# Sustainable electricity generation in rural communities using hybrid energy system: The case study of Ojataye Village

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## Abstract

In this study, PV/Diesel/Battery hybrid energy system is proposed for meeting the electrical energy needs of Ojataye village. HOMER simulation software is utilized in designing the system in such a way that it meets the desired electrical energy needs of the rural community in a sustainable manner. The electrical energy requirements of the village are projected using structured questionnaires which were interpreted to the villagers and several personal site visits. The data on the energy resources of the village (solar and wind) are obtained from Nigeria Meteorological Agency (NIMET), Oshodi, Lagos and are analyzed over a period of 16 years to determine their suitability for the hybrid energy system design. Some of the key findings reveal that the village received an average annual global solar radiation of about 5kW/m$^2$/day and the mean wind speed of 2.8 m/s. The optimization result shows that PV/Diesel/Battery is the optimum configuration that can economically and sustainably meet the electrical energy needs of the villagers. The configuration consists of 60kW PV, 20kW diesel generator, and 110 numbers of Battery. The total net present cost of the configuration is $254, 948, the initial capital cost is $132,750 and the operating cost is $9,559. The cost of generating electricity is $0.309/kWh with renewable energy fraction of 89%. There is saving in the fuel consumption of 29,971 litres/annum compared to utilization of diesel generator only. This accumulates into mitigation of 78,924kg/annum and 194.3kg of carbon dioxide and carbon monoxide, respectively.

**Keywords:** *Hybrid energy, electricity generation, sustainable development, Ojataye Village, Nigeria*

## 1. Introduction

Electricity has been considered as one of the essential ingredient that can provide economic empowerment and improve the standard of living of the rural communities [1]. However, most villages do not have access to electricity due to economic investment required to construct a robust grid network to small group of people with sparse population [2]. Hybrid renewable energy systems have been identified as a pathway towards achieving electricity for rural communities that are difficult to be connected to the grid due to difficult terrain and long distances from the load centers [3]. Hence, installation of hybrid renewable energy for rural communities has crystal potentials in enhancing sustainable rural electricity development [4] with attended positive effect on the socio-economic life of the rural dwellers.

The growing concern for rural electrification in recent years have prompted various authors to come up with different hybrid renewable energy designs based on the available local resources. Feasibility study of a wind/PV/battery hybrid energy system for an off-grid remote Dongwangsha village in China has been performed by Liqun and Chunxia using REETSCREEN with the aim of developing the most suitable hybrid energy system configuration [5]. It was concluded that wind and solar energy have the percentage electricity contribution of 82.1% and 16.2% respectively. Similarly, Huang and Huang designed a PV/Diesel hybrid energy system using TRNSYS simulation software [6], which was used to test the performance of different hybrid systems at different locations in Taiwan. Li *et al* [7] have developed an algorithm that is capable of determining the appropriate unit size of PV/Wind/Battery stand-alone hybrid energy system for a remote island in Zhoushan, China. The possibility of utilizing hybrid energy system for electricity generation in the Algerian Sahara desert was investigated by Maamar *et al* [8] using HOMER simulation software. The optimization result showed that PV/Wind/Diesel/Battery was the optimum configuration for the location. In another research, Mishra and Singh [9] proposed PV/Biomass/battery hybrid energy system in meeting electricity demand of Kaidupur village in India. It was concluded that the hybrid energy system has the capability to meet the need of the entire 80 households in the village. Hybrid energy system has been studied using HOGA simulation software as a possible option for electrification of Island of Har in Canada by Gudelj and Krcum [10]. The authors revealed that PV/wind/battery is the most suitable option for the island with good reliability and cost effectiveness. Additional studies on hybrid energy system design can be found in [11]and [12].

This work examines the possibility of utilizing hybrid energy system for meeting the electrical energy needs of Ojataye village located in South-Western part of Nigeria. The village is one of the typical rural communities in Nigeria without access to electricity and is having negative turn on their socio-economic life. The cost benefit, environmental benefit and break even period of employing hybrid energy system for meeting the electrical load requirements of the village are determined. This paper is useful as it can serve as a potential source of information that could aid national policy on green and sustainable rural electrification in Nigeria.

## 2. The area under study

Ojataye village is located in Oyo state at latitude $7.98^0$N and longitude $4.01^0$E as depicted in Figure 1. The village has 34 houses, religious centers (a mosque and a church) and a basic school (primary school), all in linear arrangement. The village has a population of about 200 people who are predominantly farmers. It is one of the many villages that are currently not connected to the Nigerian national grid.

### *2.1 Electrical load requirement of Ojataye Village*

In order to get the anticipated electrical load demand of the inhabitant of Ojataye village, a questionnaire relevant to the rural community was developed, interpreted and conducted through oral interview. Based on the questionnaire, the hourly anticipated electrical load demand and the daily load profile for the village was developed as depicted in Table 1 and Figure 2, respectively.

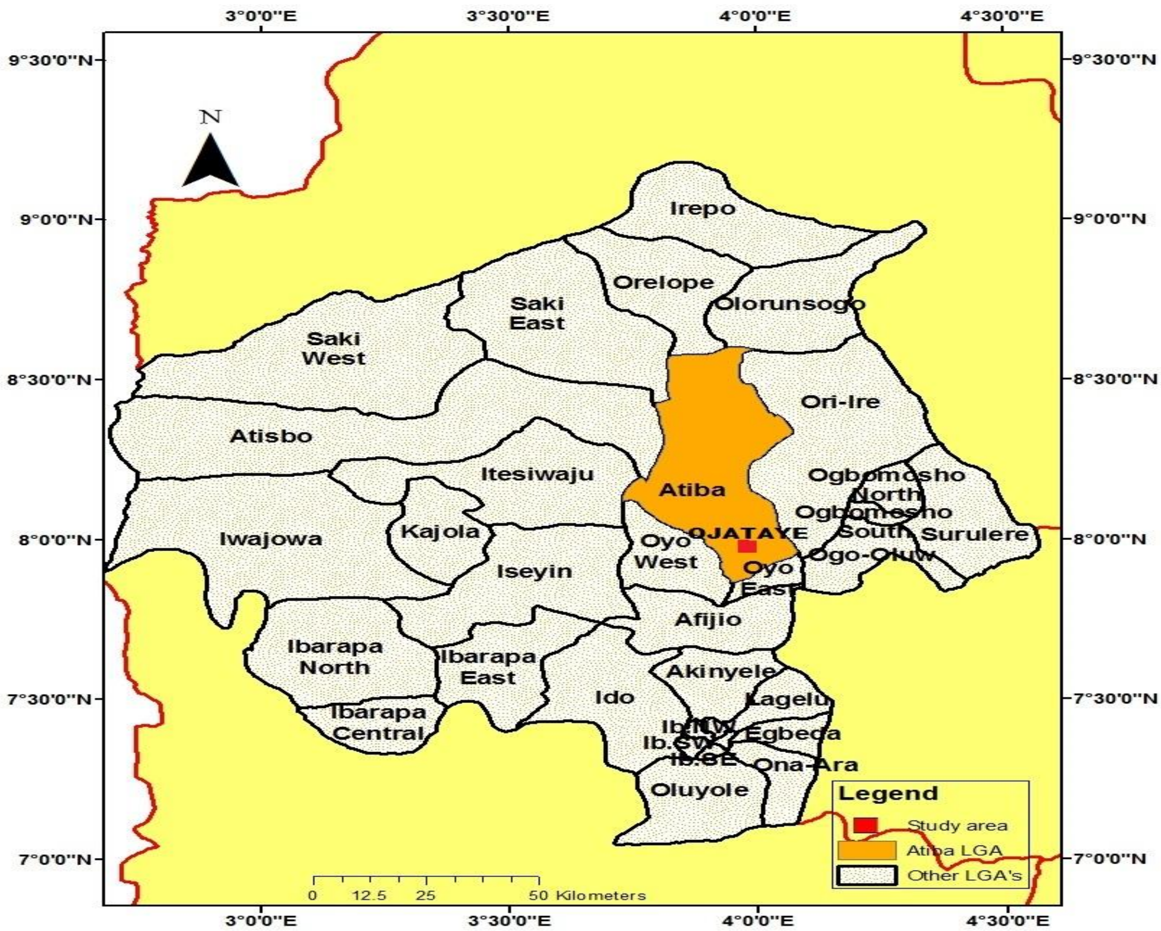


Figure 1: Map showing the location of Ojataye Village

Table 1: Projected hourly electrical energy demand of Ojataye village

| Electrical Appliances | per Buildg | No of buildng | total (W) | Hours of the day | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| HOUSES | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Seecurity ligh | 120W | 34 | 4080 | 4080 | 4080 | 4080 | 4080 | 4080 | 4080 | | | | | | | | | | | | | 4080 | 4080 | 4080 | 4080 | 4080 | 4080 |
| indoor light | 240W | 34 | 8160 | | | | | 8160 | 8160 | | | | | | | | | | | 8160 | 8160 | 8160 | 8160 | 8160 | 8160 | | |
| Radio | 20W | 34 | 680 | | | | | 680 | 680 | | | | | | | | | | 680 | 680 | 680 | 680 | 680 | 680 | 680 | | |
| cell phones | 30W | 34 | 1020 | | | | | 1020 | 1020 | | | | | | | | | | | | 1020 | 1020 | | | | | |
| Standing fan | 100W | 34 | 3400 | 3400 | 3400 | 3400 | 3400 | | | | | | | | | | | | | | | 3400 | 3400 | 3400 | 3400 | 3400 | 3400 |
| COMMERCIAL | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Clipper | 90W | 1 | 90 | | | | | | | | | | | | | | | | | 90 | 90 | 90 | 90 | | | | |
| Grinder | 1000W | 1 | 1000 | | | | | 1000 | 1000 | 1000 | 1000 | 1000 | | | | | | | | 1000 | 1000 | | | | | | |
| rrefrigerator | 150W | 1 | 150 | | | | | | 150 | 150 | 150 | 150 | 150 | 150 | | | | | | | | 150 | 150 | 150 | 150 | 150 | 150 |
| Radio | 20W | 1 | 20 | | | | | | | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | | | | |
| Television | 150W | 1 | 150 | | | | | | | | | | | | | | | | | 150 | 150 | 150 | 150 | 150 | 150 | | |
| SCHOOL | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Computer | 110W | 1 | 110 | | | | | | | | | 110 | 110 | 110 | 110 | | | | | | | | | | | | |
| Fan | 100W | 1 | 100 | | | | | | | | | | | | 100 | 100 | 100 | | | | | | | | | | |
| RELIGION | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Church | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| light | 240W | 1 | 240 | | | | | | | | 240 | 240 | 240 | | | | | | | 240 | 240 | 240 | 240 | | | | |
| PA | 120W | 1 | 120 | | | | | | | | 120 | 120 | 120 | | | | | | | 120 | 120 | 120 | 120 | | | | |
| Fan | 100W | 1 | 100 | | | | | | | | 100 | 100 | 100 | | | | | | | 100 | 100 | 100 | 100 | | | | |
| Mosque | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Light | 240W | 1 | 240 | | | | | | 240 | 240 | | | | | | | 240 | 240 | | | 240 | 240 | | | 240 | 240 | |
| Fan | 100W | 1 | 100 | | | | | | 100 | 100 | | | | | | | 100 | 100 | | | 100 | 100 | | | 100 | 100 | |
| PA | 120W | 1 | 120 | | | | | | 120 | 120 | | | | | | | 120 | 120 | | | 120 | 120 | | | 120 | 120 | |
| | | | 19880 | 7480 | 7480 | 7480 | 7480 | 14940 | 15550 | 1630 | 1630 | 1740 | 740 | 280 | 230 | 120 | 580 | 480 | 700 | 10560 | 12040 | 18670 | 17190 | 16620 | 17080 | 8090 | 7630 |

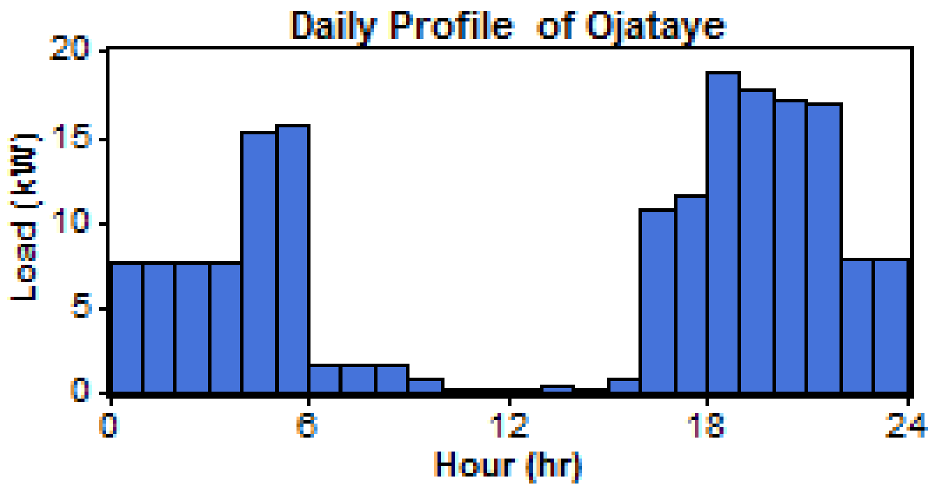


Figure 2 Daily Load Profile of Ojataye

From the daily load profile, it can be observed that there are two peak periods between the hours of 0500-0600 in the morning and 1800-2000 in the evening. The usual early morning activities in the village such as the need to use public address system in the church and mosque, cooking, listening to early local morning news before embarking on farm activities are responsible for the morning peak period while the evening activities after returning from farm such as lighting, grinding of farm products (cassava, pepper, grains), cooking, watching of television and listening to news are responsible for the evening peak period. The average load requirement of the village was found to be 177kwh/day while the peak load was determined to be 20kW.In view of the fact that they live a routine life; there is no significant difference between the ways in which energy is being consumed during the weekdays and weekends.

## 3. Assessment of available resources in the village for hybrid energy design

### *3.1 Solar radiation resources*

The global solar radiation of the location was obtained from Nigerian Meteorological Agency (NIMET), Lagos. The monthly daily average global solar radiation varies from month to month as shown in Figure 3 with annual average daily solar radiation of 5 $kW/m^2/day$. The clearness index is defined as the fraction of solar radiation that reaches a location on the earth surface [13]. In Ojataye, the clearness index varies between 0.411 (August) to 0.555 (November) with average value of 0.498 indicating that the August is the cloudiest month of the year while November presents the clearest month.

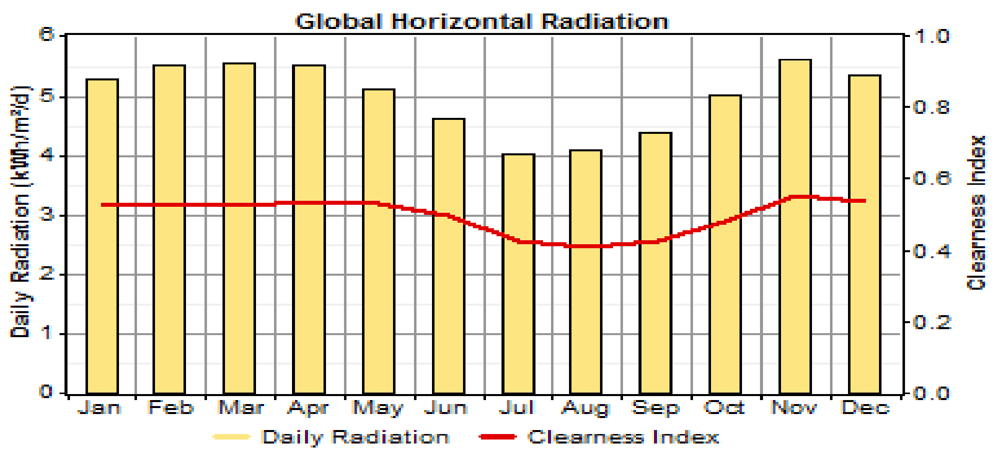


Figure 3: Monthly daily averaged global solar radiation and clearness index for Ojataye Village

### *3.2 Wind data resource*

The wind speed data for Ojataye was also obtained from NIMET, Lagos. The wind was measured at the anemometer height of 10 m. The monthly average wind speed is depicted in Figure 4. The minimum monthly wind speed occurs in October (2.35 m/s) while the maximum occurs in March (3.30 m/s). The annual average wind speed was determined to be 2.81 m/s.

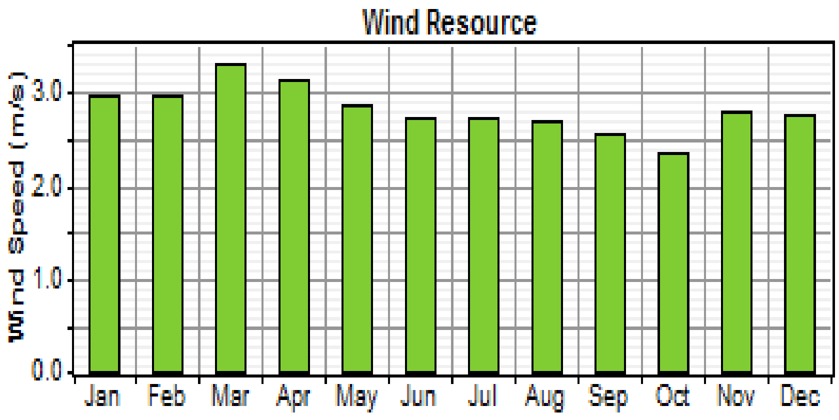


Figure 4: Monthly mean wind speed ofOjataye measured atanemometer height of 10m

## 4. Modelling of hybrid energy system

Hybrid energy system was designed based on anticipated load of Ojataye village. The hybrid system consists of the PV panels, wind turbine, power converter, storage device and diesel generator as shown in Figure 5. The estimated peak and daily load consumption of the village are scaled to 20 kW and 177 kWh/day respectively.

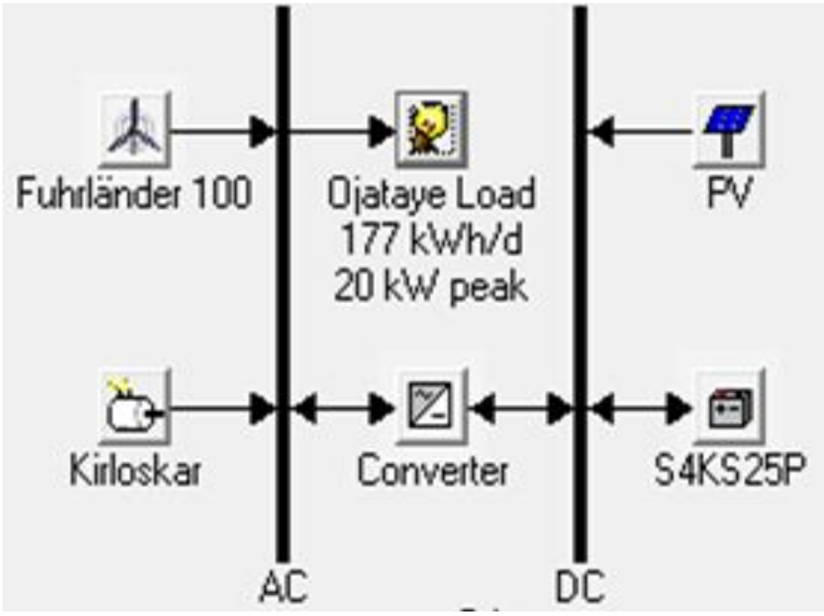


Figure 5: PV/Wind/Diesel/Battery Hybrid Energy System

### *4.1 Solar PV modules*

The initial capital and replacement cost was assessed as $1250/kW and $1000/kW, respectively [14, 15] with life expectancy of 25years. The derating factor (the scaling factor that compensates reduction in performance of PV array due to dust, weather condition and other losses from wiring) of 80% and ground reflectance (the fraction of the reflected solar radiation incident on the ground) of 20% were also employed [14, 15].The output energy for the PV was calculated using

$$P_{PV} = Y_{PV} f_{PV} \left( \frac{\overline{G_T}}{\overline{G}_{T,STC}} \right) \tag{1}$$

where: $Y_{PV}$ is the rated capacity of the PV array, meaning its power output under standard test conditions [kW], $f_{PV}$ is the PV derating factor (%), $\overline{G}_T$ is the solar radiation incident on the PV array in the current time step [kW/m$^2$], and $\overline{G}_{T,STC}$ is the incident radiation at standard test conditions [1 kW/m$^2$].

*4.2 Wind turbine*

The wind turbine employed for this study is Fuhrlander with rated power of 100kW. It has a rotor diameter and hub height (free standing tubular) of 21m and 35m respectively. The initial capital and replacement cost are taking as \$32000 while it's operating and maintenance cost per year is \$300 with life expectancy of 25years. The output power of a wind turbine in a particular hour under standard condition could be obtained by the product of power law profile and the air density ratio. The power law assumes that the ratio of wind speeds at different heights can be extrapolated using:

$$\frac{\upsilon(z_{hub})}{\upsilon(z_{anem})} = \left( \frac{z_{hub}}{z_{anem}} \right)^{\alpha} \tag{2}$$

where $z_{hub}$ is the hub height of the wind turbine (m), $z_{anem}$ is the anemometer height (m), $\upsilon(z_{hub})$ is the wind speed at the hub height (m/s), $\upsilon(z_{anem})$ is the wind speed at anemometer height (m/s), and $\alpha$ is the power law exponent.

The air density ratio is given by equation (3)

$$\frac{\rho}{\rho_0} = \left( 1 - \frac{Bz}{T_0} \right)^{\frac{g}{RB}} \left( \frac{T_0}{T_0 - Bz} \right) \tag{3}$$

where $\rho_0$ is the air density at standard temperature and pressure conditions (101,325 Pa), $T_0$ is the standard temperature (288.16 K), $B$ is the lapse rate (0.00650K/m) and R is the gas constant (287 J/kg K), z is the elevation (m), g is the acceleration due to gravity (9.81 m/s$^2$) and $\rho$ is the air density at the wind turbine hub height.

*4.3 Diesel generator*

In this work, the essence of diesel generator inclusion is to supplement the power production by the renewable energy resources. This is needed in the time when the power produced from renewable is insufficient and the storage is below the set-point for the state of charge. Since the peak load in this study is 20 kW, two 10 kW units of diesel generator manufactured by Kiloska are selected for initial simulation. The fuel consumption and efficiency curves for the generator are shown in Figures 6 and 7, respectively. Initial capital and replacement costs for the diesel generator is taken as \$1000 and \$875 respectively while the operation and maintenance cost per hour is \$0.625 with life expectancy of 40000 hours and minimum load ratio of 30%.

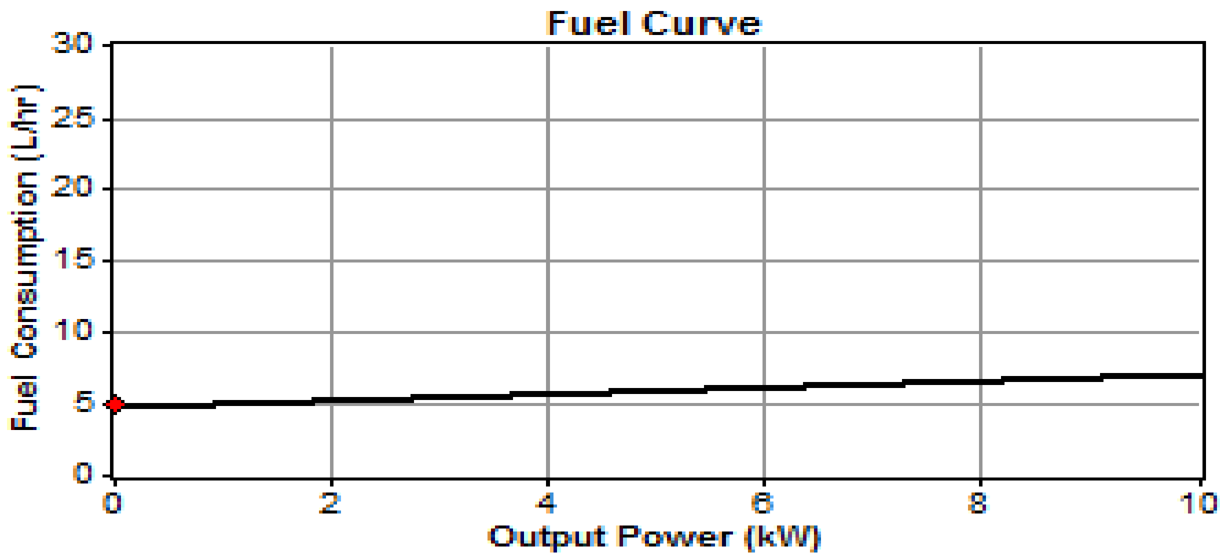


Figure 6: The generator fuel consumption curve

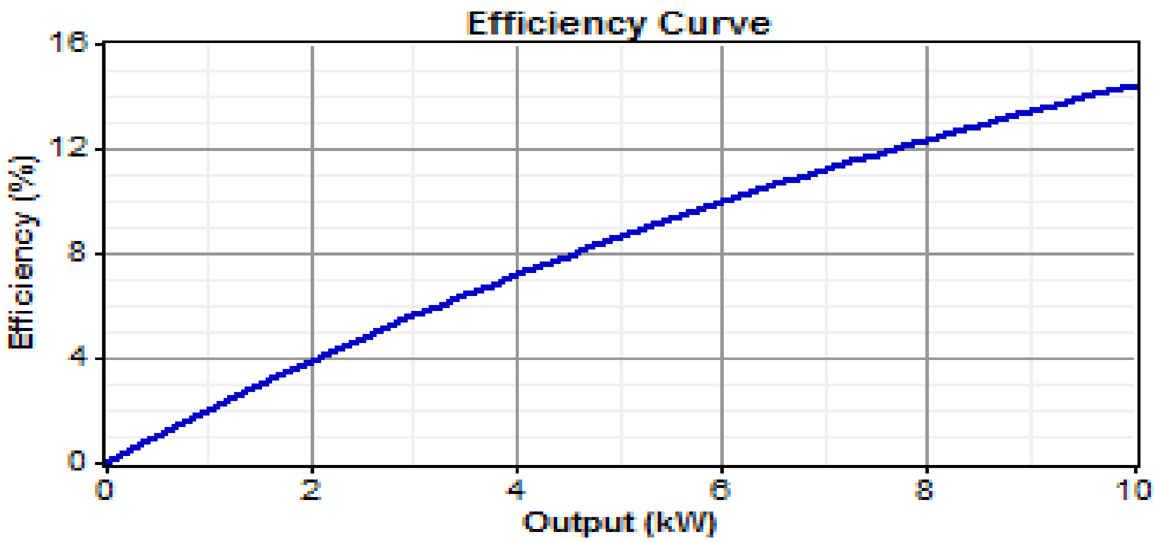


Figure 7: The generator efficiency curve

The fuel consumption was estimated using:

$$F_c = \psi P_{rated} + \beta P_{gen} \tag{4}$$

where $F_c$ is the generator fuel consumption (L), $\psi$ is the generator fuel curve intercept coefficient (L/hr/kW), $\beta$ is the generator fuel curve slope (L/hr/kW), $P_{rated}$ is the generator rated capacity (kW) and $P_{gen}$ is the generator power output (kW). The values of $\psi$ and $\beta$ are 0.04739 and 0.2284, respectively [16].

*4.4 Battery Storage*

The battery is used to bridge the gap between load demand and energy supply from renewable energy resources. There are two main models of battery dispatch strategy for hybrid renewable energy application: the cycle life-charging and load-following. However, the cycle life-charging is preferred to load-following because it better preserves the lifetime of the battery. The battery employed in this study was Surrette 4KS25P model with nominal voltage and capacity of 4V and 1900Ah respectively with lifetime throughput of 10569kWh, float life of 12years, minimum state of charge of 40% and efficiency of 80%. The capital cost and replacement cost for one battery is $500 and $473, respectively. The operation and maintenance cost is taking as $25/year. For optimum battery performance, five battery strings were considered with 55 batteries in each string.

*4.5 Power converter*

The hybrid energy system comprises both AC and DC subsystems, therefore, a power converter is needed which ensures energy flow between AC electrical load and DC components of the hybrid energy system. To initialize the simulation, a converter of 20kW in size was selected which is corresponding to the peak load of the village. The size can thereafter be adjusted after viewing the results of the simulation. The capital and replacement cost of inverter in accordance to the local market value are given as $500 and $450 respectively with operation and maintenance cost of $80/year. Converter efficiency of 90% is considered in the simulation over the life expectancy of 20years.

## 5. Economic assessment criteria of hybrid energy system

The economic viability of any hybrid renewable energy system is assessed mainly from the levelized cost of energy and the net present cost of the energy system [2]. Both economic indices can be calculated from the annualized capital cost of each component ($C_{acap}$) that makes up the hybrid energy system and it can be calculated as follows:

$$C_{acap} = C_{cap} * CRF(i, R_{proj}) \tag{5}$$

where $C_{cap}$ is the initial capital cost of the component, $i$ is the real interest rate (%), $R_{proj}$ is the project lifetime (year), $CRF$ is the capital recovery factor and can be determined as:

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \tag{6}$$

where $N$ is the number of years. The total annualized cost of hybrid energy system ($C_{ann,tot}$) in ($/yr) is the sum of the individual annualized capital cost of each component that forms the hybrid energy system and can be evaluated as:

$$C_{ann,tot} = \sum_{j=1}^{n} C_{acap(i)} \tag{7}$$

where $n$ is the total number of component that makes up the system.

The levelized cost of energy (COE) is defined as the average cost per kWh of useful energy produced by the system[3]. The COE can be determined using:

$$COE = \frac{C_{ann,tot}}{E_{prim,AC}} \tag{8}$$

where $E_{prim,AC}$ is the AC primary loads served by the hybrid energy system (kWh/yr). The net present cost $C_{NPC}$ which serves as the main economic output of the system can be calculated using:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i, R_{proj})} \tag{9}$$

It should be noted that the annual real interest rate is taking as 6%. The Carbon Emission Intensity (CEI) can be calculated as (10)

$$CEI_{(i)} = E_{(i)} \times P_{(i)} \tag{10}$$

where $E_i$ is carbon intensity of each type of power source (gCO$_2$-e/kWh), $P_i$ is the weight of each type of power source (%).

## 6. Simulation results and discussion

Simulation was carried out to determine the feasibility of hybrid renewable energy system configuration that best suit the local renewable energy resources of Ojataye and then estimates the Net Present Cost (NPC) of the hybrid energy system.The NPC is a touch stone to compare the economies of various system configurations. The one with the least NPC is considered as the optimal configuration. The optimization results comparing the NPC of different categorized hybrid renewable energy systems of the village are depicted in Figure 8

| PV (kW) | FL100 | Kirlo (kW) | S4KS25P | Conv. (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Diesel (L) | Kirlo (hrs) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 | | 20 | 110 | 30 | $ 132,750 | 9,559 | $ 254,948 | 0.309 | 0.89 | 3,025 | 675 |
| 80 | | | 220 | 30 | $ 210,750 | 10,962 | $ 350,885 | 0.425 | 1.00 | | |
| | | 20 | 55 | 10 | $ 29,750 | 26,762 | $ 371,864 | 0.450 | 0.00 | 19,765 | 3,993 |
| 20 | | 30 | | 10 | $ 28,250 | 33,922 | $ 461,885 | 0.559 | 0.30 | 23,430 | 5,671 |
| 60 | 1 | 20 | 110 | 30 | $ 452,750 | 7,542 | $ 549,156 | 0.665 | 0.96 | 1,183 | 257 |
| 70 | 1 | | 165 | 30 | $ 490,750 | 8,681 | $ 601,719 | 0.729 | 1.00 | | |
| | | 30 | | | $ 3,000 | 48,193 | $ 619,065 | 0.750 | 0.00 | 32,996 | 8,395 |
| | 1 | 20 | 55 | 20 | $ 350,000 | 23,171 | $ 646,198 | 0.782 | 0.23 | 16,589 | 3,334 |
| 20 | 1 | 30 | | 10 | $ 348,250 | 32,689 | $ 766,125 | 0.928 | 0.43 | 22,178 | 5,507 |
| | 1 | 30 | | | $ 323,000 | 40,530 | $ 841,105 | 1.018 | 0.19 | 27,519 | 7,030 |

Figure 8: Categorized Optimization Results of Hybrid Energy System of Ojataye Village

The Figure reveals that the optimum hybrid renewable energy configuration is the PV/Diesel/Battery with least NPC of $254,948 and cost of energy of $0.309. The configuration consist of 60kW PV system, 20kW of diesel generating set, 110 numbers of battery storage and 30kW of converter. The summary of cash flow i.e. the breakdown of cost contribution of the hybrid energy system is shown in Figure 9. The figure revealed that the cost of battery contributed highest into the NPC of the hybrid system followed by the cost of PV panels. In these cases, the capital cost of PV and the battery is the most significant.

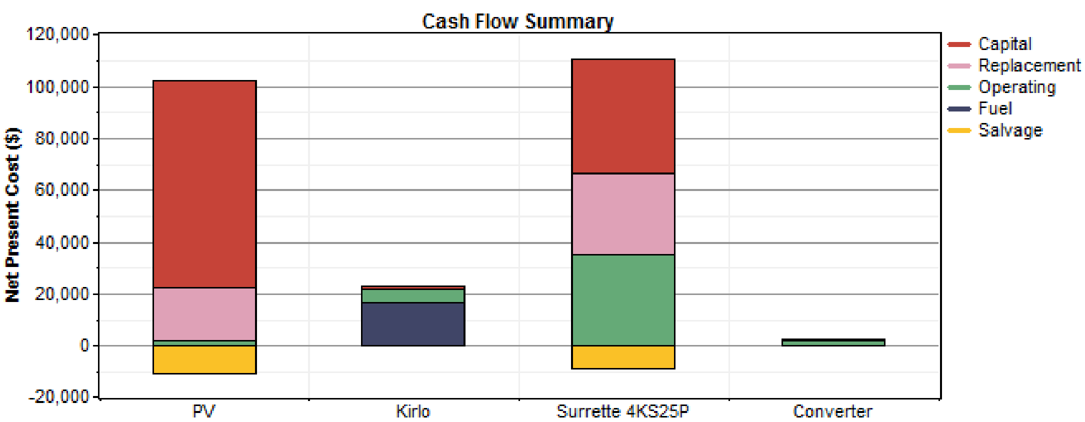


Figure 9: Cost summary of the hybrid energy system

The hybrid system comprises of 89% renewable energy fraction which cumulates into savings of 3,025 litters of diesel fuel per annum. The high renewable energy fraction indicates that in most of the time, the electrical energy requirement of the village could be met with the combination of PV and the battery storage system. The diesel generator only comes up in the remaining time thereby bridging the gap between the load demand and the energy supply. The number of run of generator is higher in the month of July, August and September as depicted in Figure 10. This is expected as these months fall into the peak of raining season when the cleanness index is low. The global solar irradiation for these months is comparatively low (Figure 3) due to the presence of cloud and therefore results in low electrical output of the PV generator.

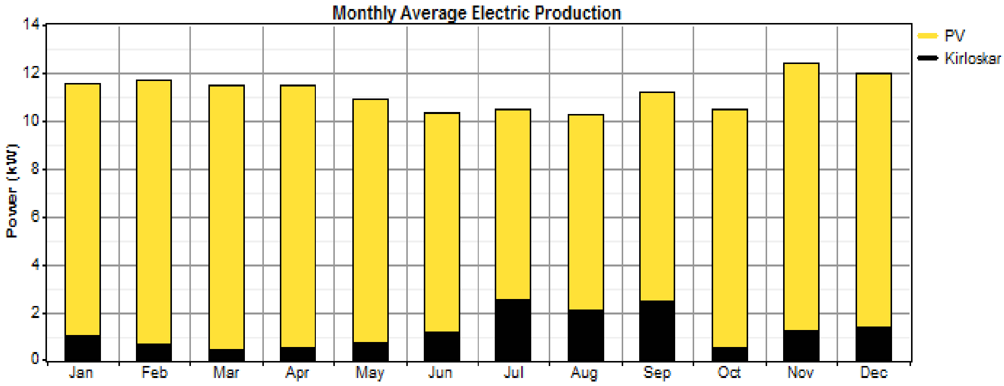

Figure 10: The monthly power contribution from PV and diesel generator

The months of February, March and April fall into the peak of dry season with higher sunshine hour, higher clearness index and higher global solar radiation. Consequently, the hour of runs of diesel generator is reduced during these months.

*6.1 Sensitivity analysis*

Sensitivity analysis shows the dependency of a given system characteristic on some defined input variable in order to examine the flexibility of the system and make good design decisions [3]. The price of diesel is not stable as it depends on the currency exchange rate, availability of diesel fuel and the haulage distance. The cost of PV system component is also fluctuating depending on improvement in technology and the exchange rate. For example, the cost of PV panel has reduced by about 70% in the last seven years as a result of improvement in PV technology [17]. It is therefore necessary to determine how the fluctuating diesel price and changing PV system component affect the cost of electricity. To achieve this, diesel prices ranging from \$0.77- \$1.37 per litter and change in PV system component by a factor of 0.8-1.2 were used in the sensitivity analysis. Figure 11 depicts the effect of diesel price and cost of system components on unit cost of electricity. The figure revealed that there is an inverse relationship between the diesel price and the unit cost of electricity. Similarly, the cost of system component is inversely related to the cost of electricity. Figure 12 reveals the relationship between the cost of electricity and diesel price at different solar irradiation. The figure shows that the Cost of Energy (COE) decreases with a decrease in diesel price and increase in solar radiation. The higher the solar radiation, the lesser the COE and the higher the price of diesel, the higher the cost of electricity. Figure 13 depicts the relationship between the cost of system component and the cost of electricity at different solar irradiation. The figure reveals a sharper slope compared to Figure 12, indicating that the change in the cost of system component affects the cost of electricity more compared to the change in diesel price.

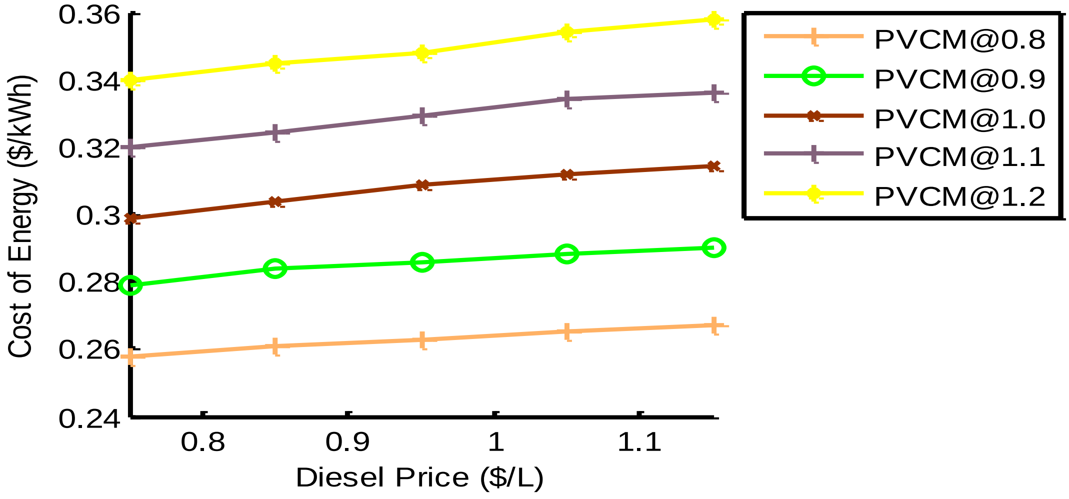


Figure 11: The sensitivity analysis of diesel price and cost of system components on COE

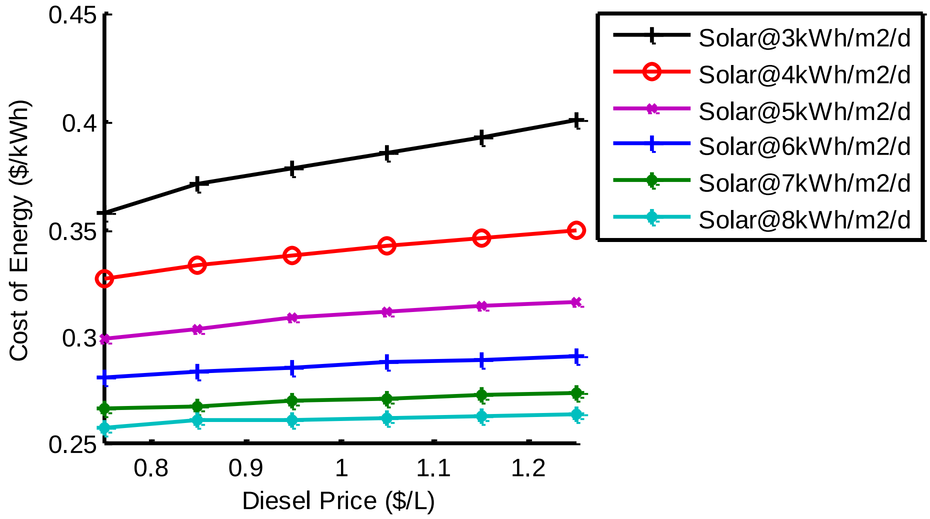


Figure 12: The sensitivity analysis of diesel price and solar radiation on COE

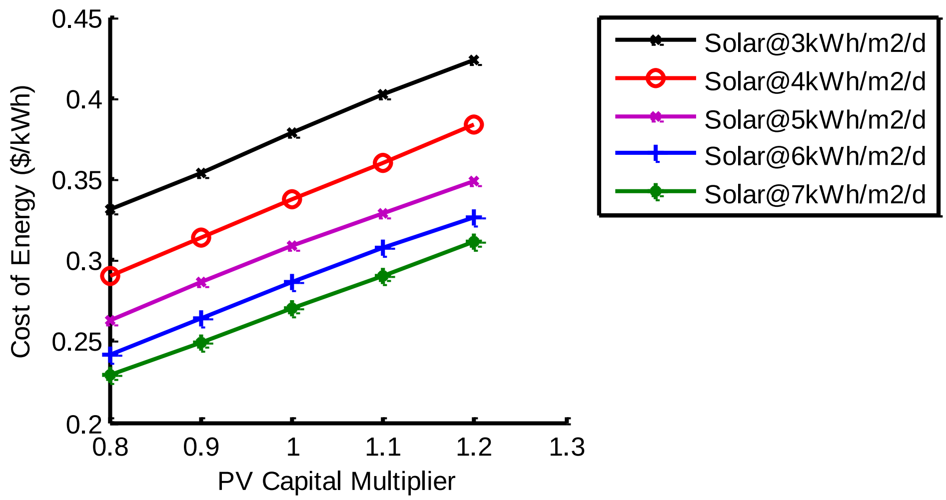


Figure 13: The sensitivity analysis of solar radiation and cost of system components on COE

### *6.2 Emission analysis of the proposed hybrid system*

To appreciate the environmental benefit of the proposed system, the emissions resulting from the hybrid energy system is compared to a situation where diesel generator alone is used to power the village. The result is depicted in Table 2 and the emission factor to arrive at the result is given in Table 3. From Table 2, the number of hours of run of the diesel generator when operated in hybrid system is 1675hrs. This represents 19% of the total hours in a year. Solar energy is able to meet up the electrical energy need of the village in the remaining 81% of time, thereby preventing the running of diesel generator. The significant decrease in the fuel consumption of the diesel generator resulted in about 90% reduction in $CO_2$, 91% cut in CO emission and significant reductions in other particulate matters. Consequently, the air pollution is greatly reduced and life of the diesel generator is better prolonged. In this way, the energy need of the village is met in a greener and more sustainable manner.

Table 2:Emission Comparison of Different System Combinations

| Diesel Generator | PV/diesel/Battery | Diesel only |
|---|---|---|
| Generator operational hour (hrs) | 1675 | 8,670 |
| Fuel consumption (L) | 3,025 | 32,996 |
| Carbon dioxide (kg/yr) | 7,967 | 86,891 |
| Carbon monoxide (kg/yr) | 19.7 | 214 |
| Un-burned hydrocarbons (kg/yr) | 2.18 | 23.8 |
| Particulate matter (kg/yr) | 1.48 | 16.2 |
| Sulfur dioxide (kg/yr) | 16 | 174 |
| Nitrogen oxides (kg/yr) | 175 | 1,914 |

Table 3: Emission factors used in the analysis

| Emissions | Factor |
|---|---|
| Carbon monoxide (g/L of fuel) | 6.5 |
| Unburned Hydrocarbon (g/L of fuel) | 0.72 |
| Particulate Matter (g/L of fuel) | 0.49 |
| Proportion of fuel surfur converted to PM (%) | 2.2 |
| Nitrogen Oxide (g/L of fuel) | 58 |

### *6.3 Break even period of the system*

For any power project, the interest of every investor is to know the probable period he will recoup his investment, hence, the need to determine the payback period of the proposed hybrid energy system. The payback period is determined as:

$$Payback\ period = \frac{NPC\ (\$)}{Annual\ \ load\ consumption\ (kWh) \times COE\ (\$/kWh)} \tag{11}$$

The computed payback period based on the COE of $0.309/kWh is 12.8 years. This is the period beyond which the investor would begin to have return on investment. Considering the economic incapability in the rural communities, the dweller might not have economic power to pay for electricity bill at this rate ($0.309/kWh). In order to make electricity affordable to the villagers, the COE can further be reduced by extending the payback period through government intervention/private investors. The longer the payback period, the lower the cost of energy as depicted in Figure 14. For affordable rural electrification, the payback period should not be less than 25years. This results into the cost of electricity of about $0.158kWh. However, this long payback period may discourage private investors. As such, there should be government intervention to subsidize the cost of electricity. In this way, sustainable electricity which could boost the socio-economic life of the rural communities could be achieved in a greener manner.

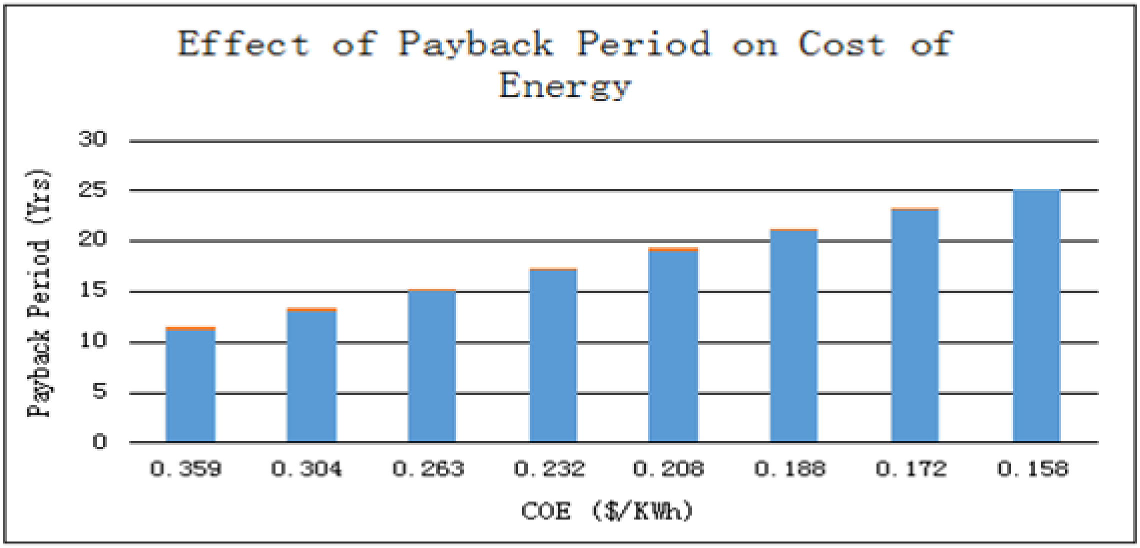


Figure 14: The payback period and the cost unit electricity

## 7. Conclusion

This study has investigated the technical, economic and environmental benefits of utilizing sustainable hybrid energy system for electricity generation at Ojataye village through an extensive load audit and analysis. From the findings, the estimated peak and daily load consumption of the village are determined to be 20 kW and 177kWh/day respectively. Assessment was carried out on both the wind and solar resources of the village; however it was found that solar energy is the only renewable energy resource viable in the village. Based on this available resource, the optimum architecture for electricity generation in the village was determined to be PV/Diesel/Battery hybrid energy system. The configuration consist of 60kW PV, 20kW diesel generator, and 110 numbers of Battery. The total net present cost of the configuration is $254, 948, the initial capital cost is $132,750 and the operating cost is $9,559. The cost of generating electricity is $0.309/kWh with renewable energy fraction of 89%. The study also revealed a saving in fuel consumption of 29971 litters/annum compared to utilization of diesel generator only. This cumulates into mitigation of 78.924kg/annum and 194.3kg of carbon dioxide and carbon monoxide. The break-even period is 12.78 years at $0.309/kWh.

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