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OFF-GRID SOLUTIONS TO THE ELECTRICITY NEEDS OF THE RIVERINE AREAS OF RIVERS STATE

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ABSTRACT
Access to electricity in the riverine areas of rivers state is very poor. The area is mostly off grid as a result of the intricacy in extending the national grid through its difficult mangrove swamp terrain. This study investigated potential sources of energy in the riverine areas and to find out the cost effective off-grid option in meeting their electricity needs. Onsite visitations and observations, wind speed measurements using anemometer, and literatures show that the area is home to hydro resources, with average wind speed of about 7.22m/s at the coast line, and solar radiation of 4.39kWh/m2. A linear optimization model of a power system to meet a local demand was simulated using HOMER software with a view of solar, wind and diesel energy resources. The result revealed that the optimal configuration option among ten feasible options is a hybrid wind/diesel/battery system. The least cost of electricity is 22.21N/kWh while the diesel generator which is the existing system was higher at 108.72N/kWh. The result also showed that adding renewable energy fraction to the existing diesel system was seen to be economical at 20% fraction and above. In the light of these, access to electricity in the riverine areas of rivers state can be greatly increase by harnessing available renewable energy resources in the area for off grid electrification with backup from diesel generator pending sufficient power from the national grid and subsequent extension.

INTRODUCTION
Following the poor state of electricity in Nigeria for decades, the quest for access to reliable and affordable electrical energy has been on the forefront of National discourse in recent times. The current approach by the government at meeting the challenge is the deregulation of the power sector. This has removed federal government monopoly through NEPA thus allowing state, local governments, and private organizations to partake in the generation and distribution of electric power directly to consumers. The vision is to ensure that all nook and crany of the nation has access to electricity.

In Rivers state, more than 50% of the riverine areas are off grid, lacking electricity and inaccessible by road. The riverine areas of Rivers state are the parts of the state located in the coastal mangrove swamp region. It is characterized by a crisscross of rivers and swamps. Local government areas in this region include Andoni, Akuku-Toru, Asari-Toru, Bonny, Degema, Ogu/Bolo, Okrika, and Opobo/NkoroL.G.As. I.e. eight out of the twenty three L.G.As of the state.

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With the exception of Bonny town which enjoys steady supply from the gas turbines of the oil/gas firms NLNG and Shell, all other off grid LGA headquarters rely on power from diesel generator sets which are scarcely put to use due to high cost of fuel and maintenance of the generators. Smaller villages do not have distribution network in most cases and rely on candles, kerosene lamps or personal generators.

There is high rate of rural – urban migration in the coastal areas due to the poor state of electricity, access roads, government presence and other basic amenities. Although the electricity demand in these areas is not as high compared to other parts of the state, the mangrove swamp has continued to remain without electricity and as dark as the crude oil extracted from its region. High cost of project implementation due to difficult terrain is cited as the major reason for the dearth of these basic amenities; however the area has remained an attractive heaven for the multibillion oil and gas exploration in Nigeria despite the adjudged difficult terrain.

The Rivers State government has planned a number of electrification projects to link all parts of the state to the grid. In this vein, it is pertinent to explore other options apart from the traditional approach of grid extension or diesel generator system in meeting electricity needs. Off grid power systems using renewable energies is gaining more popularity in recent times especially in the developing nations. It is a complete system of meeting electricity needs without relying on power from the grid. The term off-grid simply means not connected to the grid. It is suitable for areas where the national grid not easily accessible or unreliable. The electricity generation can be of any kind, usually not in very large scale to provide power for a single home or clusters in a locality. It can be used as an alternative or complement to an existing system. The system encourages the harnessing of resources localized within an environment to meeting the needs of the locality.

The main objective of this work is to identify cost effective off-grid options in meeting the electricity needs in the riverine areas of Rivers State with a view of utilizing resources immediate to the environment.
The study attempts to achieve the following among others:

1. To investigate the potentials for off-grid electrification in the riverine areas of Rivers State?
2. To evaluate the economic importance of off-grid options by using renewable energy or hybrid systems.
3. To examine if off grid options will improve access to electricity in the riverine communities?

RELATED WORK

Off-grid electrification is gaining importance in the developing countries where the access to electricity is often limited (Subhes, 2012). In Nigeria, several contracts were awarded in 2013 by the federal government for the implementation of Wind, Solar, Biomass and hydroelectricity projects in different locations nationwide especially off-grid distant ones. Feasibility studies are ongoing for more proposals (Federal Ministry of Power, 2014). Other countries in Africa, Asia, and Latin America with support from international organizations are also working in this regards to provide access to electricity for rural locations (Fraunhofer, undated). Some urban consumers also resort to off-grid options as

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a result of poor supply from the grid and high cost of running diesel generators (ARE, 2011). A view of renewable energy penetration in Nigeria and other parts of Africa is shown in the following tables.

Table 1.0: Off-grid/Renewable Energy Utilization in Some African Countries

Country	Harnessed Power (Mw)	Number of Wind Pumps	Geothermal Power Generated(Mw)
Nigeria	33.0	10	-
Kenya	6.28	272	2000
Tanzania	4.00	100	-
South Africa	0.40	300,000	-
Uganda	0.50	7	450

Source: NAEE 2011

Table 2.0: Applications of Solar Energy in Nigeria

S/No	Off-grid Solar-PV Application	% By Capacity
1	Residential Mostly Lighting	6.9
2	Village Electrification & TV	3.9
3	Office/Commercial Lighting & Equipment	3.1
4	Street, Bill board, etc Lighting	1.2
5	All Lighting	15.1
6	Industrial	0.4
7	Health centre/Clinic	8.7
8	Telecom & Radio	23.6
9	Water Pumping	52.2
	TOTAL	100

Source: NAEE 2011

Economics of Off-Grid Electrification

A number of studies have been carried out to ascertain the feasibility, viability, and risk involved in the provision of electricity for off grid areas. Alliance for Rural Electrification (2011) noted that long distance from national grid, difficult terrain; low size of demand, small population size, and limited use of energy contribute to high cost of grid extension thus making off-grid a favorable option.

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The German Energy Agency (2012) carried out a global market analysis and found that countries in Latin America, Asia and Africa would benefit much from the use of off-grid applications. This analysis was based on their electrification rates, local diesel prices, political and economic conditions, the security situation and data on the rural population.

Reports from the media houses (Chinedu, 2013; Vanguard, 2014) have it that a lot of customers have complained about the high cost of bill from the electricity utility companies, and they have staged one form of protest or the other to register their grievances. Alliance for Rural Electrification, (2011) noted that grid electricity tariffs are the same for rural consumers connected to the grid as they are for urban users. Considering the poverty level in the rural communities, they will not be able to pay for electricity at the current production cost reflective rate. Of course the investors are in to make gains.Sinha and Kandpal (1991) in India found that villages located 25 kilometers away from the grid are viable for off grid option. They however added that the result obtained may differ from other countries based on their economic factors.

Uduak and Salisu (2012) had a conservative view considering the economic viability of using solar photovoltaic panels in providing electricity in a decentralized off-grid system to rural communities in Nigeria to meet the government set target of achieving 80% electrification by 2015. The research employed the total life-cycle cost and an estimated total life-time cost of 25 years of an off-grid electrification project using solar photovoltaic panels and compares with the cost of paying for grid electricity within the same period. They found out that such projects will not be economically viable under the prevailing market conditions. They however added that the viability of the project increases with favorable conditions like reduction in interest rate, availability of start-up grant, and reduction in equipment cost.

Generally the economics of off-grid technologies looks at the following case: Firstly, grid extension versus off-grid option for grid isolated settlements (rural areas). Secondly, the cost of utility bills versus cost of self-generation for already connected grid users and also benefits of complimenting off-grid technologies in a weak grid. Renewable Energy hybrid electric power systems can offer an economically competitive alternative to diesel engine generator (genset) systems in many off-grid applications (Rosenthal et al., 1997; Slaoui, 2011).

Sustainability of Off-Grid Electrification Technologies

A lot of concerns have been raised as to the sustainability of off-grid electrification options given the merits of the grid system and the variability of the popular green off-grid technologies. Sambo (2008) has it that sustainable energy development (supply and consumption), entails the exploitation, production and utilization of energy resources in such a manner that it meets human needs, while preserving that environment so that these needs can be met not only in the present but in the future.

With the negative environmental impact of fossil and nuclear sources of energy, renewable energy is considered a more suitable energy resource for sustainable development in view of its lesser environmental impact, social acceptability and its potentials for stimulating economic growth especially in the rural areas (Sambo, 2007). The need

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is explicit for an urgent paradigm shift from energy sources promoting CO_2 emissions and other forms of environmental degradation to eco-friendly sources (UsenobongandChuku, 2011).

Reiche et al., (2000) presented emerging design issues regarding off-grid electricity service, including new business models and, least cost options for village power, as well as initial lessons learned from rural off-grid concessions in Argentina and twelve solar home system projects. They concluded that developing sustainable local markets for off-grid service provision, which will outlast the funding requires innovative solutions in the demand side, supply side, financing and institutional strengthening. Social and economic sustainability needs can be met via an integrated utilization of RE systems, promoting localized energy that will greatly reduce dependencies on diesel and other conventional sources of energy. Though cost maybe higher in some instances, it is highly preferable for rural areas where installations and O&M to extend grid system are costly (Deepak et al., 2007).

METHODOLOGY

Research Design

The goal is to achieve the least feasible cost of electricity by minimizing the total cost of production subject to a number of constraints such as resource availability, demand, generator capacity, etc. Linear optimization method was employed in arriving at the optimal option. The researcher camped in the location during the period of the research to get a firsthand experience of life in the area and access the potential sources of energy in the study location. Solar resource was gotten through global irradiation information and wind speed data gotten by random sampling using anemometer. HOMER software was then utilized as a tool to simulate for an optimal configuration of the power system with an option of wind, solar, Battery and diesel generator in view.

Study Location

The project main site is Ikuru Town on the Andoni main Island; one of the group of islands in Andoni Local Government area of Rivers State. According to 2006 population census, the LGA covers an area of about 233square meters and population of 211,009. The geography of the area is typical of the Niger delta mangrove forest swamp and an aerial view depicts a shattered constellation of lakes, creeks and islands.Ikuru is an off grid, semi-urban community with scarcely populated fishing settlements scattered around the border to the Atlantic coast. It is situated around latitude 4° 22' 30" N, and longitude 7° 43' 29" E. on the Andoni main island. Other riverine areas along the Atlantic coast which share similar characteristics of the study location include Bonny Island in Bonny LGA and the Kalabari Islands in Akuku –Toru and DegemaLGAs.

Load Profile Assessment in the Study Location

Until now, the electricity need of the area was maintained by operating a diesel generator with the capacity of 500kVA. Electrical energy in the area is required for domestic, community and small scale businesses. The power demand in a typical semi-rural area shows a gradual rise from the morning hours, averaging at noon, peaking in the evenings, and gradually drops towards midnight. Estimated energy demand in the area is 324kWh/d.

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Potentials and Data of Energy Sources in the Study Area

Despite the fact that the area is not connected to the grid, electricity is still been utilized though in a microscopic nature. Diesel and gasoline generators are the primary source of power in the area. Domestic energy needs for cooking is largely met using firewood, or kerosene stoves, while lighting is by kerosene lamps, candles, or battery operated torches. The subsections that follows highlights the modes of meeting electricity needs in this area and potentials for other sources.

Solar Photovoltaic Energy

Solar radiation profile in the study area collected from global horizontal radiation information for the location of latitude 4° 22' 30" N, and longitude 7° 43' 29" E. shows an average radiation of 4.26kWh/m^2/d. Assuming the temperature effects on the PV cells are ignored, given the solar radiation (G) available on the tilted surface, the surface area (A), the PV penetration level (P) or yield in %, and the efficiency of the solar generator, (n_{PVG}), then the hourly energy output (E_{PVG}) of the PV generator can be calculated using the following equation

$$E_{PVG} = G(t) * A * P * n_{PVG} \quad (1)$$

Wind Energy

Onsite measurement of wind speed at Ikuru town along the open coastal beach bordering the Atlantic Ocean shows that the average wind speed point measurements gotten from the location at various hours of the day is 7.22m/s. This was gotten from a randomly selected sample of 169 populations. The energy generated per hour (E_{WEG}) by wind generator with rated power output (P_{WEG}) is defined by the equation:

$$P_{WEG} = \frac{1}{2}\rho_{Wind} AV^3 C_p(\lambda, \beta) * n_t * n_g \quad (2)$$

$$E_{WEG}(t) = P_{WEG} * t \quad (3)$$

Where ρ_{wind} = Density of air
A = surface area
v = wind speed in (m/s)
C_p = Performance coefficient of turbine, λ-tip speed ratio, β -pitch angle
n_t, n_g = wind turbine efficiency and genrator efficiency respectively

Hydro/Tidal Power

The riverine areas of rivers state is home to hydro/tidal power resources. Tidal power utilizes water trapped from a portion of the sea as it flows to run a turbine during ebb tide. Tides are caused by the combine gravitational forces of the sun and moon on the revolving earth. There are approximately 705 full tidal cycles in a year. The complementary nature of the tide and wind can be maximized to achieve a continuous generation of electricity as when the tide flows

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it is accompanied by great winds compared to the ebb tide. Also, tidal movements can be predicted to a large extent. This feature is an advantage in planning estimated available power.

Two high tides and low tides are usually experienced each day. The period of separation of each tide from the other is 12 hours 25 minutes (Obed and Jemima, 2011); hence each high and low tide occurs twice a day. Coastal Nigeria has been predicted to follow this pattern of tide called a semidiurnal tide, although some parts of the word experience diurnal tide, having only one high tide each day.

Fig. 1: Tidal waves of the Atlantic Ocean bordering Coastal Rivers state

The power available from a given head of water is proportional to the square of the head. The head varies with the tidal range, which is the difference in amplitude between the high tide and low tide. The tidal range in some part of the coastal rivers state has been predicted to be up to 3meters. (Chineke and Nwafor, 2007). Hence the coastal areas of Rivers state, bounded to the south by the Atlantic Ocean are well suited for this kind of power generation.

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Biomass

The coastal areas of Niger delta, despite the challenges environmental degradation caused by oil exploration still holds some of the richest belts of forest reserves. The mangrove tree commonly known as "ngala" is the widely used fuel wood resource though now in depletion. However another specie of the mangrove called nipper palm with great potentials for bio-products and fuel is in vast quantity and fast taking over the hinter parts of the area.

Off Grid Electrification Configurations

The popular off grid electrification configurations are the isolated systems, micro grid and mini grid. **Isolated systems** are stand-alone systems customized to power a specific load. Their output values may or may not be standard but are suited only for the designed load. Examples of this include the solar street light systems, solar lamps, solar radio etc. **Micro grid Systems** makes use of inverters, battery and an energy source preferably renewable. The loads are often AC, and can be adapted for different kinds of loads depending on the size of the inverter. Most home systems make use of this configuration to power a whole building and possibly few buildings. **Mini grid System,** as the name implies, can power a whole community. It is more of a hybrid system combining more than one source of electricity which could be only renewable or with a gen set. The network for this system is similar to the grid distribution system. Hence it could be grid integrated if provision is made. Typically off grid, distant rural locations are suitable for this kind of system.

Hybrid Wind/Solar Power system Architecture for the Location

A hybrid power system is proposed for the location. It consists of wind and solar will as main sources of energy with occasional use of diesel as a backup. The major components of the system will include diesel, renewable energy generators such as solar panel and wind turbines, battery, and converter. The proposed hybrid power system for the location is shown in figure 3.10 below:

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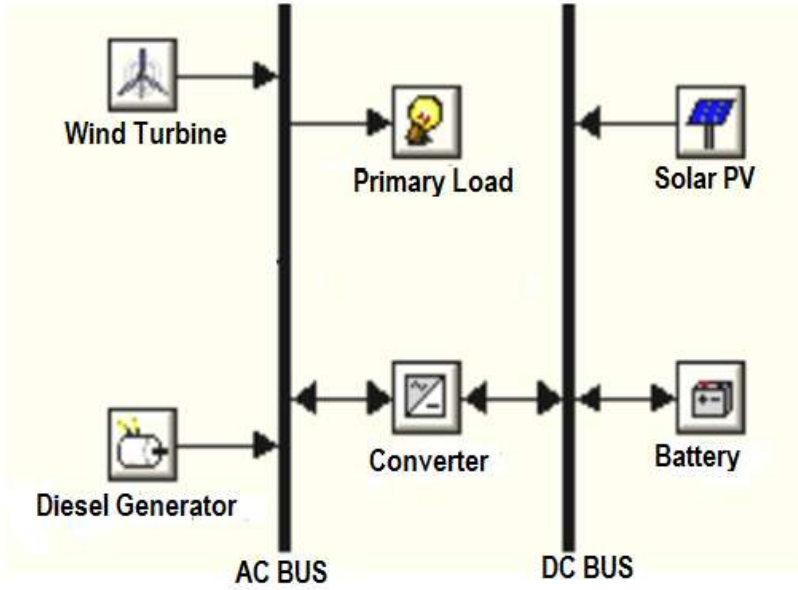

Fig. 2   Proposed scheme of hybrid power system for the study area

Optimization Model Equation

The model assesses the output constraints of each of the generating supply inputs with the objective of achieving a minimum cost of energy generation to meet the power demand. A general linear programming model for the hybrid system can be formulated as shown below:

Minimize: $C_t = \sum_{i=1}^{k} C_i * P_{Gi}$₦/$kWh$ (4)

Subject to: $P_{Gi\,min} \leq P_{Gi} \leq P_{Gi\,max}$ $\quad i = 1,2,\ldots k$

$$\sum_{i=1}^{k} P_{Gi\,max} \geq P_D kW/yr$$

$$\sum_{i=1}^{k} P_{Gi\,max} > P_D$$

$$P_{GI} \geq 0$$

Where $P_{Gi,min}$ and $P_{Gi,max}$ are the lower and lower real power generation limits of the i_{th} generator $P_{Gi,}$ and C*i* is the co7st/unit of the ith resource option. The cost of energy production from literatures reveal that cost of energy using

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solar, wind or diesel/gasoline is ₦70.14/kWh, ₦29.06/kWh, and ₦68.47/kWh respectively. Estimated annual available energy from the sources areSPV (1555kWh/m2/yr at average radiation of 4.26kWh/m^2/d), WEG (55,512kWh/N/yr at average wind speed of 7.22m/s) and DEG (151,478kWh/yr for 50kW Gen) respectively. With the estimated energy demand of 118,341kWh/yr, our model equation becomes:

Minimize: $C_t = 70.14SPV + 29.06WEG + 68.47DEG$ (5)

Subject to: $\mathrm{SPV} + \mathrm{WEG} + \mathrm{DEG} = 118{,}341\mathrm{kWh}/yr$ (6)

$$SPV \leq 1555kWh/m^2/yr$$
$$WEG \leq 55{,}512kWh/N/yr$$
$$WEG \leq 151{,}478kWh/yr$$
$$SPV, WEG, DEG \geq 0$$

HOMER Simulation

The optimization equation is solved using HOMER software. The energy resources available as well as the cost of generating units, and demand are inputted into the software to get an optimal feasible option.

RESULTS AND DISCUSSIONS

Table 3.0: Cost of Components

Resource	Size (kW)	Capital Cost ($/kW)	Replacement Cost ($/kW)	Fixed O&M Cost ($/kW-yr)	Life span
Solar	4	4340	2126.6	48	25
wind -Onshore	1kW	1980	1603.8	60	20
Converter	4	516	516	0	0
Battery	2.4	335	301	0	5

Result of Homer Simulation for feasible Off Grid Configuration Options

The result of the simulation of feasible combination of hybrid off grid wind, solar, battery, and diesel generator energy systems is represented in the table shown below:

Table 4.0: Feasible off grid configuration options

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S/N	PV (kW)	No. of WT	Diesel Gen (kW)	Battery	Converter (kW)	Initial capital (₦)	Operating cost (N/yr)	Total NPC (₦)	COE (₦/kWh)	Renewable Energy fraction	Diesel (L)	Diesel Gen (hrs)
C1		4	50	16	20	16,272,313	1,359,714	33,654,174	22.211	97%	3,849	493
C2	4	4	50	16	20	19,168,093	1,364,557	36,611,243	24.215	97%	3,787	485
C3		9		16	20	31,085,380	1,601,029	51,551,063	34.068	100%		
C4	4	9		16	20	33,981,160	1,616,226	54,641,398	36.072	100%		
C5		9	50			31,479,333	2,334,159	61,316,889	40.581	98%	4,883	630
C6	4	9	50		4	34,461,285	2,321,300	64,135,181	42.418	98%	4,712	608
C7	30		50	16	30	24,979,693	9,076,116	141,002,275	93.353	27%	43,543	4,619
C8			50	16	10	2,830,483	11,365,519	148,119,147	98.029	0%	60,388	6,850
C9			50			1,719,933	12,713,877	164,245,168	108.717	0%	72,906	8,759
C10	4		50		4	4,701,885	12,675,968	166,743,655	110.22	3%	72,560	8,759

Optimal Configuration -Hybrid Wind/Diesel Genset/ Battery System (C1)

The result shows that the most economically feasible solution is the hybrid wind, diesel generator and battery system configuration. This is a fossil fuel, RE and storage system mix. The cost of energy at this configuration is 0.133$/kWh (22.3₦/kWh) of electricity. Four wind turbines were utilized in combination with a 50kW diesel generator which is put to use for only 493hrs/y at a diesel consumption of 3,849L/y, and a battery bank of 16pieces of 200Ah batteries, with a 20kW converter. The renewable energy fraction is 97%. This is a great improvement from the 100% diesel generator system which had cost of energy at 0.647$/kWh (108.72₦/kWh). The summary of cost of energy for the various off grid options is as show in figure 4.1 below:

Existing system - Diesel Generator off Grid Option (C9)

The diesel generator system, which is the traditional off grid electrification option, was found to be expensive. Details of the option are as follows.

- **A.** System architecture – 50kW Diesel Generator
- **B.** Cost Summary

Total Net Present Cost : ₦164, 245,165
Operating Cost : ₦12, 713,877/yr
Levelized cost of energy : ₦108.72/kWh

The cost summary of the various options is shown in the chart 4.1 below:

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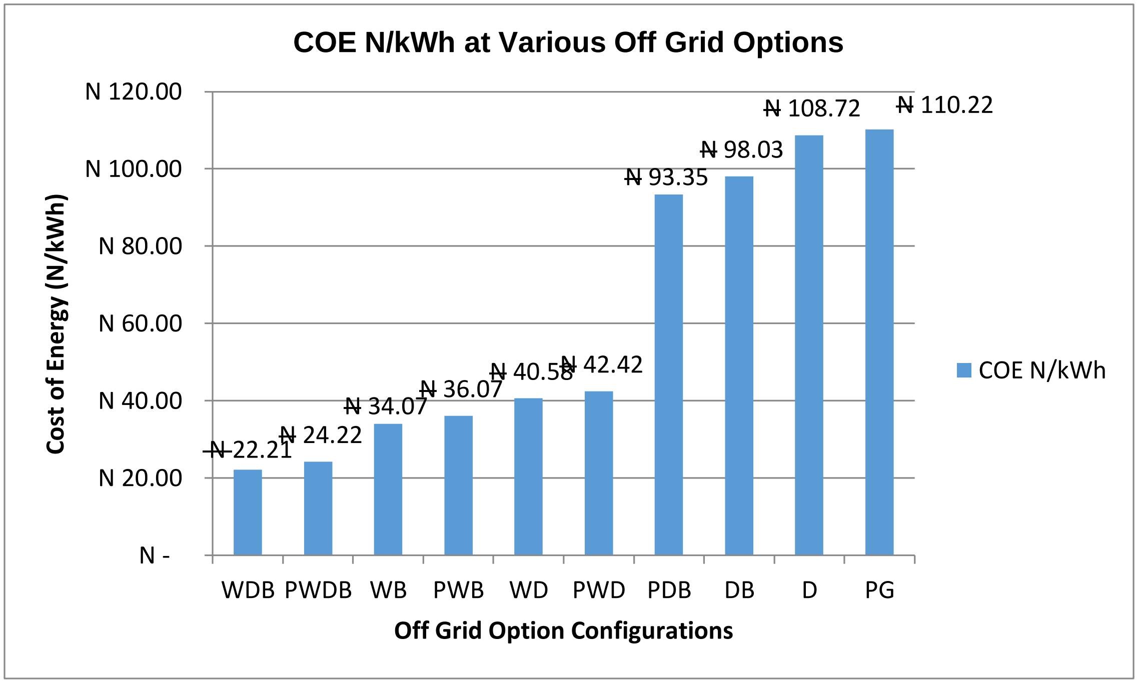

Figure 3.0: Chart of energy cost at various off grid options

Details of the Optimal Off Grid Configuration
The following tables and figures show the details of the optimal off grid configuration using HOMER software simulation:

System Architecture

Table 5.0: System Architecture of the Optimal Off Grid Option

Wind turbine	4 Wind Turbine
Gen 1	50 kW
Battery	16 Battery
Inverter	20 kW
Rectifier	20 kW

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Dispatch strategy	Cycle Charging

Cost Summary

Table 6.0: Cost summary of the Optimal off Grid Option

Total net present cost	₦33,654,174
Levelized cost of energy	₦22.21/kWh
Operating cost	₦1359714/yr

Cost Implication for Renewable Energy Utilization in the System

The utilization of renewable energy systems as part of the energy mix in the off grid configuration has some noteworthy characteristics as shown on the Initial Capital cost, Operational Cost and NPV cost VS renewable energy penetration graph below.

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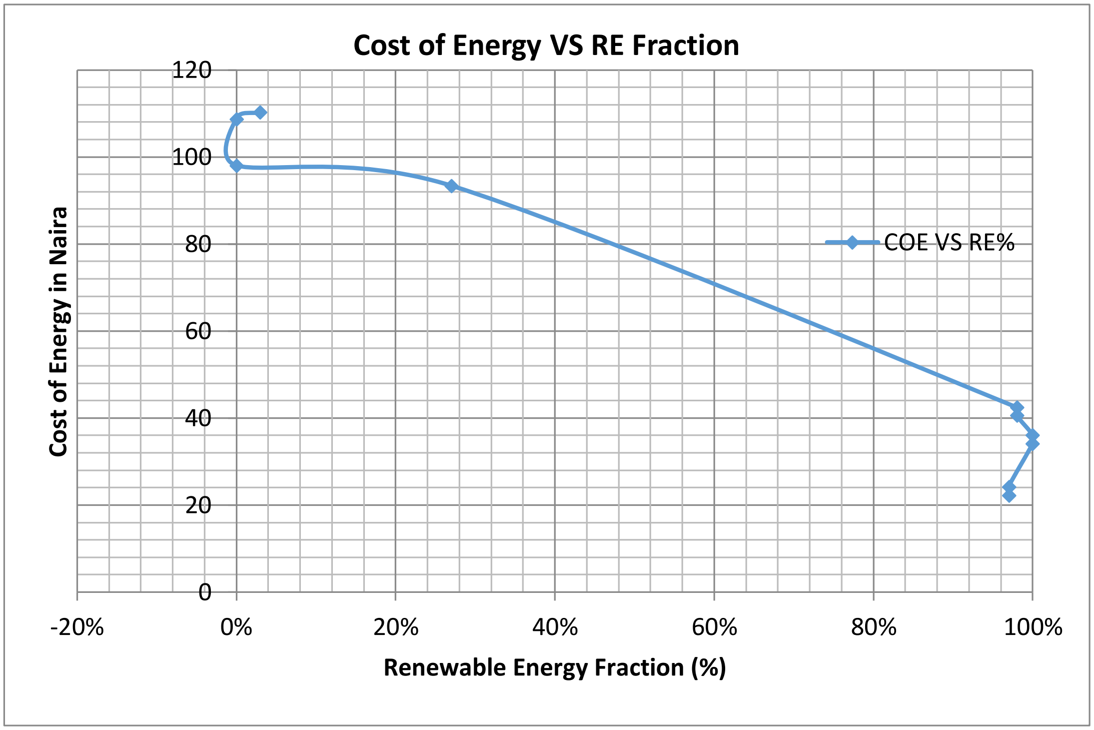

Figure 4.0: Cost of Energy versus Renewable Energy Fraction

Both Renewable energy and storage system mix in the off grid option is seen to reduce the overall cost of electricity. The cost of energy at 0%, 64% and 100% RE mix is ₦98.03, ₦68, and ₦34.07 respectively, and even lower at some configurations. This is a great boost to improving electricity access in the location as it will be affordable to most people. The benefit is that the usual high expenditure on diesel/gasoline generator systems can then be saved to meeting other important needs.

CONCLUSION AND RECOMMENDATIONS

Summary

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The uneven access to electricity across the geographical landscape of rivers state motivated this study as most of the riverine communities are off grid due to its difficult swampy forest terrain. The study attempted to know the potential sources of energy in the in the riverine areas and to identify the cost effective off-grid option in meeting their electricity needs. An optimization model for the system was framed, and HOMER software was used as an optimization tool to simulate for an optimal system. The work also sought to know if off-grid options using renewable or hybrid systems will are cost-beneficial, and sustainable.

Conclusion

Off grid electrification using standalone diesel generators in the riverine areas have not worked satisfactory due to the high cost of operation and maintenance. However, having a renewable energy fraction at 20% and above using wind turbine in addition to the diesel generator is found to reduce the cost of energy production. Among the ten feasible off grid configuration options with solar, wind, diesel, and battery system in view, the hybrid wind/Diesel generator/battery option having 97% fraction of RE was the most cost effective configuration option. Its cost of energy is 22.3N/kWh, while standalone diesel generator system costs 108N/kWh. The hybrid off grid power system will ensure sustainability in that the needed resources are almost free, with less maintenance and shortages can be met with the occasional use of the diesel generator.

The riverine areas of rivers state (the coastal Niger Delta) is replete with abundant natural resources that can be harnessed for its development. There exists oil/gas, wind at 7.22m/s, solar radiation at 4.39kWh/m^2, hydro and biomass in great potentials. These resources if sufficiently utilized can guarantee the region constant electricity supply without depending on the national grid. There needs to be a paradigm shift in our national approach of providing electricity for the masses. The traditional approach of depending on the national grid has not worked satisfactorily, and until now we are yet to have even up to 5000MW from the grid. We do not expect to achieve a different result using the same approach. Off grid hybrid electrification using renewable energy is the key for sustainable electrification in the riverine and by extension other rural areas in Nigeria.

This work was typed and printed at home with an uninterrupted power supply provided by 80watt solar panel and battery system amidst intermittent grid supply. The hardship caused by lack of supply to power our light load gadgets/appliances like phones, laptops, lighting, etc can be eliminated with the application of some of these off grid technologies. The time is ripe for us to follow global trend in the generation and utilization of electrical energy. The time is now!

Recommendations

Government should strengthen the existing framework for off grid and rural electrification. It should encourage renewable energy market through various financial support mechanisms like free import duties, subsidies, public private partnerships, etc. Already existing contracts for renewable energy and off grid projects should be followed to a logical conclusion, and new ones awarded especially in the off grid riverine areas where the resources have been found to exist in abundance.

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Finally, as the world moves towards smart grid and environmentally friendly energy options, we should embrace more innovative and environmentally friendly ways of meeting electricity needs in the present state of insufficient grid supply. Energy savings and storage should also be a culture to imbibe.

Suggestions for Further Studies

In view of getting sufficient data for a more accurate representation of the potential energy resources, an integrated online mini weather station apparatus could be employed for twenty four hours continuous measurements in the study area. Also, other sources of energy such as Bio and hydro can be considered in the optimization model. Furthermore, study can be made on the viability of off grid versus grid extension with respect to the proximity of the community from the nearest grid. Finally, a comparison of optimal system result can be made using different approaches and software such as LINGO, RET Screen, etc.

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