



## Energy Cost Analysis of Hybrid Stand Alone Solar PV/Diesel Generator: A Case Study of Adora Farms, Hayin Dan Bushiya, Kaduna Nigeria

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### ABSTRACT

This study presents the performance and cost analysis of PV/diesel hybrid power system with battery backup for a rural application at Adoro farms kaduna. It consists generally of a Photovoltaic (PV), Diesel generator, battery bank and electric converter. The power demand of Adoro farms using hybrid energy sources were presented energy, cost analysis was conducted using HOMER software. This project gives the detail hypothetical study for standalone hybrid energy system for Adoro farms in five stages: 1) Select Diesel Generator as the only energy source; 2) select diesel generator as a primary energy source coupled with a battery bank as backup; 3) select solar PV as the primary energy source coupled with a battery bank as a backup source; 4) select solar PV as primary source of electric energy coupled with a battery bank and diesel generator as a back ; 5) compare all the cases one to four for optimal configuration. PV/diesel hybrid power system is very cost effective and more environmental friendly. It was found the hybrid Solar PV, Diesel Generator and Battery as Energy source have initial capital if higher and the operating cost is lower which constitute the net present cost to be the lower and also lowest the cost of electricity.

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### INTRODUCTION

Energy is very important in any individual lifecycle. As a developing country, Nigeria is facing tremendous challenge of satisfying the power demand of its large population and propel the country's economic growth, considering the fact that the current supply is by far less than the demand (Dioha *et al.*, 2006). Now, it is the time to think alternative energy source with maximum performance and cost effective. Therefore, alternative means of satisfying the demand is highly in need. A hybrid energy system is an electrical power source that combines different energy sources, from both renewable energy and non-renewable sources (Rekioua, *et al.*, 2013) In addition, it includes electricity storage bank. In general, hybrid energy systems of PV/Diesel Generator can provide a steady electricity service for rural application with cost effective and high performance, offering also the possibility to be connected to the grid in the future (Hoque *et al.*, 2012). Renewable energy use also reduce environmental impacts, ensure the potential of sustainable energy production and reduce the cost of providing it the end uses (Surekha *et al.*, 2012).

Energy in Nigeria is one of the major constraint to economy growth of the country (Dioha *et al.*, 2006).

The electrification of rural and remote production areas using renewable energy sources will no doubt provide sustainable economic development of such regions. The usage of medium to large scale wind/diesel, PV/diesel and wind/PV/diesel hybrid power systems for remote and rural electrification in around the world is gaining increased attention (Shafiqur and Luai, 2010). This paper presents energy cost analysis of a hybrid power system for a remote farm in Kaduna State of Northern Nigeria.

### DATA COLLECTION

#### Solar Energy Resource

The solar energy source was used for the stand alone hybrid system. The data for area of Kaduna town with geographical coordinate's 10°34.6'N 7°26.4'E was obtained with the annual average of solar irradiation is estimated 5.92 kWh/m<sup>2</sup>/d (Ikechukwu *et al.*, 2016). The solar radiation data inputs as used in HOMER software, on the top bar readings is the clearness index of the solar radiation as shown in Figure 1. The clearness index is generated automatically by HOMER.

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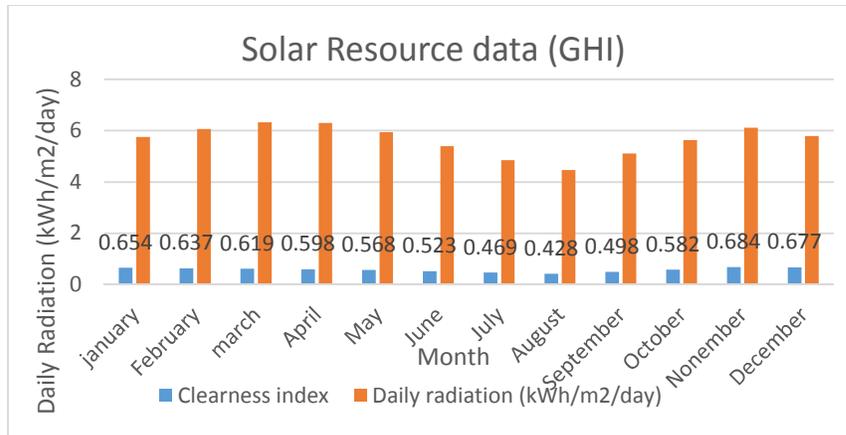


Fig. 1: The annual solar radiation and the clearness index for the location Kaduna, Nigeria

### Electrical Load Demand

In this study, Adoro farms was selected to test the feasibility of the design of stand-alone PV/diesel

hybrid power system with battery backup for a rural application.

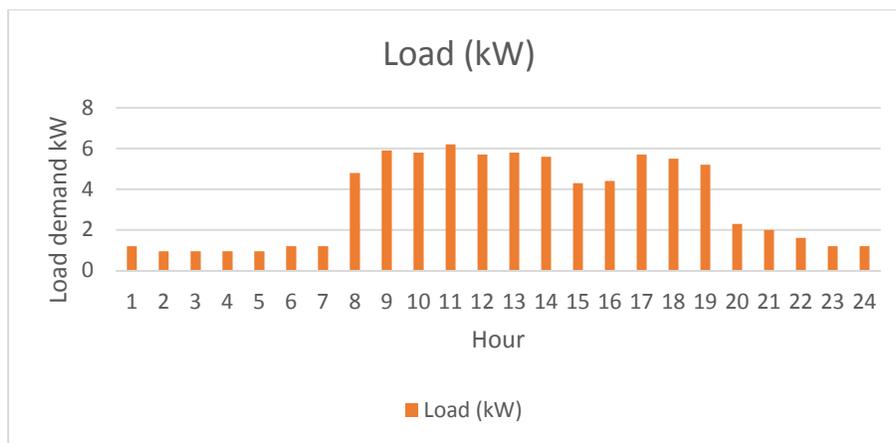


Fig 2: Daily load profile for the studied Area at Adoro Farms.

Fig 2. Daily load profile for Adoro Farms.is shown in Figure 2, it can be seen that the maximum load is between 8:00 hours to 19:00 hours. The scaled

annual average energy demand of the farm is shown in Fig 3 as simulated by HOMER software.

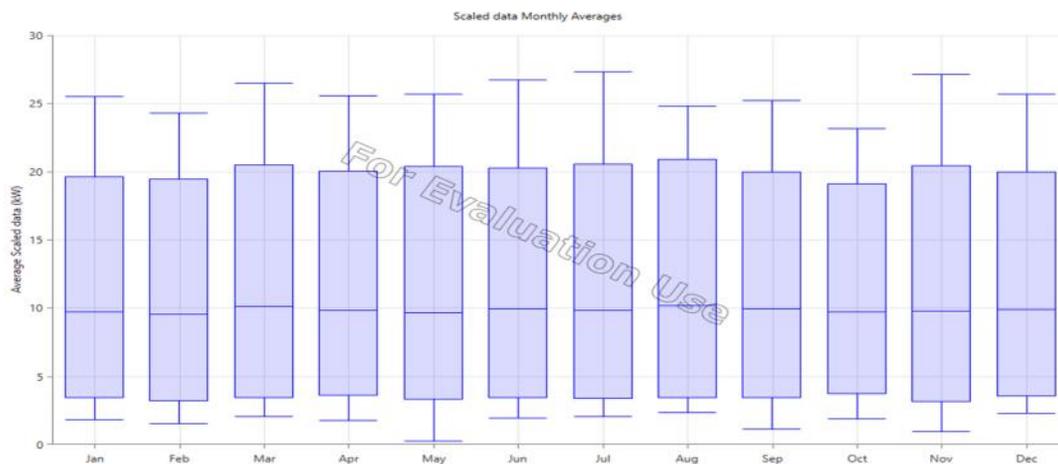


Fig.3: Monthly load detail

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In determining the maximum electrical load used in the study area each and every electrical appliances wattage was recorded, the table 3.1 below shows the details of the electrical appliances energy consumption.

Electrical load in Adoro farms varies with the activities in the farm. Usually from about 07:00hrs to

18:00hrs the load use to be high up to about 6.2kW and from 19:00hrs to 06:00hrs in the next morning the load goes down because there is no much activities going on in the farm. The load profile analysis calculation is listed in Table 1.

**Table 1:** maximum electrical load in the study area

S/N	Appliances	Number of unit	Watts per unit (W)	Total watts (W)
1	Energy saving bulb	50	24	1200
2	Water pump	2	700	1400
3	Electric cooker with oven	1	1800	1800
4	Electric water heater	1	1200	1200
5	Television 25'	3	150	450
6	Satellite dish	1	70	70
7	Room Air conditioner	3	1000	3000
8	Ceiling fan	8	65	520
9	Computer PC	4	120	480
10	Refrigerator	2	500	1000
11	Variable loads (socket outlet)	10	250	2500
Total watts (W)				13,620

**SYSTEM DESCRIPTION AND SPECIFICATION**

Hybrid energy systems are electrical power source that combines two or more energy sources. (Hoque *et al.*, 2012). In addition, it includes electricity storage bank. In this study, each system, and technical and economic performance parameters was conducted using HOMER software tools.

Current Type	DC
Life time	25
Abbreviation	PV

**A. PV array**

In this paper, the nominal power rating for the PV modules is 1 kW, which would be enough to provide the peak Adora farms demand. The PV module adopted is a polycrystalline silicon type with maximum output of 1000W. The specifications of the PV in this study, are listed in Table 2. In this project, the initial cost of a 1000W solar PV panel is ₦120,000 with a replacement cost of ₦134,976. In this study, the derating factor is assumed to be 92%. The ground reflectance of solar radiation is also assume to be 20%, and the lifetime is assumed to be 25 yr.

**B. The Battery Bank**

The study assume that the battery properties remain unchanged throughout its lifetime and will not withstand all external factors such as temperature. The Kinetic Model Batteries, voltage of 12 V, with a capacity of 260 Ah storage batteries were chosen in this simulation. The batteries are connected in series, which form battery string that consists of 2 batteries in each string. Each string of battery can produce 4.8 kWh of electricity. The estimated price of each battery is ₦100,000 with a replacement cost of ₦112,480. The life expectance of battery is 6yr. The specifications of the battery in this study, are listed in Table 3.

**Table 2:** Solar PV panel Properties

Solar PV properties	
Description	Specification
Make	Generic solar PV
Capacity	1000W

**Table 3:** Battery Properties

Battery properties	
Make	Kinetic Battery Model
Rated Capacity	260Ah
Charging current	43A

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Nominal Voltage	12V
Life time	6 years
Abbreviation	Dis 12V

### C. Inverter

The inverter adopted for this in this project is a Su-Kam 10kVA/180V Electric Converter. The estimated capital cost of an inverter is ₦720,000 and replacement cost of ₦ 809,856. An estimated lifetime of 15 years was used. HOMER was used to simulate each system with power switched between the inverter and the generator. For more detailed specifications, see Table 4.

**Table 4:** Electric converter Properties

Electric converter properties	
Description	Specification
Make	Su-Kam 10KVA/180V
Rated Capacity	10kW
Life time	15

### D. Diesel Generator

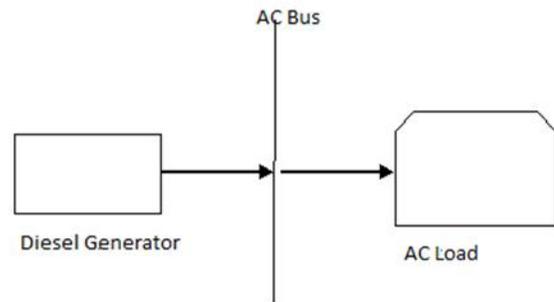
Wilson 12.5kVA Fixed Capacity Generator set was selected. The Diesel price used for sensitivity analysis was ₦214 per liter as present diesel price in the market the initial cost of a 100W solar PV panel is ₦120,000 with a replacement cost of ₦134,976 and operational and maintenance (O&M) cost is ₦1,806/year. The Diesel Generator data is shown in Table 5

Battery properties	
Make	Wilson 12.5kVA Gen set
Rated Capacity	12.5kVA
Charging current	43A
Nominal Voltage	3 phase 415V
Life time	6 years
Abbreviation	Dis 12V

**Table 5.** Diesel Generator Properties

#### Case I (Diesel Generator as only Energy source)

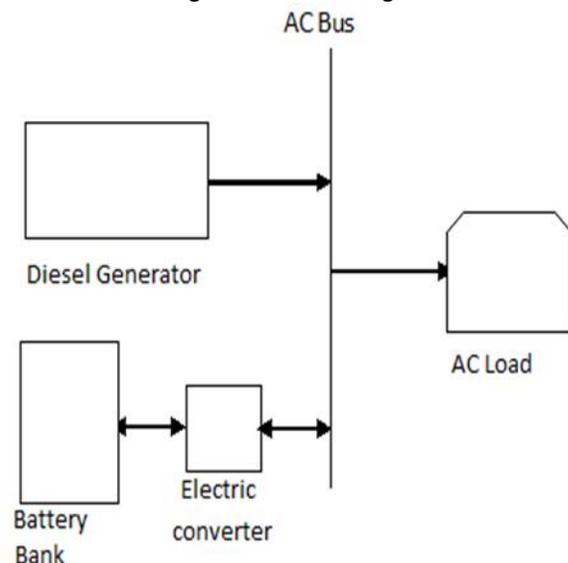
In case I configuration, diesel Generator set was selected as the only source of electric energy in adoro farm. Diesel Generator set was connected directly to the farm settlement through the AC bus. Down time of three hours was considered daily from 05:00hrs to 08:00hrs to allow the Generator rest and make some technical checks. Fig 4 shows the configuration Block diagram



**Fig. 4.** Case I configuration (Diesel Generator as only energy source)

#### Case II (Diesel Generator coupled with Battery storage as energy source)

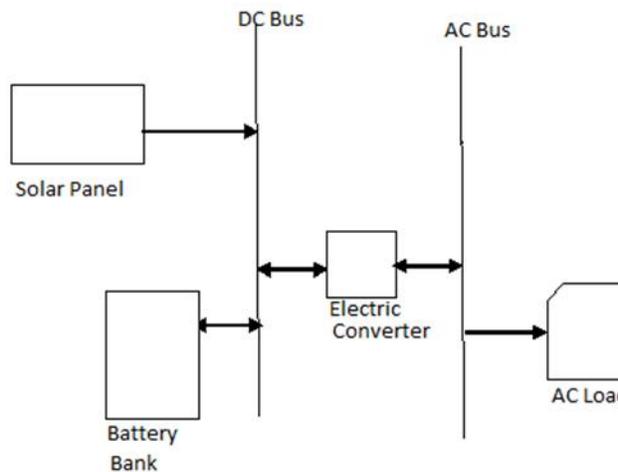
In Case II configuration Diesel Generator was connected to AC Bus and the AC Bus supplies to Adoro farms, an electric inverter is also connected to the AC bus which convert AC to DC to charge battery bank. the inverter will convert the DC power stored in the battery bank to AC at standard level of voltage and frequency and then supplies to the AC load, the battery bank serve as a back-up supply during the generator down time. The excess energy of the generator supply is used to charge the battery bank when there is low demand in the farm. The diesel gen down time in this case was considered to be 6hrs. Fig 5 shows the configuration block diagram.



**Fig. 5** Case II configuration (Diesel Generator and Battery Bank as energy source)

**Case III (Solar PV and Battery storage as Energy source)**

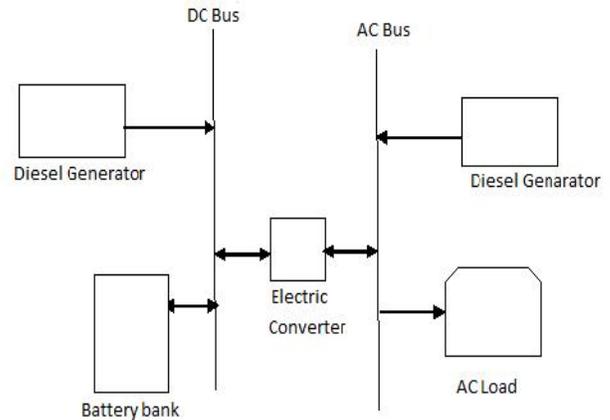
In case III configuration, Solar PV was selected as the primary source of energy. power is to be supplied from PV-system to DC bus, battery bank was also connected to DC bus, electric inverter connects to the DC bus to converts the DC to AC at standard level of voltage and frequency and then supplies to the AC load in the farm, the battery bank serve as a back-up supply during the Solar PV down time when there is no sun light. Fig 6 figure shows the configuration diagram block diagram.



**Fig. 6:** Case III configuration (Solar PV and Battery Bank as energy source)

**Case IV (Solar PV, Diesel Generator and Battery as Energy source)**

In case IV configuration, Solar PV was selected as a primary source of Energy while Diesel Generator was selected as a backup sources of energy. Solar PV was connected to DC bus in parallel with a battery bank, electric inverter is connected to the DC bus it converts the DC to AC at standard level of voltage and frequency and then supplies to the farm settlement through the AC bus, the battery bank serve as a back-up supply during the Solar PV down time when there is no sun light. Diesel Generator is connected directly to the AC bus as a backup supply. Fig 7 shows the configuration block diagram.

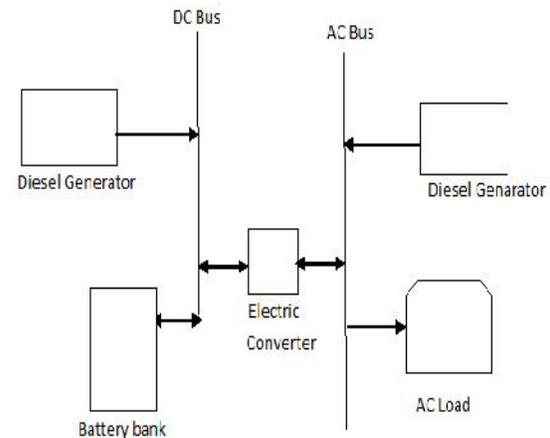


**Fig. 7:** Case IV configuration (Solar PV, Diesel Generator and Battery Bank as energy source)

**RESULTS AND DISCUSSIONS**

**Simulation energy system with HOMER tools**

In this study, the selection and cost analysis of the hybrid energy system conducted using HOMER software. The software was used to conduct sensitivity analysis for various hybrid power system options after providing the sensitivity of the hybrid system design key parameters, such as the resource availability or component costs. The simulation was done with a project's lifetime of 25 years. The schematic diagram of the stand-alone hybrid energy system as designed in HOMER simulation software is shown in Figure 4.



**Fig. 4:** Stand-alone hybrid PV/Diesel generator schematic Diagram.

In this study Simulation result. Solar PV panel, Diesel generator set and battery bank as source of Electricity, simulation design architecture in this case consists of 97.5kW capacity of solar PV panels as a primary source of electric energy, 10kW of

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Diesel generator set as backup supply, 45 number of 12V Battery connected in Parallel as backup supply, and electric converter of 10kW the inverter mean output is 3.35kW. Table 6 show the Capital cost, Operating cost per year, Net present cost and Cost of electricity. The capital cost is high but the operating cost per year is low compared to the previous cases that will make the net present cost to be lower than the other case. Table 7. Diesel Generator Simulation Result shows the generator energy production, hours of operation per year, fuel cost per year and maintenance cost per year. The hours of is not much hence the energy produce by diesel generator is less, and also the fuel cost per year. Table 8. Solar PV Panel

Simulation Result, shows the capital cost of solar PV panel and Energy production by Panel, being the solar as the primary source of energy 99% of the total energy produce in this scenario is from solar PV and only 1% is from diesel generator. Table 9. 12V Battery Simulation Result shows number of batteries used in simulation, Annual throughput in kilo watt hour per year, Nominal capacity in kilo watt hour, and usable capacity in kilo watt hour. The hours of autonomy determine the throughput, the usable capacity is almost 80% of the nominal capacity. The generator gas emission in this case is very little because of little hour of operation, table 10. show the emission of gases.

**Table 6:** Comparison analysis for all cases Simulation Result

Comparison analysis for all cases				
Parameter	Case I	Case II	Case III	Case IV
Capital Cost (₦)	2,500,000	6,430,000	16,700,000	19,600,000
Operating Cost (₦/yr.)	5,530,000	3,980,000	514,052	203,458
Net Present Cost (NPC) (₦)	828,000,000	601,000,000	93,500,000	49,900,000
Internal rate of return (%)	nill	44.6	35.6	29.7
COE (₦/ kWh)	188.46	136.78	21.29	11.35

**Table 7:** Diesel Generator Simulation Result

Case II Diesel Generator simulation Result					
Generator capacity on simulation(kW)	Hours/yr.	Maintenance (₦/year)	Cost	Fuel Cost (₦/year)	Production (kWh/yr.)
10	14	1,806		7,974	107

**Table 8:** Solar PV Simulation Result

Case IV Solar PV simulation Result	
Capital Cost (₦)	Production (kWh/yr.)
11,702,083	164,372

**Table 9:** 12V Battery Simulation Result

Case IV 12V Battery simulation Result					
Number of Battery in simulation	Autonomy (hours)	Annual (kWh/yr.)	Throughput	Nominal Capacity (kWh)	Usable Capacity (kWh)
45	33	8,347		140	112

**Table 10:** Diesel Generator Gas emission

Quantity	Value	Unit
Carbon dioxide	97.4	kg/yr.
Carbon Monoxide	0.736	kg/yr.
Unburned Hydrocarbon	0.0263	kg/yr.
Particulate matter	0.0446	kg/yr.
Sulfur Dioxide	0.239	kg/yr.
Nitrogen Oxide	0.837	kg/yr.

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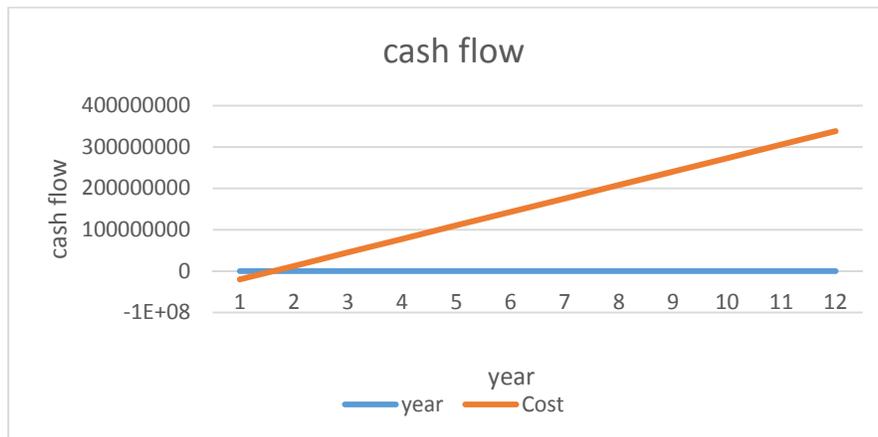


Fig 5. Simulation result cash flow

## CONCLUSION

This investigative study uses the concepts of levelised cost of electricity (LCOE) as tools to uncover the different angles to evaluating the costs of power generation. According to the load data of Adoro farms, the hybrid energy system is one of the strongest options for Nigeria to deliver the needed power in the most cost competitive way. It was found the hybrid Solar PV, Diesel Generator and Battery as Energy source have initial capital if higher and the operating cost is lower which constitute the net present cost to be the lower and also lowest the cost of electricity. The initial capital needed for this kind of hybrid energy system is high so it can be considered as the disadvantage in the beginning. In the long run this hybrid energy system will be more profitable than and as well as environment friendly solution when we look at it is annual operation and maintenance cost. What we have seen so far here in this design, we can conclude that this technology is the need of the future.

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