A Comparative Analysis of Renewable Energy Using Biogas and Solar Photovoltaic Systems: A Case Study of Ajaba, In Osun State

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Abstract
Renewable energy source is the energy obtained from natural and persistent flow of energy occurring in the immediate environment. Renewable energy systems are becoming widespread due to adverse environmental impacts and escalation in energy costs linked with the exercise of established energy sources. Solar and biogas are recognized as having the highest social, economic and environmental benefits of the renewable energy sources existing and also are the most feasible to use in a renewable hybrid energy system for electricity generation. This paper compares biogas and solar energy for "Ajaba" near Ila-Orangun in Osun State to know the best renewable energy source for the area. The study considers photovoltaic cells as the device for trapping and converting solar energy to electrical energy while pig dung was used to prepare the digester materials for biogas energy and bio-digesters were used to convert the digester to electrical energy through dual ac generator. The simulation was carried out using MATLAB software to calculate the output energy. The result reveals that biogas energy generated more energy and performs better as compared to the solar energy for the area. This paper forms a basic for evaluation and performance of biogas energy for rural communities.
Keywords: Renewable Energy, Biogas Energy, Solar Energy, MATLAB, Power, Photovoltaic, Bio-digester.

I. INTRODUCTION

Electricity plays a very crucial role in the economic growth of a country, and forms the backbone of a sustainable electricity supply in Nigeria. For decades, Nigeria is still facing problems of generating enough electricity to meet demand. The increase in unemployment rate in the country can be traced to the epileptic supply of electricity (Abdullah, Risdiyanto and Nandiyanto, 2017; Erbach, 2016).

Many remote communities in the country cannot be physically or economically connected to an electric power grid. The electricity demand in these areas is conventionally supplied by small isolated diesel generators. The operating costs associated with these diesel generators may be unacceptably high due to discounted fossil fuel costs together with difficulties in fuel delivery and maintenance of generators. In such situations, renewable energy sources, such as biogas generator and solar photovoltaic (PV) provide a realistic alternative to supplement engine-driven generators for electricity generation in off-grid areas (Asian Development Bank, 2015; Pradhan *et al*., 2013).

Unlike fossil and nuclear fuels, which have only finite reserves expected to last for tens to hundreds of years, renewable energy source will last over a very long timeframe. Moreover, renewable energy source generally have lower greenhouse gas emissions than fossil fuels and are therefore expected to play an important role in reaching global climate targets.

A. Renewable Energy Sources

The basic concept of renewable energy has to do with issues of sustainability, renewability and pollution reduction. Based on the balance sheet and predicted energy shortages and environmental problems, renewable energy resource management has attracted much attention in literatures. To solve this problem, there is the need to replace conventional fuels because renewable energy source provides high electrical efficiency and low environmental impact (Jurgensen, 2015; Sheriff, Goje and Zannah, 2014).

The use of renewable energy sources promotes sustainable development since it runs on infinite energy sources. Renewable energy facilities enhance the value of the overall resource base of a country by using the country's indigenous resources for electricity generation to power base stations. The evolution and utilization of renewable energy can really improve the variety in the energy supply markets and can be instrumental to gain extended period and uninterrupted sustainable energy supplies. In addition to reducing global emissions, they will also aid in providing profit-oriented possibilities to meet targeted energy demand, especially in the rural areas, besides leading to social and economic progress (Ibe, Oke and Esobinenwu, 2015; Pradhan *et al*., 2014).

Renewable energy sources offer a viable alternative to the provision of power in rural areas. Utilizing alternative sources of energy will make communications more accessible and will reduce reliance on fossil fuels and further reduce the environmental impacts. One of the widely available renewable energy sources includes the biogas and solar energy. The reason for choosing this types of renewable energy (biogas and solar energy) is that in remote areas, biogas is easily and economically available in the form of dung of cow, buffalo, goat etc. In addition, sunlight is naturally available as a source of solar energy (Erbach, 2016).

B. Biogas Energy

Biogas energy is an energy source and renewable fuel that can be applied in many different circumstances. It is a combustible gas mixture produced from anaerobic fermentation of biomass by bacteria that requires several days to form. The remainder of agricultural products is a good resource for biogas energy. For example, woods and remnants of the harvest can be processed by thermal conversion to produce energy, vegetable oils and animal fats to produce biodiesel, or starch crops to produce ethanol (Mandal *et al*., 2017; Sawle, Gupta and Bohre, 2016).

Moreover, biogas energy can be produced from animal manures. Livestock manure left on the ground will rot go through natural fertilization that will produce biogas. Biogas can also be produced from human activity such as domestic landfills. Biogas contains about 55-70% methane by volume and heating of biogas is about 4600-6000 $kcal/m^3$ (Oyejide *et al*., 2014).

C. Solar Energy

Solar energy is the energy radiated by the sun and used in a way to tap the light photons to excite electrons. At present, solar energy is widely used, and was raised on a large scale by various energy investment company. Sunlight provides an abundant source of renewable energy. Solar technologies take advantage of the sun's energy using two different capture methods: active and passive (Ghenai and Janajreh, 2016). Active solar technologies use complex mechanized collectors, such as photovoltaic panels, to collect and store solar energy. Passive solar technologies are less complicated and rely on the design and orientation of the collector rather than mechanical devices to absorb and store the sun's energy. Technologies that use these methods include Photovoltaic (PV). PV systems directly convert sunlight into electricity using solar cells (Mandal *et al*., 2017).

These systems, which produce electricity even in the absence of strong sunlight, can generate significant quantities of electricity depending on several factors, including quality of the sunlight and the systems mounted pitch. A 10-kW system that produces 1,500 kWh per kW capacity per year could thus produce 15,000 kWh annually (Efunbote and Adeleke, 2015).

D. Related works

Pradhan *et al.,* (2013) analyzed the economical consideration and simulation approach for a stand-alone hybrid system having PV, wind and biomass for electrical production in remote areas. The average solar radiation, quantity of biomass, average wind speed for the remote area were taken for predicting the general performance of the generating system. The results obtained enhanced the performance of the model. Pradhan *et al.,* (2014) focused on the economic consideration of solar PV and biomass for electrical production in remote areas. The average solar radiation and quantity of biomass required data that were used to predict the general performance of the generating system. The results and analysis improved the development of the model.

Oyejide *et al*., (2014) presented the development of a grid-based rural electrification design for Ishashi and Ilogbo communities in Lagos state, Nigeria using grid-based method. A load audit of the two communities was carried out to determine their energy demands. The proposed electrical model design for the two communities was implemented using AutoCAD Software. The result showed that the developed electrical model designs and information provided could be employed for the actualization of electrification of both communities while Sheriff, Goje and Zannah (2014) proposed the coefficient equation of Angstrom type of model for the estimation of global solar radiation in Maiduguri, Borno state, Nigeria using relative sunshine hour. The performance parameters of the model were root mean square error (RMSE), Mean Bias Error (MBE), mean percentage error (MPE) and coefficient of determination (R^2). The overall performance of parameters showed that the method used was meaningful for estimation of global solar radiation on the basis of sunshine hour.

Efunbote and Adeleke (2015) designed hybrid solar-wind power system for a coaster area in Lagos State, south western Nigeria using HOMER software to simulate a solar and wind hybrid system. The result showed that the energy supplied using solar-wind hybrid power system was reliable and can produce electrical energy to power appliances in the community. Ibe *et al* (2015) investigated the potential sources of energy in the riverine areas to find out the cost effective off-grid option. The result revealed that the optimal configuration option among ten feasible options is a hybrid wind/diesel/battery system. In addition, Ghenai and Janajreh (2016) designed renewable energy-based micro grid system: solar biomass system for the electrification of the city of Sharjah. The principal objective was to explore the available renewable resources in Sharjah and to determine the optimal configuration to meet the desired electric loads of the city. Input information on the primary loads, solar and biomass resource availability, technology options, components cost, constraints, and controls were determined. Hourly simulations with sensitive analysis were performed to calculate the energy and to design the most favorable renewable energy-based system.

Furthermore, Mandal *et al*., (2017) suggested how renewable sources of energy can be an alternative option to produce electricity in an off-grid area by surveying 235 households in an off-grid area. Techno-economic analysis of the hybrid energy system was employed using Hybrid Optimization of Multiple Energy Resources (HOMER) software. Four solar-PV modules (each of 1kW), two biogas generators (each of 3kW), three diesel generators (each of 5kW), five batteries (each of 160 Ah) and 5kW converter was found to be the best configuration in terms of cost of energy, environmental conditions and renewable fraction.

This work therefore improves on the work of previous researchers by carrying out the comparative assessment for biogas and solar energy for Ajaba communities in Osun State, Nigeria.

E. Study Area

Ajaba is a town near Ila-Orangun in Osun State, Nigeria located 8.67^0 latitude and 3.39^0 longitudes and it is situated at elevation of 472 meters above sea level. The place has a good potential for biogas electricity generation because it is easy to get enough amount biogas materials. The solar irradiation in this area is around 1900 kWh/m^2, which is also moderate for solar electricity generation (Efunbote and Adeleke, 2015).

II. MATERIALS AND METHOD

The method applied in this work is centred on the possible optimization scenario representing expansion of the electricity generation system with an objective of meeting projected demand between biogas and solar energy using empirical method for proper analysis. The optimization was done on the long-term basis with a planning horizon for four months in order to argue the best renewable energy between biogas and solar energy.

A. Design of Biogas Digester

The bio-digesters used for this study are 60,000 L and 50, 000 L capacity of gas holder drum and the study was carried out between January to April 2018 in Ajaba in Osun State. A total of 1000 pigs each considered to have a weight of approximately 60 kg were used to prepare the digester, which was collected from the slaughter house in Ajaba, Osun state. The biogas plant detail consists of five main structures: inlet pipe, digester vessel, gas holder, outer chamber and mixing tank as depicted in Figure 1.

The required quantity of fresh pig dung and water was mixed at ratio 1:1 in the inlet tank and the slurry was discharged to the digester vessel for digestion. The digested slurry flew to the outlet tank through the main pipe. The slurry flew through the overflow opening in the outlet tank to the compost pit. The fully digester slurry drained out through the outlet pipe and the gas pipe line from the gas collector drum was connected to the 10 kVA dual fuel ac generator for generating electricity. Hence the ac generator was connected to cables that transferred electricity to a power distribution (Load) for consumption.

The mathematical equations for the biogas digester used for this study comprises of the mass of the solid waste available, volume of the fluid, volume of the digester required for processing the solid waste, volume of the biogas produced by the digester within the range of the retention time and the energy output from the digester.

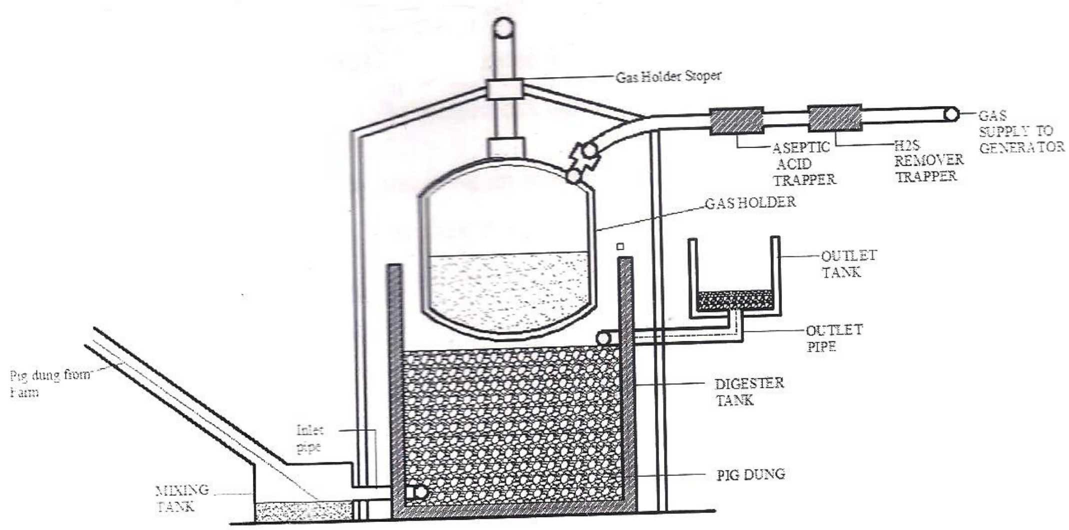

Figure 1: The Biogas plant

The mass of dry solid in waste is given as:

$$m_o = N_a S_w \quad (1)$$

The volume of biogas is given as

$$V_b = cm_o \quad (2)$$

The volume of fluid in the digester is given as:

$$V_f = \frac{m_o}{\rho_m} \quad (3)$$

The volume of the digester is given as:

$$V_d = \frac{V_f}{t_r} \quad (4)$$

The energy generated is given as:

$$E = \eta H_b V_b \quad (5)$$

where; N_a is the number of animals that produced the dung, S_w is the solid in waste per animal per day/kg, c is the biogas yield per unit dry mass of whole input $0.2 - 0.4 m^3 kg^{-1}$, m_o is the mass of dry input, ρ_m is the density of dry matter in the fluid, V_f is the flow rate of digester fluid, t_r is the retention time in the digester and H_b is the heat of combustion per unit volume of biogas.

B. Design of a Solar PV Panel

Photovoltaic (PV) cells were considered in this paper as the device for trapping and converting solar energy to electrical energy. PV cells, when operated under light generate power. It supplies a direct current with positive convention when flowing from the positive terminal of the external load. PV cell used is made from the silicon p-n junction single solar crystal cell. When illumination is radiated on the photocell, the P-N junction conducts in forward bias mode and a positive current is passed from the P to N junction, by considering equivalent circuit that consists of a current source in parallel with diode as shown in Figure 2. The current and power generated by the PV can be calculated as below.

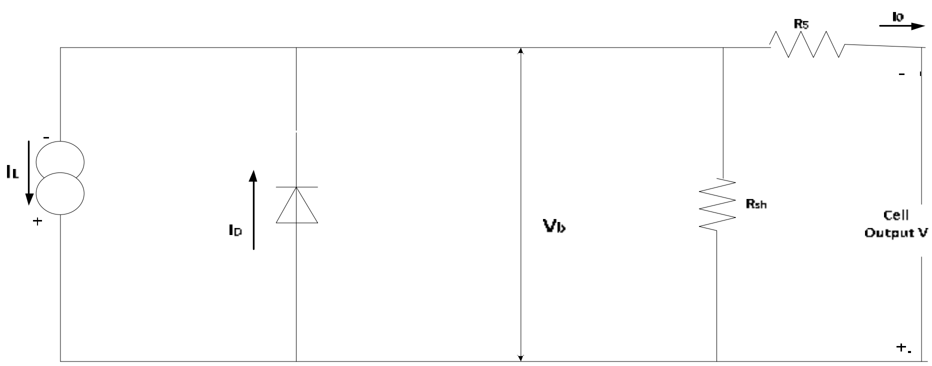

Figure 2: Equivalent circuit of PV system

$$I = I_L - I_D - \frac{V + IR_{ser}}{R_{sh}} \quad (6)$$

With voltage drop across R_{ser}

$$I_D = I_0 \left(e^{\left(\frac{V + IR_{ser}}{AKT}\right)} - 1 \right) \quad (7)$$

For a given illumination, open circuit voltage, V_{OC}, slightly increases with irradiance while short circuit current I_{SC} reduces. Maximum power is transmitted to the external load R_L. When R_L equal to internal resistance R_{int} of the source. An increase in temperature θ causes a decrease in V_{OC} and increase in I_{SC}. The empirical relationships for this effect are given as:

$$V_{OC}(\theta) = V_{OC}(\theta_1)[1 - a(\theta - \theta_1)] \quad 8$$

$$I_{OC}(\theta) = I_{OC}(\theta_1)[1 - b(\theta - \theta_1)] \quad 9$$

θ is the material temperature which is often taken as $25^0 C$.

Temperature coefficients are given as:

$$a = 3.7 \times 10^{-3} \left({}^0C\right)^{-1} \quad 10$$

$$b = 6.4 \times 104 \left({}^0C\right)^{-1} \quad 11$$

The value of available power is given as:

$$P(\theta) = P(\theta_1)[1 - c(\theta - \theta_1)] \quad 12$$

Where

$$c = 4 \times 10^{-3} \left({}^0C\right)^{-1} \quad 13$$

With an average of 7 hours of sunlight and using a solar panel of power rating of 250 W, the number of solar panel required to generate the same amount of generated energy by biogas for 7 hours is given as:

$$N_P = \frac{E_B}{P_{SP} \times D_S} \quad 14$$

Where, E_B is the electric energy generated by biogas, P_{SP} is the power of solar panel and D_S is the duration of sunlight. Equation (14) was used to determine the best renewable energy between biogas and solar energy.

C. Data Collection

Data on renewable energy in the area were drawn from various sources. The technical potential of solar energy was based on the degree and intensity of solar irradiation, the estimated land area suitable for photovoltaic (PV) installations, and the efficiency of the solar systems of the area while biogas digester was sampled using pig dung. The data collected was translated, interpreted and simulated using MATLAB software in order to extrapolate the measurements.

III. DISCUSSION OF RESULTS

The simulation results are presented according to the power generated by the bio-digester, power generated by the solar panel and comparison between the generated energy are illustrated in Figures 3 - 5.

After processing the dung of 1000 fattening pigs, the volume of biogas generated was 60 m^3, which was equivalent to 60000 liters of gas and the electric energy generated was 200.16 kWh/day. In addition, 900 fattening pigs produced 54 m^3 (54000 liters) of gas and 180.144 kWh/day of electrical energy. In addition, 800, 700, 600, 500, 400, 300, 200 and 100 fattening pigs produced 48 m^3, 42 m^3, 36 m^3, 30 m^3, 24 m^3, 18 m^3, 12 m^3 and 6 m^3 of biogas respectively and thus generated 160.128 kWh/day, 140.122 kWh/day, 120.096 kWh/day, 100.08 kWh/day, 80.064 kWh/day, 60.048 kW/day, 40.032 kWh/day and 20.016 kWh/day of electrical energy respectively. Figure 3 shows that there is a positive linear relationship between the number of fattening pigs used, the volume of the biogas produced and the electrical energy generated. From the Figure, it was shown that the amount of electrical energy generated has a direct proportionality with the volume of gas produced and with the number of fattening pigs used.

Figure 4 illustrates the relationship between power generated by the solar panel and the ambient temperature of the area. An open circuit voltage of 32 volts and short circuit current of 5.5 Ampere at an ambient temperature of 25^0C was used as the standard temperature condition of the area. From the Figure, at ambient temperature of 25^0C, the electric energy generated was 4.224 kWh/day, 30^0C generated electric energy of 4.1395 kWh/day. Also, 35^0C, 40^0C, 45^0C and 50^0C generated electric energy of 4.055 kWh/day, 3.9706 kWh/day, 3.8861 kWh/day and 3.8016 kWh/day respectively. Moreover, 55^0C, 60^0C and 65^0C generated electric energy of 3.7171 kWh/day, 3.6326 kWh/day and 3.5482 kWh/day respectively. The highest electric energy generated was 4.224 kWh/day at 25^0C while the least electric energy generated is 3.5482 kWh/day at 65^0C. This shows a linear decrease in the electrical energy with increase in temperature. The Figure shows a negative gradient in the energy-temperature relationship.

Figure 5 shows the comparison between the biogas energy and solar energy based on the volume of biogas and corresponding number of solar panel required to generate the biogas energy. From the Figure, the volume of biogas of 12 m^3, 18 m^3, 24 m^3 and 30 m^3 generated energy of 20.016 kWh/day, 40.032 kWh/day, 60.048 kWh/day and 80.064 kWh/day respectively required number of solar panel of 23, 34, 46 and 57 panels respectively. In addition, 36 m^3, 42 m^3, 48 m^3, 54 m^3 and 60 m^3 generated electric energy of 120.095 kWh/day, 140.112 kWh/day, 160.128 kWh/day, 180.144 kWh/day and 200.16 kWh/day respectively with 67, 80, 92, 103 and 114 panels respectively. It was observed that an increase in the amount of biogas energy required an increase the volume of biogas and concurrently increased the number of solar panel.

The result shows that biogas energy is the best renewable energy source for Ajaba community.

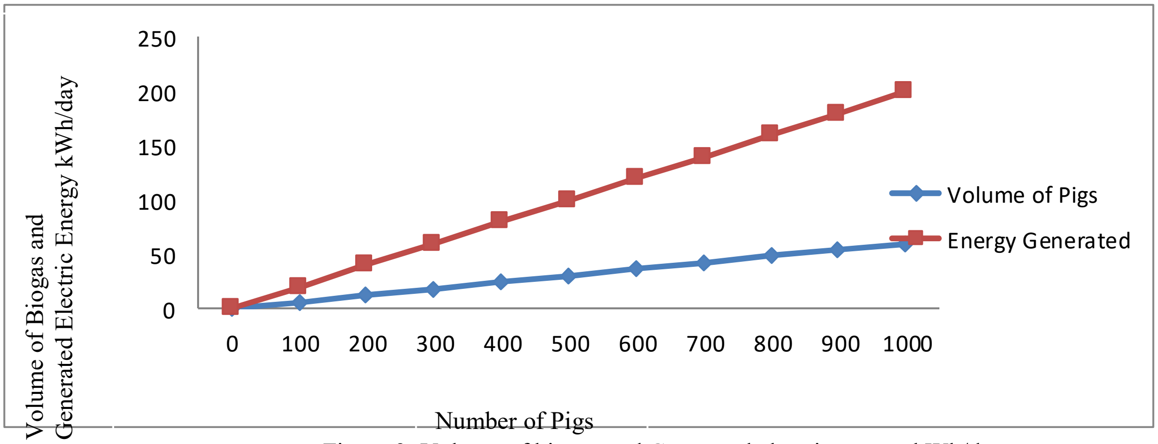

Figure 3: Volume of biogas and Generated electric energy kWh/dag

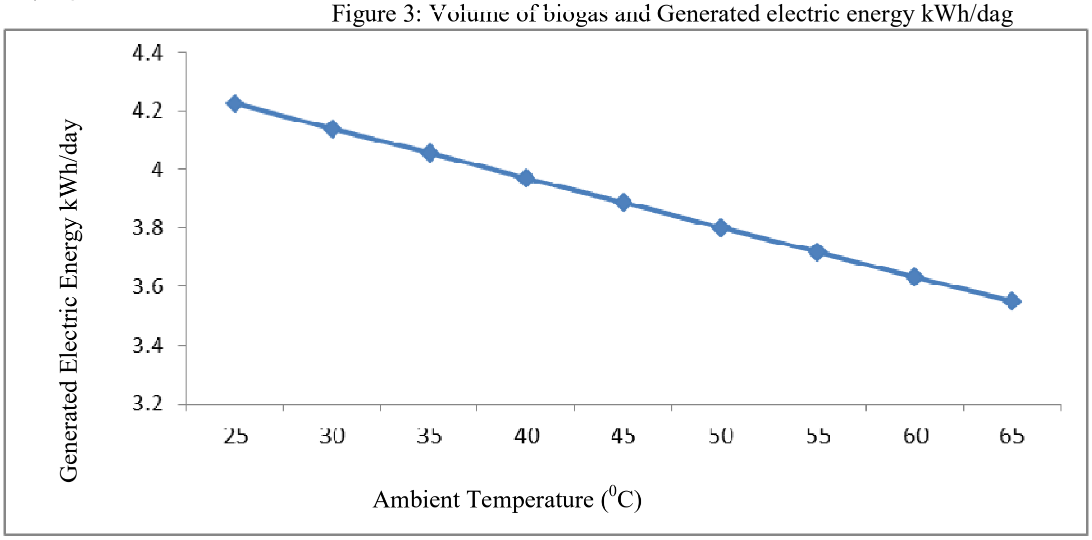

Figure 4: Generated electric energy kWh/day

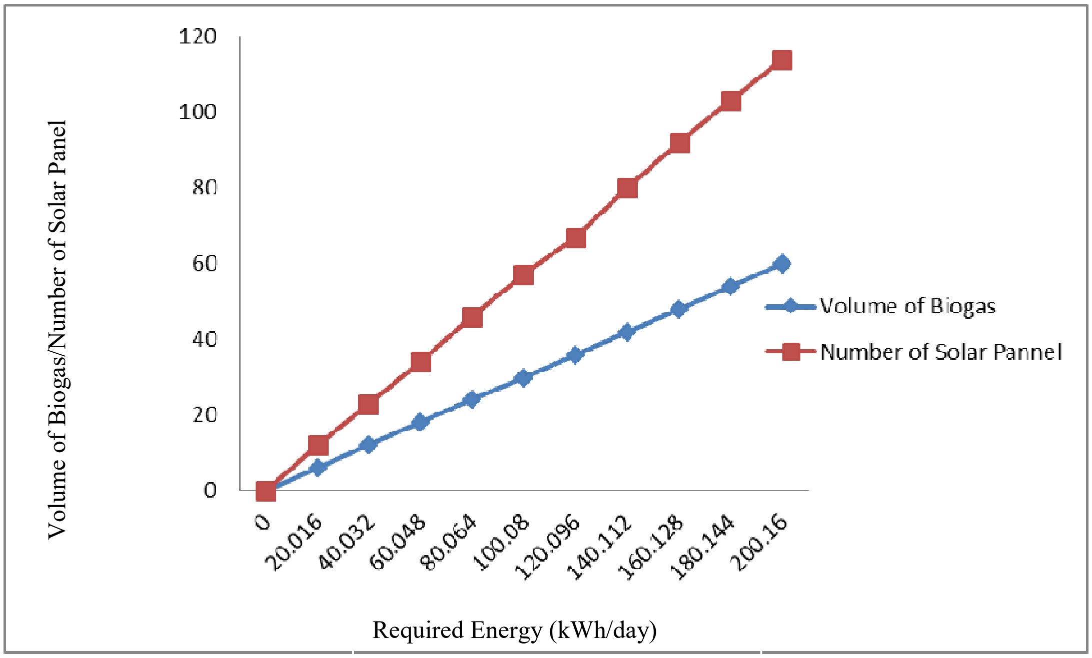

Figure 5: Volume of biogas and Number of solar panel

IV. CONCLUSION

This paper has modeled both the biogas and solar energy for Ajaba community in Osun state by comparing both energy sources with respect to the volume of biogas and number of solar panel and their productivity in order to argue the best renewable sources for the community. The results were presented based on the electric energy generated by the biogas and solar energy as well as number of solar panel required to generate the same amount of energy generated by the biogas energy. From the result, it was deduced that generating energy from biogas is more effective and reliable for the community compared to solar energy. The results also revealed that the biogas energy generated more energy and performed better as compared to the solar energy for the community area.

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