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Design and Feasibility Study of a PV-Micro Hydro Off-Grid Power Generating System

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Abstract

Renewable energy- based off-grid electricity supply has been considered as the solution to off-grid electrification problems of remote locations globally and also in Nigeria. This paper explored the potential of using a hybrid PV-hydro system to meet the electricity need of an off-grid settlement in Okuhuepen Waterside Community, Edo State Nigeria in a reliable and sustainable manner. The study shows Okuhuepen's capacity for sustainable off-grid power generation using the available energy potentials of the city. The socio-economic load demand of Okuhuepen was carried out, population growth rate and the corresponding due allowance was also considered.

1. Introduction

Energy is a rare and precious commodity and its value cannot be over-emphasized[1]. Energy is utilised in all households and it is one of the benchmarks of comfort and modern living. Its versatility is evident in being used in services ranging from domestic purposes such as cooking, heating of water, lighting, comfort to industrial purposes like mining, production and storage of food, transportation and warfare. Absence or shortage of energy has negative impacts on economic and industrial activities and also the general standard of living [2].

Presently, vast amount of the energy used in Nigeria are generated by fossil fuels. They are non-renewable and as such cannot be replenished once used up. The processes involved in generating energy from these fossil fuels usually leads to significant environmental degradation concerns.

Prominent amongst the renewable energy sources are hydropower energy, wind energy, solar and geothermal. These energy sources are self-replenished and can be used continuously without depletion. Emission of harmful environmental pollutants are considerably lower with these renewable energy sources. They are becoming conventional and a mainstay in many countries who are looking to move from environmentally detrimental fossil fuels. Researches and other environmental sensitization programs have been major reasons for this shift in focus in energy type.

National Electric Power Authority was established in 1972 for the development and maintenance of an efficient, co-ordinated and economical electric power supply system to cater for parts of Nigeria [5]. Forty-six years in the running now, we are still in the clutches of energy poverty.

Presently, Nigeria is estimated to have the potential to generate (installed capacity of) 12,522MW of electric power and an available operating capacity of about 3,879MW, and transmission capacity of 5300MW [3]. Due to several factors which range from logistics problems (gas supply, maintenance, etc.) and losses related to transmission and distribution, the portion of the installed capacity distributed to consumers is significantly lower. Even when grid connected power is present, only about 45% of the populace can access it [3].

Small scale renewable energy setup as a means of electrification are very few, but attention has begun to be drawn to it in recent times. With Nigeria having potential for power generation through different means of renewable energy sources such as; solar energy, wind energy, hydro energy, biomass energy, these renewable energy sources though available, have limited means to attain sustainability, leading up to the introduction of hybrid renewable energy technologies.
Okuhuepen Waterside Community is a small settlement in Uhunmwonde local government area of Edo State, Nigeria. It represents one of those settlements in Nigeria that are not connected to the national grid with the availability of renewable energy sources like a river. It is a settlement with vast potential for economic activities and hence economic prospects. Currently, Okuhuepen waterside community is a fish-farming hub and also there is the presence of cash crops farming, but there is potential for so much more. The effect of lack of electricity in Okuhuepen waterside community is adverse, affecting both the standard of living and the economic and all-round development of the settlement. Supplying electricity to Okuhuepen has been a daunting challenge for successive governments through the national grid network. To supply this electricity so craved for, we propose a hybrid system of photovoltaic and hydro components.

Table 1: Geographical particulars for case study

Particulars	**Details**
Village Name	Okuhuepen waterside community
District	Egbede
Local Government Area	Uhunmwonde
State	Edo
Country	Nigeria
Latitude	6.309727^{o}N
Longitude	5.855167^{o}E
Elevation (in meters)	86
River(s) available	1
Grid connection	0

1.1. Necessity of Hybrid System

Hybrid systems are viewed as the means with the highest efficiency to harness electric power from locally available resources where grid connection is infeasible geographically or economically. Populace living in communities with the aforementioned problems benefit majorly from these hybrid systems. They serve as helpful alternatives to these locations. Moreover, with the rising cost of harnessing or purchasing conventional more countries are shifting focus to these healthy and cost effective hybrid renewable energy technologies. Hybrid systems help in subsidizing clean renewable energy projects [1-9].

2 Methodology

2.1 Load Assessment

Electricity in Okuhuekpen is needed for domestic use in appliances such as; fans, radios, televisions, lamps, etc. and also socio-economic activities like agricultural and community activities; processing of crops like cassava and yam, water pumping for the fish farms, town hall, shrines, powering of relaxation centers. The scope was restricted to carrying out load assessment of only the social economic activities of the settlement.
The variation in seasonal usage of these appliances and also time usage of these appliances was not put into consideration. The load consumption for the socio-economic aspect of Okuhuepen was calculated to be 99.570kWh/day, with a peak load of about 4.15kW.

2.2 Socio-Economic Power Estimate of Okuhuepen Waterside Community

Table 2: Socio-economic load estimate

Appliance/Machine	Wattage(w)	Proposed number(n)	w*n	Operating hours (h)	Watts hour(w*n*h)
Cassava milling machine	373	4	1492	4	16412
Oil palm digester	5595	1	5595	4	22380
Fish-pellets producing machine	11800	1	11800	3	35400
Bore-hole pump	2000	1	2000	2	4000
Fish farm water pumps	400	6	2400	1	2400
Ceiling fan	35	8	280	12	3360
Fridge	150	3	450	24	10800
Freezer	350	1	350	24	1400
Led bulbs	10	8	80	12	960
Microphone	40	2	80	4	320
Power outlet(sockets and extensions)	50	3	150	12	1800
summation					99570

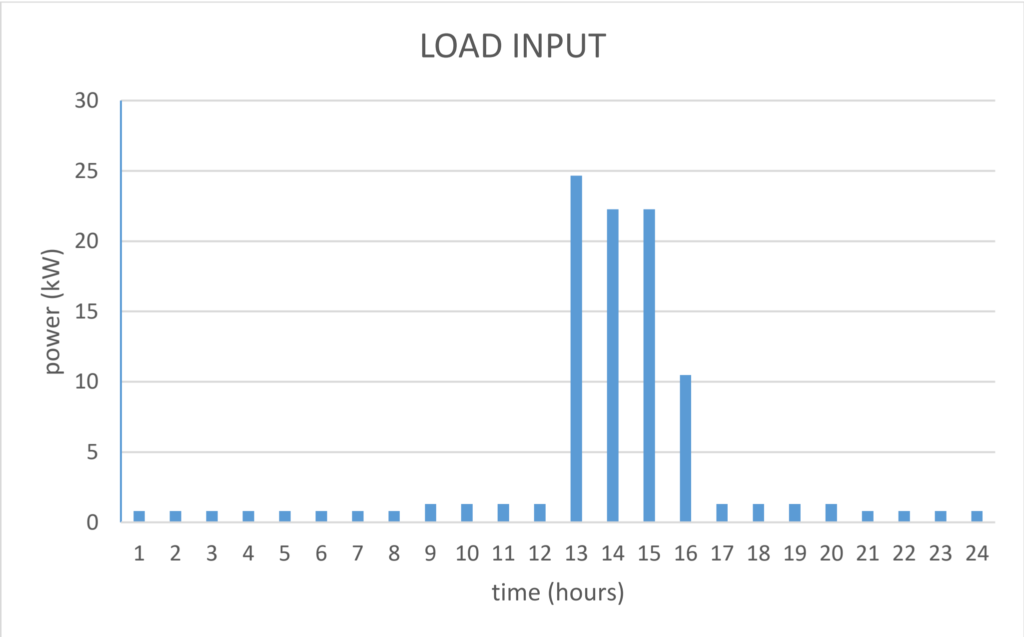

Figure 1: Socio-economic load input

2.3 Load Allowance

With the population growth rate of Edo State estimated at about 2.5%. We have accommodated the eventuality of population growth, in the demand for electricity in Okuhuepen Waterside Community. Currently Okuhuepen has a population of 298 people. In a ten year period (2018-2028), the population of Okuhuepen is estimated to be about 383 persons. Thereby considerably increasing energy demand in Okuhuepen. A graph of this projected growth rate is presented in Figure 2.

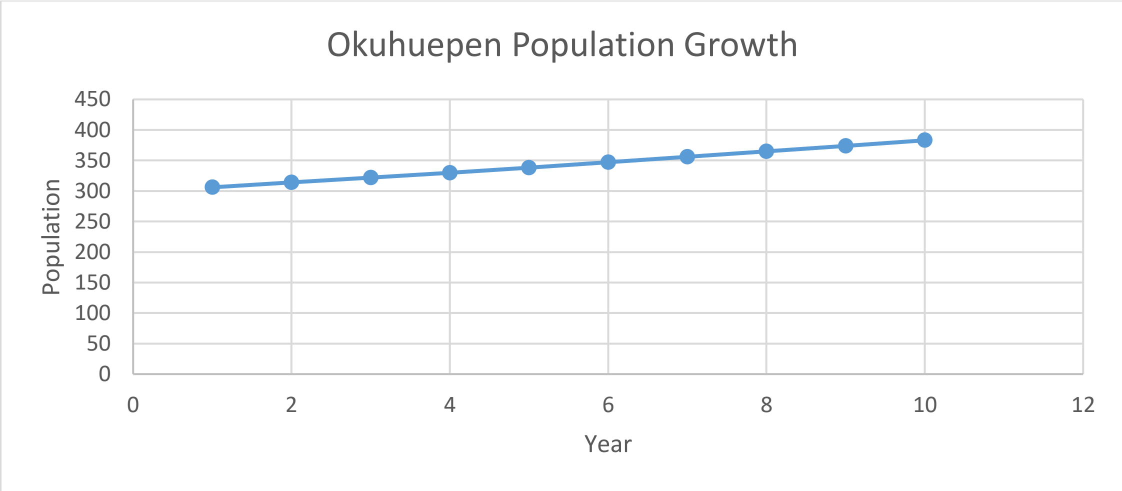

Figure 2: Graph showing steady population increase in Okuhuepen over the next 10 years

With these values in mind and in-order to accommodate population growth and consequent increase in demand, we have arbitrarily selected an allowance of 10%. The effect of this allowance on the load profile can be seen in Figure 3.

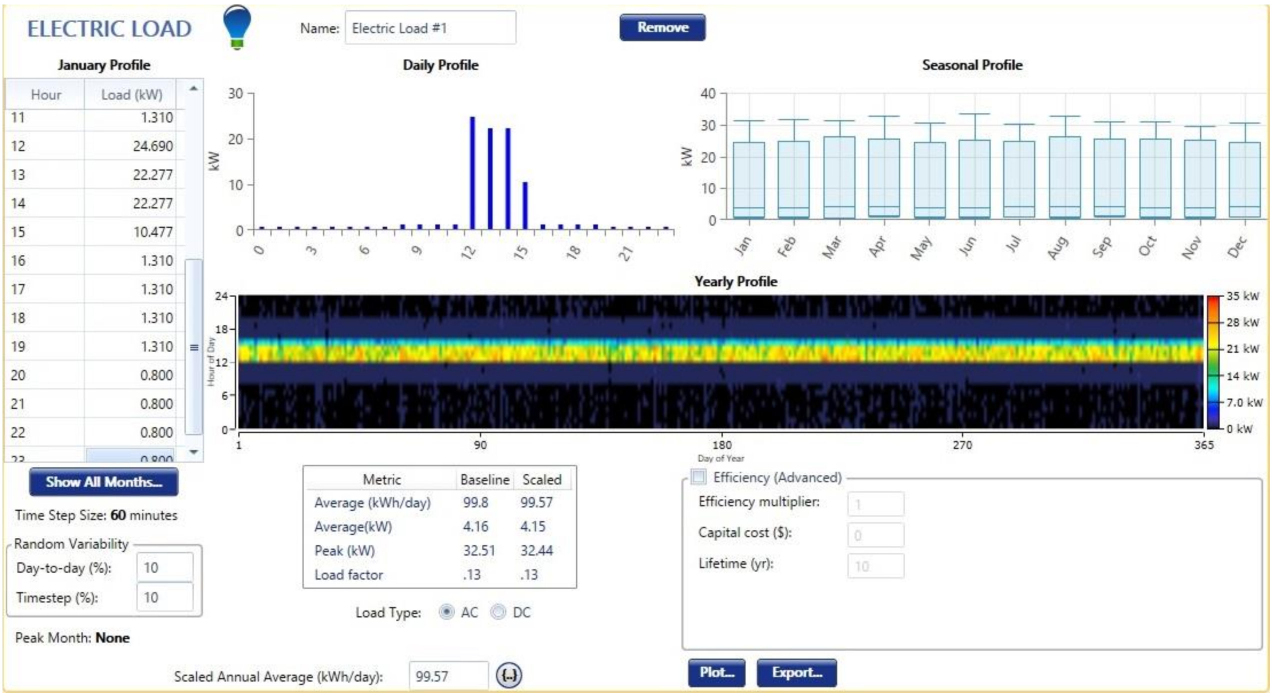

Figure 3: Load profile with 10% allowance

2.4. Solar Resource Assessment

The solar resource used for Okuhuepen Waterside Community was gotten from NASA Surface meteorology and Solar Energy database incorporated within the HOMER software. The values were taken at Latitude 6.5^o and Longitude 5.5^o. The annual average solar radiation was scaled to be 4.66kWh/m^2/Day and the average clearness index obtained was gotten as 0.470. Solar radiation is available all year round, therefore a good amount of power can be generated from it

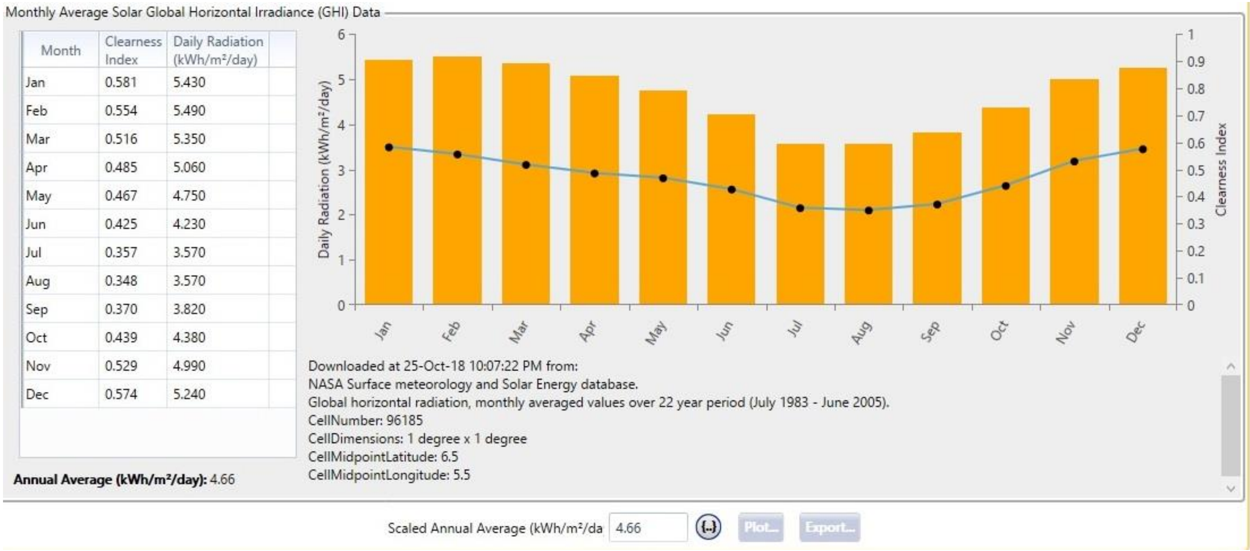

Figure 4: Okuhuepen's solar irradiation values

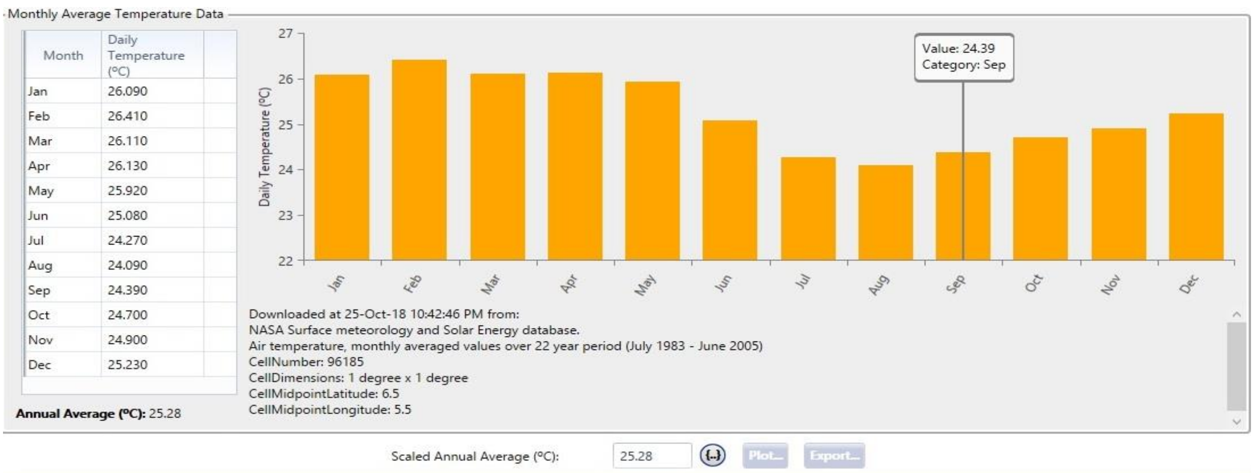

Figure 5: Okuhuepen's ambient temperature values

2.5 Hydro Resource Assessment

For the hydropower input, it was very important to know the quantity of water flow available from the river for power generation and the available head which are precursors to determining the potential of water in a river.

The values for our water flow was gotten from the book of proceedings of the 9th international conference of the Nigeria association of hydrological sciences (NAHS) for an estimation of stream discharge data for ungauged basin using SCS.CN method[10] from one of the research work done on ugonoba forest reserve area ,Okhuwan river which flows through the village and the stream flow rate data recorded annually across the 12 months exhibits a very high potential for use in the modeling and simulation of an hydropower plant system.

The stream flow data was acquired by field measurement (FM). To achieve this, a gauge height (staff gauge) , which was the measuring tool, graduated in black bars and similar to a tape measure was used to produce a visual indication of the depth of the river which was placed in Okhuwan river to take readings of water stage for 12 months, January to December. This water stage which is the measure of the stream surface height indicates how much water is moving through a stream or river at a particular point and is usually monitored by means of the staff gauge and then the discharge reading is gotten with the help of a float meter and recorded for different points. Having obtained the water stage and the discharge reading for the river, the actual discharge is then obtained with the aid of the rating curve. Which simply is plotting the water stage reading against discharge reading gotten from a float meter on a log paper to obtain a rating curve, where discharge values for the different gauge heights were obtained.

Figure 6: Average monthly stream flow at Okhuwan River

From the previous data, a summary of the flow properties can be made.

Table 3: Summary of the flow properties of the river

Maximum flow	Minimum flow	Average flow
317,010 L/s	208,102 L/s	261,142 L/s

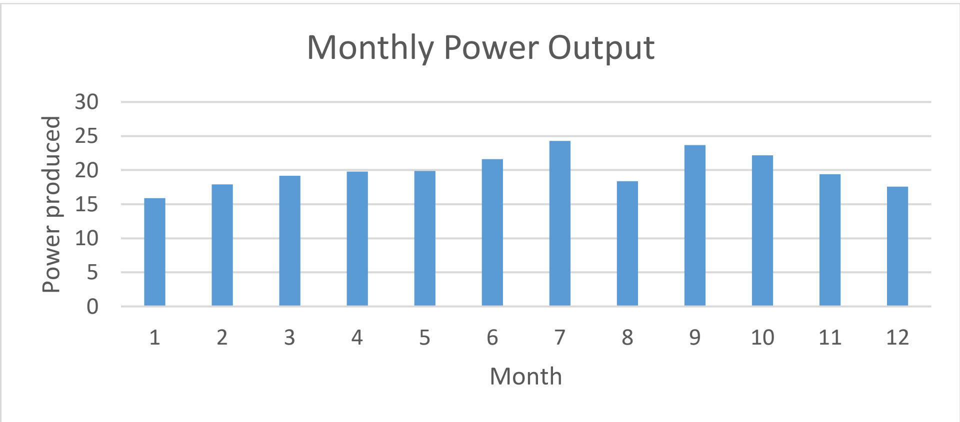

Figure 7: Monthly Power Output

2.6 Hybrid System Configuration

The hybrid system is principally made up of the photovoltaic and the micro-hydro components with the battery component acting as the storage system and the converter for conversion purpose of DC to AC.

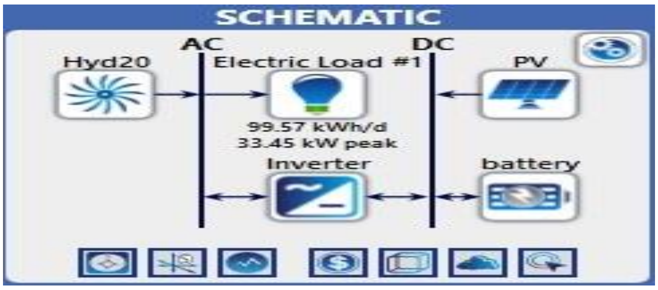

Figure 8: The structure of the hybrid system

2.7 Economic Modelling

Seeing that HOMER aims to minimise the total net present cost (NPC) in arriving at the optimal system configuration and also in the sensitivity analysis of the system, economics have a very critical role to play in the simulation. The benchmark chosen for the comparison of the different configurations' economics is the Life Cycle Cost (LCC), and the total Net Present Cost is its symbolism. All economic estimations used in this work are in terms of dollar.

3 Results

3.1. Optimization Result

Subsequent to the simulation performed by HOMER with the various possible combinations of components of our Hybrid system, two optimization results in terms of the proposed hybrid system were arrived at. Namely;

1. A hybrid system composing of only the micro-hydro component (Generic Hydro 20), the battery system (Surrette 6 CS 25P) and the system converter with the dispatch strategy used being HOMER cycle charging.

Table 4: system architecture of 1st hybrid

Component	Name	Size	Unit
Storage	Surrette 6 CS 25P	2	Strings
System converter	System Converter	15.0	kW
Hydroelectric	Generic Hydro 20	20.0	kW
Dispatch strategy	HOMER Cycle Charging		

2. A hybrid system that include a photovoltaic component (Generic flat plate PV), a micro-hydro component (Generic Hydro 20), the battery system (Surrette 6 CS 25P) and the system converter with the dispatch strategy used being HOMER cycle charging.

Table 5: System architecture of 2nd hybrid

Component	Name	Size	Unit
PV	Generic flat plate PV	10.0	kW
Storage	Surrette 6 CS 25P	1	Strings
System converter	System Converter	15.0	kW
Hydroelectric	Generic Hydro 20	20.0	kW
Dispatch strategy	HOMER Cycle Charging		

Table 6: Table comparing economic criteria between the two hybrids

Criteria	Hybrid 1	Hybrid 2
Net Present Cost (NPC)	$101,387	$122,736
Cost of Energy (COE)	$0.216	$0.261
Operating Cost	$1,944	$1,631
Initial Cost	$76,255	$101,655

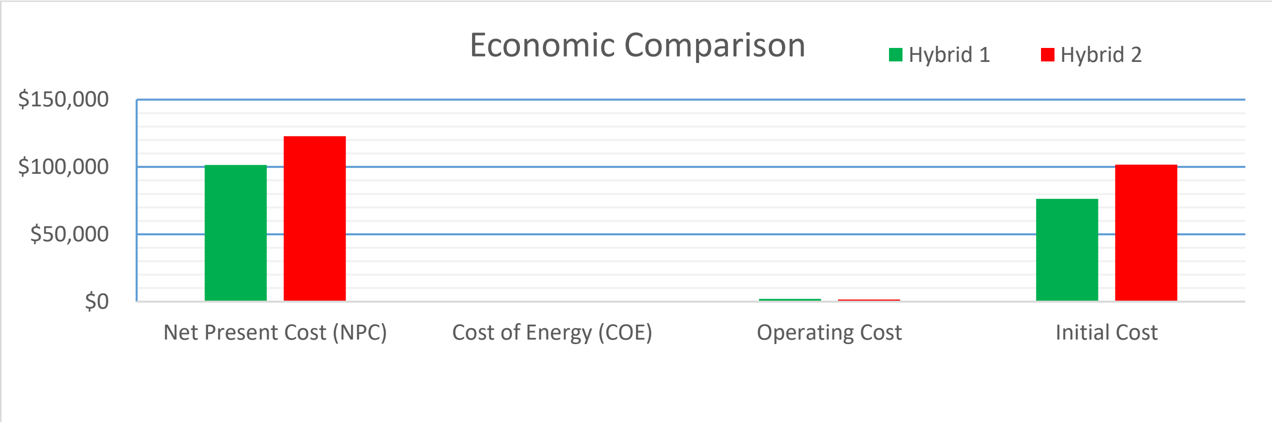

Figure 9: Graph showing economic criteria of the hybrid systems

3.2 sensitivity result

Sensitivity analysis performs the elimination of all possible combinations which are infeasible while ranking the combinations which are feasible taking into consideration uncertainty of parameters. HOMER enables us to take into consideration future developments, such as the increase or decrease of energy demand together with fluctuations relating to the renewable.

For the sensitivity analysis, the economic cost (NPC) and the cost of energy (COE) were chosen as the required criteria. Based on these criteria, the hybrid consisting of only the micro-hydro component (Generic Hydro 20), the battery system (Surrette 6 CS 25P) and the system converter was chosen having a **Net Present Cost value of $101,387** and a **cost of energy (COE) of $0.216** as against the hybrid consisting of a photovoltaic component (Generic flat plate PV), a micro-hydro component (Generic Hydro 20), the battery system (Surrette 6 CS 25P) and the system converter having a **Net Present Cost value of $122,736** and a **cost of energy (COE) of $0.261.**

This sensitivity result showed that our 1st hybrid is feasible for Okuhuepen waterside community and the right choice.

3.2 Analysis of Selected Hybrid

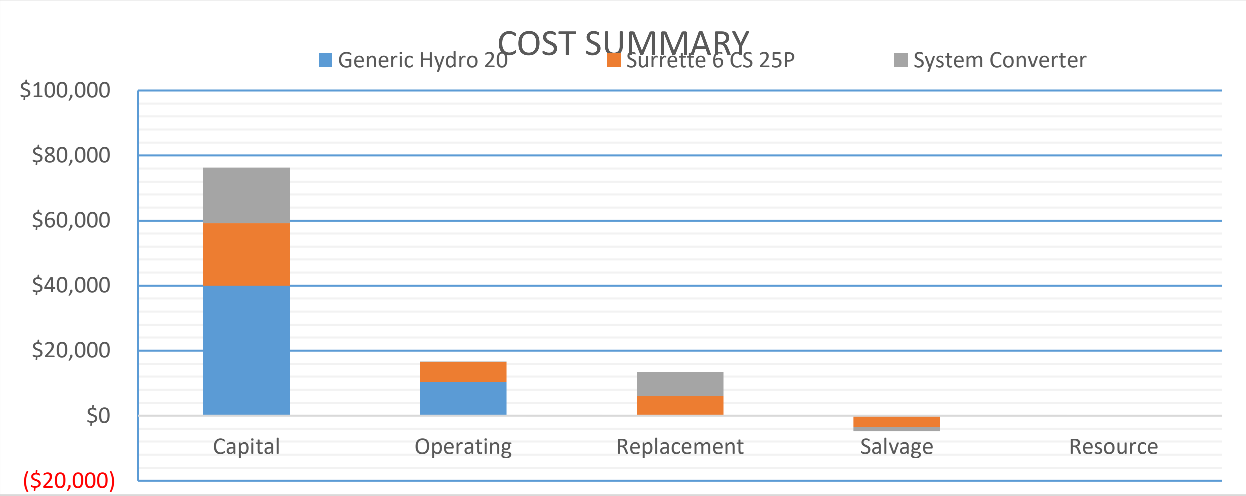

Figure 10: Chart showing cost summary of selected hybrid

Table 7: NPC of components of selected hybrid

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic Hydro 20	$40,000	$10,342	$0.00	$0.00	$0.00	$50,342
Surrette 6 CS 25P	$19,200	$6,205	$6,121	-$3,450	$0.00	$28,077
System Converter	$17,055	$38.78	$7,236	-$1,362	$0.00	$22,968
System	$76,255	$16,586	$13,357	-$4,812	$0.00	$101,387

As seen above in Table 7, the hydro component represents 52.5% of the capital cost, 62.4% of the operating cost and 49.7% of the total cost. Consequently, representing the component with the highest cost at net present value.

Table 8: Annualized costs of selected hybrid

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic Hydro 20	$3,094	$800.00	$0.00	$0.00	$0.00	$3,894
Surrette 6 CS 25P	$1,485	$480.00	$473.49	-$266.84	$0.00	$2,172
System Converter	$1,319	$3.00	$559.74	-$105.35	$0.00	$1,777
System	$5,899	$1,283	$1,033	-$372.19	$0.00	$7,843

Also in this Table 8, for the annualized cost, the same percentages as seen in Table 9 represent the value of the hydro component

Table 9: Summary of production

Component	Production (kWh/yr.)	Percent
Hydro	212,868	100
Total	212,868	100

With the hydro component being the only power generating component in the hybrid system, it is responsible for the total power produced by the system at 212,868kWh/yr or 24.3kW.

Table 10: Summary of consumption

Component	Consumption (kWh/yr.)	Percent
AC Primary Load	36,343	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	36,343	100

All the loads considered and proposed for Okuhuepen were all alternating current loads, thereby making up the total load.

Table 11: Result data of the battery

Quantity	Value	Units
Average Energy Cost	0	$/kWh
Energy In	2,219	kWh/yr.
Energy Out	1,777	kWh/yr.
Storage Depletion	1.23	kWh/yr.
Losses	444	kWh/yr.
Annual Throughput	1,986	kWh/yr.

Table 12: Converter Summary

Quantity	Value	Units
Hours of Operation	607	hrs/yr.
Energy Out	1,688	kWh/yr.
Energy In	1,777	kWh/yr.
Losses	88.8	kWh/yr.

Table 13: Summary of the hydro component

Quantity	Value	Units
Nominal Capacity	20.0	kW
Mean output	19.99	kW
Capacity factor	113	%
Total Production	198,161	kWh/yr.

3.3 Comparison with Grid Extension

The cost of grid extension considered in this work is the average cost of grid extension in Edo State, which has a value of 0.42$/kWh [8]. Whereas the cost of energy of our selected hybrid is 0.216$/kWh. The cost of energy of $0.216/kWh from this hybrid system is cheaper than that of $0.42/kWh from grid extension as considered for this study. Consequently grid extension does not seem to be a viable option to meet the Okuhuepen's demand.

3.4 Business Analysis

The optimal hybrid electricity supply system will require a development of 24.3kW power generating capacity in Okuhuepen Waterside Community. This business analysis will cover the business aspect of this project to a considerable extent. The business evaluation is needed to make for the total understanding of the economic impact of this work. Subsequently some of this aspects are briefly analyzed.

The first issue of this business analysis would relate to financing of the 'investment'. In the optimal case, an initial investment of $76,255 is going to be required for a 24.3kW system. Even though the investment cost is not too much for a conventional lender (e.g. banks) or utility investors, there are crucial risks attached to the investment.

Firstly, there is the possibility of failure of the particular project at Okuhuepen's Waterside Community, and the investment particularly for the small hydro turbine is not re-deployable. In the event of failure of the investment, it will represent lost resources for the investor and a generally bad business.

Secondly, the market for energy at Okuhuepen is not a developed one and may not meet projected estimations. This will affect the recovery process of the invested capital.

Thirdly, Okuhuepen Waterside Community which represents the business environment may be affected by series of negative occurrences such as political/security challenges or even climatic challenges making it unsuitable for investors.

Also, due to rate of illiteracy and other geographical difficulties like unavailability of skilled manpower and some unfavourable logistics which will minimize the profitability of the investment. In cases like this, suitable economic incentives will play a major part in attracting investors.

Another issue is the selection of a suitable business model to actualize the project. Whereas a private investor brings efficiency, experience and expertise to the business, he will likely be profit-oriented and unless the investment seems profitable, it will be infeasible for a private investor. Another option in this case will be the government who have been grossly unsuccessful in providing electricity in rural areas and consequently are not a reliable option.

A compromise may be achieved by a combination of the aforementioned bodies in order to actualize the project.

On an ending note, the regularization of the project and whichever body will efficiently run it must be considered.

4.Conclusion

This paper has been able to identify and optimize the best renewable energy technology using a combination of photovoltaic and hydro suitable for Okuhuepen's electricity need in a cost effective, reliable and sustainable way. The search for the off-grid solution to Okuhuepen's power demand resulted in a hybrid system composing of only the micro-hydro component (Generic Hydro 20), the battery system (Surrette 6 CS 25P) and the system converter that could meet and surpass the electricity need of this settlement at **$0.216/kWh**.

From the preceding analysis, the following conclusion can be drawn

i. Okuhuepen Waterside Community like some other off-grid locations in Nigeria is capable of meeting their energy needs using their available resources.
ii. The selected hybrid is a feasible off-grid solution to Okuhuepen's electricity problems.
iii. Seeing that the selected hybrid consisted of only the hydro component as the main energy generating component, the advantage of having a hydro source for off-grid generation remains a big one.
iv. As the power available for the hybrid is largely dependent on the river which is affected by seasons, the hybrid can be more reliable than it is presently.
v. From the value of initial cost of $76,255, it can be seen that the off-grid electrification is a cash-intensive project which should be assisted by the government or able private investors.

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