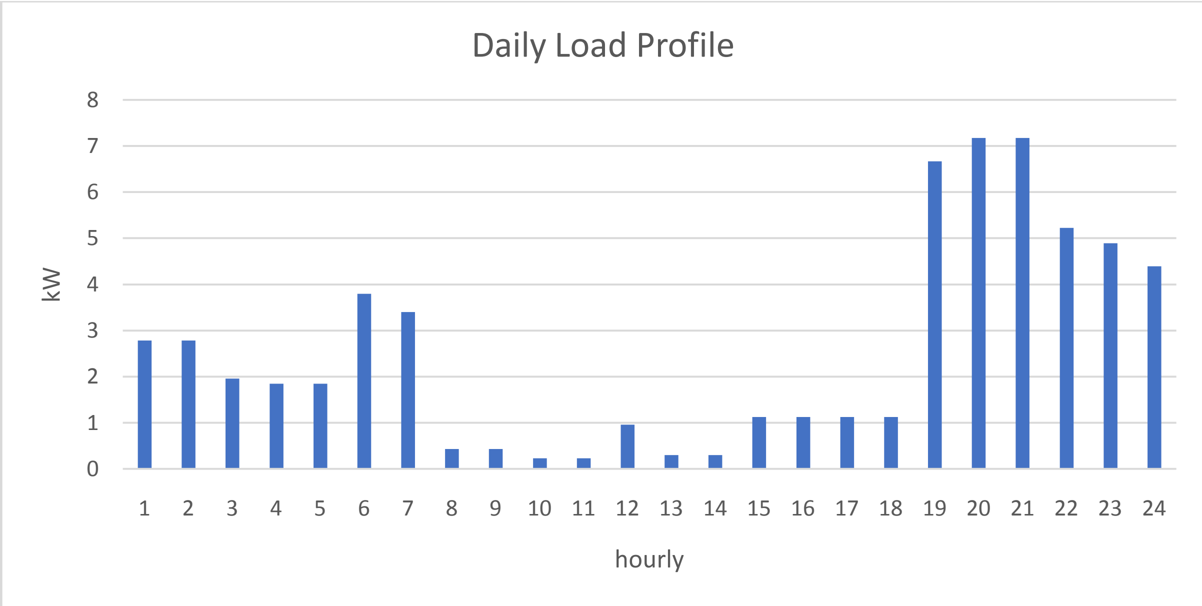

Figure 3 Daily load profile

2. 4 Solar resource assessment

Ghana's geographical location gives it good exposure to solar radiation which is ideal for both electricity and thermal energy applications. The country receives an average solar radiation of about 4-6 kWh/m^2/day and sunshine duration of 1,800 hours to 3,000 hours per annum, with the highest occurring in the northern belt. The average annual solar irradiance of 5.57 kWh/m^2/day in the region as taken from the NREL database showed that solar resource is adequate to sustain a solar PV system. Based on the data from NREL, the estimated solar energy potential of the study area is 2,033 kWh/m^2/year. The solar resource of the region displayed in Figure 4.

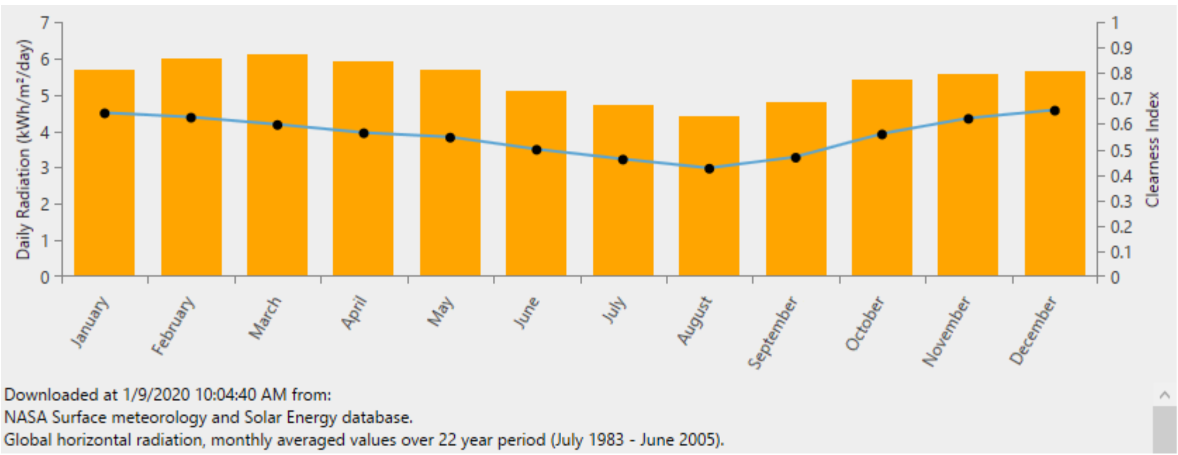

Figure 4 Solar resource of area

2.5 System components costing

In a rural setting as the study area, land ownership is by the royal family, and the settlement area is different from farmland. The land around settlement are not cultivated and can be used for the project. Land cost is therefore not factored in simulation. The system fixed capital cost in HOMER includes the capital cost of equipment, installation labor cost, replacement cost, operation and maintenance (O&M), transportation cost and auxiliary component cost. Prices may vary for the system in other parts of the country due to transportation cost, demand and supply. Decommissioning and installation cost need to factor in replacement cost. It was assumed to be the same as the initial costs. Linear cost curve was considered forthe size of the components, prices of the component increases and vice versa. Electricity extension cost from mini-grid was not an input to the simulation. Table 3 below gives a breakdown of economic data used in the configuration.

Table 3 Economic inputs

Components	Size	Capital cost (US$)	Replacement cost (US$)	O&M (US$/year)	Source
Flat plate Solar PV	250 W	160.00	160.00	5.00	[24]
Storage Battery Surrette S-260	12 V /200 Ah	420.00	420.00	5.00	[24]
System converter	10 kW (48V)	2200.00	2200.00	-	[24]

2.6 Proposed System design

The proposed solution for electricity generation for the community is a standalone decentralized solar PV mini-grid with storage batteries. The batteries will supply the load at night when the solar resource is unavailable. Figure 5 below, is the schematic of the proposed standalone system.

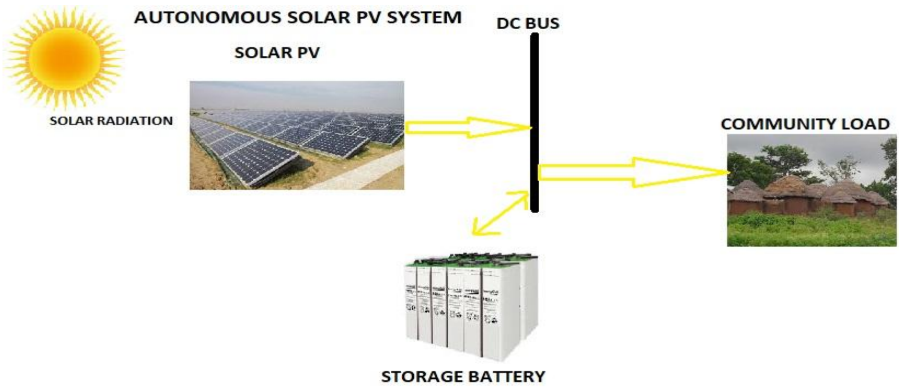

Figure 5 Schematic of standalone solar PV

III. DISCUSSION AND ANALYSIS OF RESULTS

The autonomous solar PV system comprises of 11.4 kW converter, 24.4 kW PV array and 156 acid lead batteries. Table 4 illustrates the cost summary of the system, while Figure 6 displays the bar graph of the major components of the system. The electricity generated by the system has a yearly surplus of 46.5% of the annual 53211kWh with the insignificant unmet load. Monthly average electric production illustrated in Figure 7. The hours of autonomy of the system recorded 83 with an expected battery life span of 8.62 years. Figure 8shows the boxplot of the state of charge of batteries of the system.

Table 4 Cost summary

Parameter	Value
Net present value	$ 119,479.00
Cost of Energy	$ 0.480/kWh
Operating cost	$ 4233/ yr
Initial capital cost	$ 72,324.00

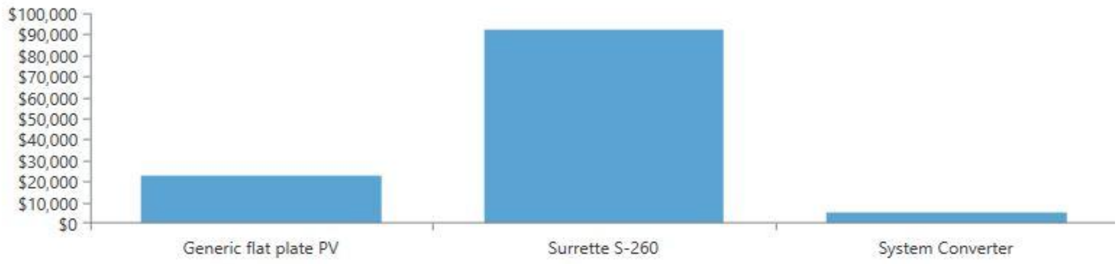

Figure 6 Contribution of the component to system cost

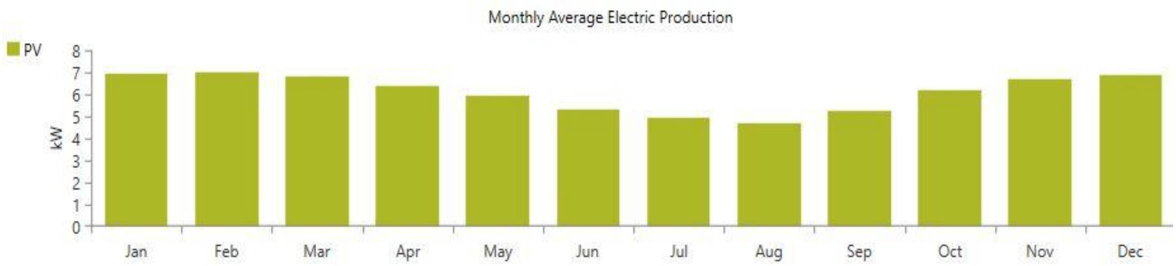

Figure 7 Monthly Average electric production

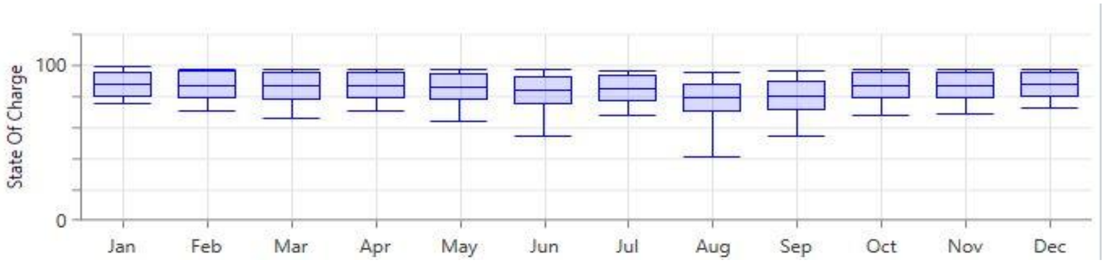

Figure 8 State of charge of batteries

3.1 Sensitivity

The sensitivity on the effect of free solar panels on the system cost illustrated in Table 5. The free solar panels project reduced the COE and NPC by approximately 31%. Reduced discount, inflation, component cost impact on the COE ($ 0.331/kWh) is similar to the free PV panel project effect. Variation in the cost of solar PV effect on COE and TNPC displayed in Figure 9.

Table 5 Effect of free panels on COE and NPC

Parameter	Cost of PV inclusive	Without PV cost
Net present value	$ 119,479.00	$ 82,166.00
Cost of Energy	$ 0.480/kWh	$ 0.330/kWh

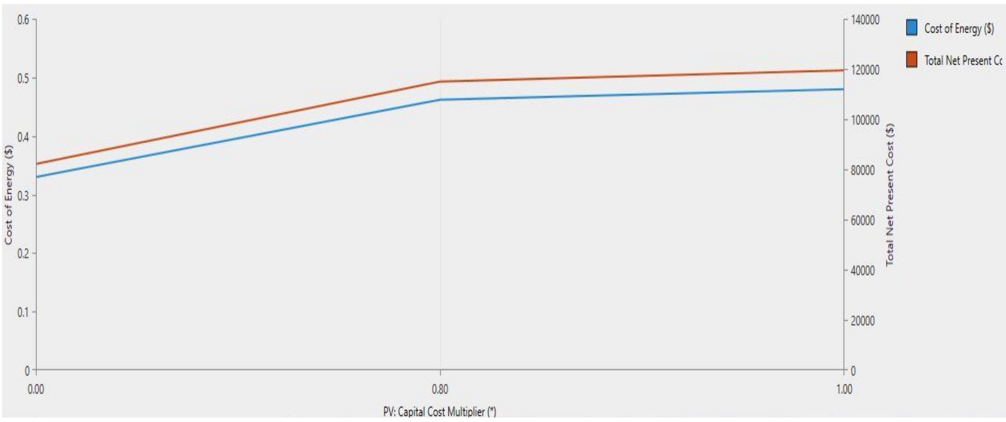

Figure 9 Variation in PV cost on COE and TNPC.

IV. CONCLUSION

The study looked at the technical viability of an autonomous solar PV system to provide electricity to a rural farming community in Northern Ghana using HOMER Pro software. Sensitivity analysis conducted to assess the behavior of economic parameters of the system. The Energy Commission 2019 outlook for Ghana averaged end-user tariff from 2013 to 2018 as US$ 0.17/kWh for grid electricity[25]. The finding of this study suggests that power from standalone solar PV is twice the COE from the national grid.Free solar PV panels installation from the governmentcould reduce the cost of energy by 31%. Considering the improvement in the quality of life, electrification brings, it's worth the investment. The excess electricity generated from the system could be used for water pumping to address potable water scarcity. With the right financial arrangement in place, the simple payback period of 7.1 years could be extended to reduce the cost of energy to competitive rates. The rooftop solar PV programme of the energy commission when adequately executed can bring clean and affordable energy to rural communities in Ghana.

V. RECOMMENDATION

The study has provided valuable information for stakeholders, governments and Non-Governmental Organizations of the potential of solar resource to meet the electricity demand of rural communities. As a farming community, further studies into the use of crop residue for electricity generation should be carried out. Currently crop and animal residue are either left in the farm or burnt openly in farmland. These crop/animal residues could be converted to electricity or heatingsource for domestic purposes. This work considered the technical variability of solar PV technology and economics. Political, environmental and social dimensions could be considered to achieve sustainability in further studies.

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