Department of Mechanical and Aerospace Engineering

Investigation of hybrid energy systems for domestic houses in sub-Saharan Africa; Abuja, Nigeria as a case study.

Author: Ochiba David Enonche

Supervisor: Dr. Nick Kelly

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Signed: Ochiba David Enonche Date: 30/08/2016

Abstract

The issue of power inconsistency is one that has become common say in Nigeria. A country blessed with an abundance of resource but has never really lived to its full potential of establishing herself in Africa as a commercial giant. If electricity is the force that pushes development, then we lack its presence in abundance. With an ever increasing population and constant additions to our daily demands on power, there has been a stunted growth of electricity generation and supply in the country. In turn, industry, agriculture, and the common citizen have been at the mercy of a dilapidated system.

This thesis aims to examine new possibilities associated with the current technologies available in our modern era and purpose a more definite solution to the rural and urban communities trapped in the web of the inconsistent power supply. To this end, I have selected certain communities in the countries capital which is an important landmark for leadership in Nigeria. The first chapter of this report introduces the reader to the region and paints a picture of the current issues that are being faced by home users. Chapter 2 discusses the problem statement and also highlights ambient potentials that lay dormant in the region as they are still left unharnessed. The third chapter highlights the steps taken in order to eliminate or totally reduce this problem. Chapter 4 shows the implementation of real life scenarios associated with the region itself, so as to draw out a process to solve the current existing issue plaguing these areas. HOMER pro which is a demand and supply matching tool, was used to map out technical and economically viable options that could be implemented to help alleviate the energy needs. Chapters 5 and 6 contain discussions and conclusions about the project in general and all the steps taken to achieve my objectives. The end result has shown that communities in the capital city can solve their energy issues if more renewable technologies are implemented. Opportunity abounds even for the undiscovered resource, yet all research and simulations invoked have deduced that hybrid systems are proven technologies that can solve an old but current issue in communities that desire power.

Acknowledgements

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I would also like to thank all the lecturers from Mechanical and Aerospace Engineering department of the University of Strathclyde that handled all modules, their academic insight I will not take for granted.

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Table of Contents

List of figures

List of tables

1. INTRODUCTION

1.1. BACKGROUND

Nigeria is located in west Africa of the African continent and hosts a population of around 182.2 million people (world bank, 2015). Amid the growing population of the country, there has been inconsistent power supply dating as far back as the 1980s (Oluwole, A., et al, 2012, p.1). This is due to the increasing energy demands that come with population accompanied with no expansion of preexisting supply technologies. In the past decade, it has solely depended on the use of fossil fuel based forms of electricity generation for the countries power supply. Over the earlier years this means has proven to be reliable, but with present factors, there is an urgent need for an increase in supply for an ever increasing demand.

Placing the limelight on the residence of the Capital city (FCT) as it is the target location of this thesis, we evaluate the position of the state. The FCT as described in **figure 1** is located in the north-central geopolitical zone of the country and occupies a land area of 7,753.9 sq.km (NPC, 2016). Data from the National Population Commission archives places the FCT's population to be 2.23 million as of 21/03/2011 thus making it one of the most populated states in the country. The united nation estimates an urban population growth of around 4.7% annually (UN, 2010-15).

Going by the European commission for research and innovation description of the importance of energy which it defines "as being a fundamental presence for improving the quality of life in our present society as it is dependent on an abundant and uninterrupted supply for our socio-economic advancement". The above statement accompanied with facts have shown that population growth and energy advancement within the country are not parallel to each other.

To this end, certain critical events have played a massive role in the degradation of power in the country, these factors which include; the unstable nature of oil prices, failing power infrastructure (poor maintenance policy) and an unstable economy has greatly affected power generation in the region. With some of these issues, a new method of approach is required to meet the electricity demands of the basic consumers.

Although this erratic nature of power supply has plagued the country and had negative effects on industry, it cannot be compared to the adverse effect it has had on the socio well-being of the domestic consumers who require energy the most for their daily activities. Present conditions have led to rationing of supply for average homes to a mere 6hrs per day in most urban areas and 3 hours daily in rural communities. Only a selected few can purchase diesel generators which are the most accessible option, but costs of fuel and its non-availability still plays a major factor (Mas'ud et al., 2015, p.778). The need for energy cannot be over emphasized which makes it of utmost importance that alternatives are investigated for the urban and rural communities in the region.

Figure 1: (*Federal capital territory, Nigeria*, 2016) source: Wikipedia

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1.2. AIMS & OBJECTIVES

This thesis aims to investigate the feasibility of installing Hybrid energy systems in the urban and rural communities of the FCT. Principle objectives will include:

- Investigation of renewable technology for urban and rural power generation.
- Highlighting the benefits of Hybrid system design as an alternative.
- Creating awareness for energy-saving lifestyle.
- Carrying out a feasibility test on application of this technology

- Investigating the potential of available power to at least 14hrs daily
- Carrying out a technical and economic analysis of the implementation of this technology.

1.3. STRUCTURE OF REPORT

Chapter 1: Introductory chapter into the region and its present problem state are discussed with several objectives drawn out to solve these issues.

Chapter 2: Literature review containing a brief historical analysis of power generation in the country from renewable and nonrenewable technologies. It aims to establish a consciousness of the present state and future potential of the power industry in the country. This chapter will also give insight to the resource potential (pulling data from different professional sources) available for harnessing in the region.

Lastly, we analyze the requirements for the functionality of a variety of Hybrid energy systems and also investigate storage potentials for these systems.

Chapter 3: Outline of approach methodology is discussed in this chapter. Its involves the creation of demand profiles based on the present information from average homes of 3 bed room flats with their occupancy data. It also discusses the methodologies of the simulating tool used (HOMER) in the derivation of results for technical and economic variables.

Chapter 4: Contains results obtained after the simulations have being carried out. The assessment of these results will be used for better technical and financial analysis. these results will determine the feasibility of this technologies implementation.

Chapter 5: This chapter will discuss all the findings from the previous chapters and make selections/suggestions based on financial and technical feasibility.

Chapter 6: concluding chapter to summarize all findings from previous chapters. The content of this chapter will either approve or disapprove the use of Hybrid systems.

2. LITERATURE REVIEW

2.1. BRIEF HISTORY OF POWER IN NIGERIA

The generation of electricity in Nigeria dated as far back as the 1900's where the first generating system of 60kW was installed in the former capital Lagos (Obadote, D.J., 2009, p.1-3). Leading from this era, the Federal Government of Nigeria commenced the establishment of generation, transmission and distribution stations and agencies across the country. Among them are some 4 major commissions which stand out, they are; The Power Holding Company of Nigeria which is the agency in charge for distribution and supply of power (previously the National Electric Power Authority (NEPA)) in 2004.

The National independent Power Project (NIPP) was also commissioned in 2004, its purpose is to increase the generation, transmission and distribution of electricity to more customers by building more infrastructure. Although this initiative is welcomed, more immediate solutions are required to alleviate shortages in urban and rural communities

The Nigerian investment promotion commission (NIPC) which handles investments in all sectors of the country estimated that in 2013 daily demand for power in the country was at **10,000MW** with a total generating capacity averaging **3500MW**. The commission also noted that the current access to electricity by the total population is at 40% although power is not consistent. Another commission of great importance is the Energy Commission of Nigeria (ECN). It is charged with the responsibility of policy creation as well as the research and identification of potential energy sources. A 2015 report by the ECN estimated that the total demand within the country would be **31240MW** with the national grid generating **4389MW** that year (Salau, S. 2015). **Appendix 1** gives a list of the available and proposed generating capacity of the total grid within the country.

Present generation stats are compiled by the Bureau of Statistics. Figure 2 represents the current state of power production in the country. This forecast shows levels of inconsistencies in generated power which implies the need for proper change in the industry to achieve better production.

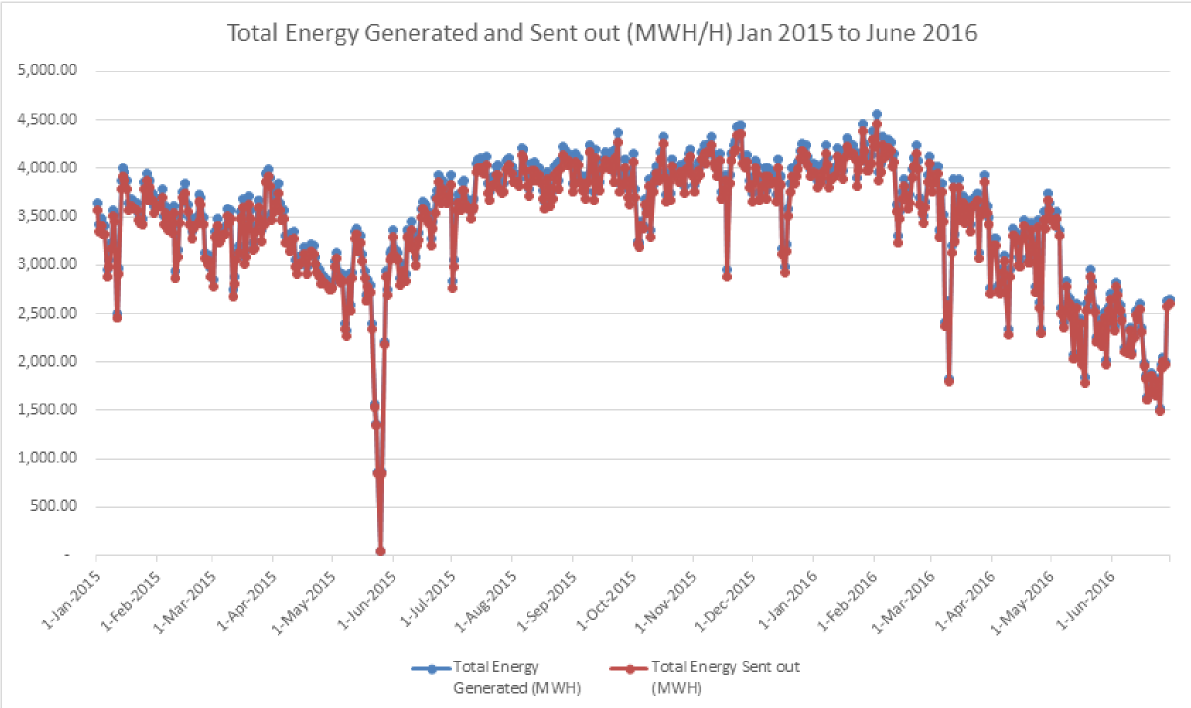

Figure 2 Energy generation forecast from Jan2015 to June2016 (National Bureau of Statistics Nigeria)

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2.2. Resource and generation potential

Nigeria is blessed with an abundance of resources that can be used to generate power to match its demand with its ever increasing population. Its landscape is naturally designed to accommodate and incorporate technologies that fit the resource that is associated with any region within the state. There is the potential to incorporate both renewable and non-renewable technologies to meet urban and rural demands in areas that are not connected to the grid as well as areas which have erratic power distribution.

2.2.1. Renewable resource

The most popular forms of renewable technologies in our modern era are; solar, the wind, biomass, and hydro power. As for all of the aforementioned and their required resource, Nigeria can be said to have a vast potential for incorporating these technologies. The ECN has identified these technologies as feasible within the country. Information from the commission and experts have further enhanced this belief with some of the resource potentials describe below.

2.2.1.1. Solar potential

The country has an abundance of solar radiation which is more dominant in the north western and north eastern part of the country. The annual incident solar radiation is at 1.804×10^{15}KWh with an average estimation of 5.535kWh/m^2/day based on its land area (Shaaban and Petinrin, 2014).

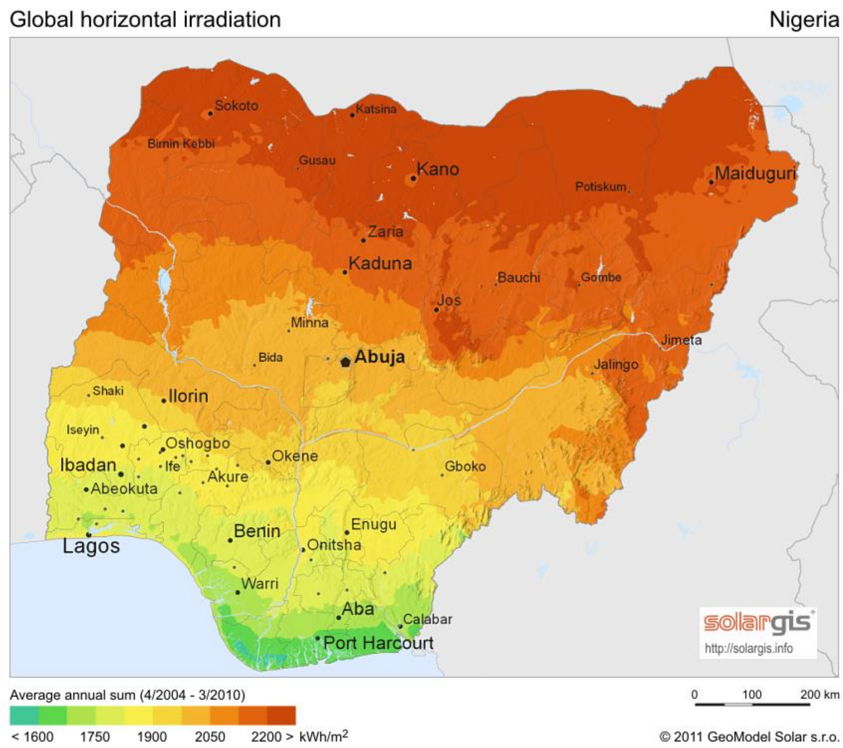

Figure 3 solar radiation for Nigeria (source: solargis maps)

Global radiation figures put the FCTs monthly solar average at 5.337 kWh/m^2/day. A 4KW Photo panel in such a region is estimated to produce the power of 5653KWh/year which is equivalent to 15KWh/day for a home with installed PV. If this potential could be harnessed, it would make a good contribution to the local grid and help boos generation more than its present state.

2.2.1.2. Wind potential

The ECN has estimated that wind speeds in the country have a higher potential to support the use of turbines for a generation. It is estimated that wind speed ranges from 4.0m/s to 5.12m/s in the northern areas of the country and 1.4m/s to 3.0m/s in the south (Ngala, G.M, et al 2007). Estimations made by the commission put the height at 10meters in the northern part which could produce generation variation between 8MWh to 97MWh annually. Revising weather data from Metoblue, the FCTs average wind speed is estimated to be at around 2.2m/s This is shown in figure 4

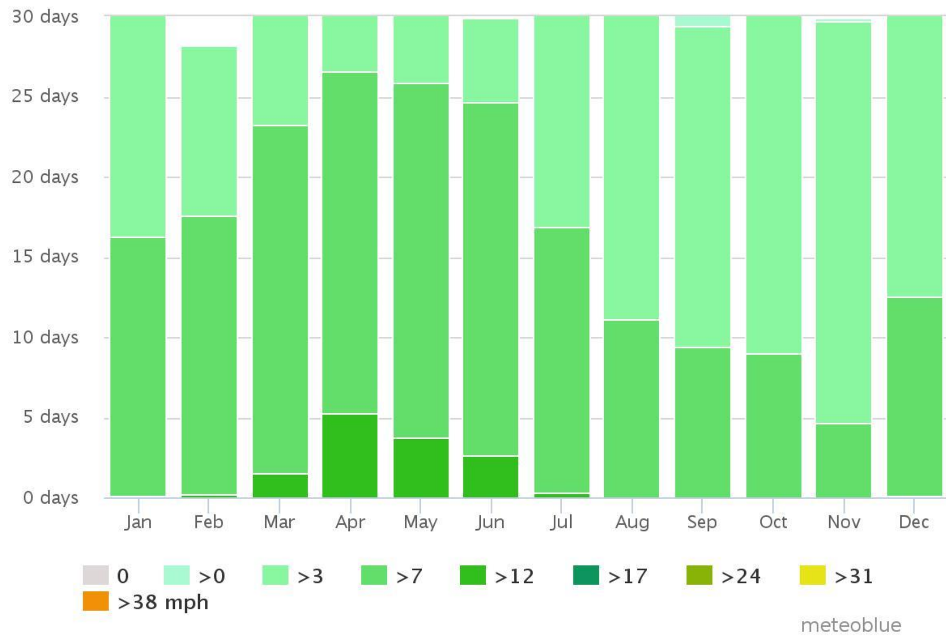

Figure 4. Abuja annual wind speed (source; www.meteoblue.com)

Although the wind in the state is not powerful enough to generate much electricity for major equipment, it has the potential to power small scale turbines for water pumping. This technology would be of great service to the rural communities in that area.

2.2.1.3. Hydro potential

Hydropower was the pioneer of major power stations in the country, the first large-scale power station (kanji) exceeding 400MW was built in 1968 and has been in operation till date. Power generated at Kanji makes a massive contribution to the grid as shown in fig 5 below. As of 2001, it was estimated that all functional large hydro sources were responsible for about 35.6% to 40% of the total power being generated in the country (Darling et al. 2008).

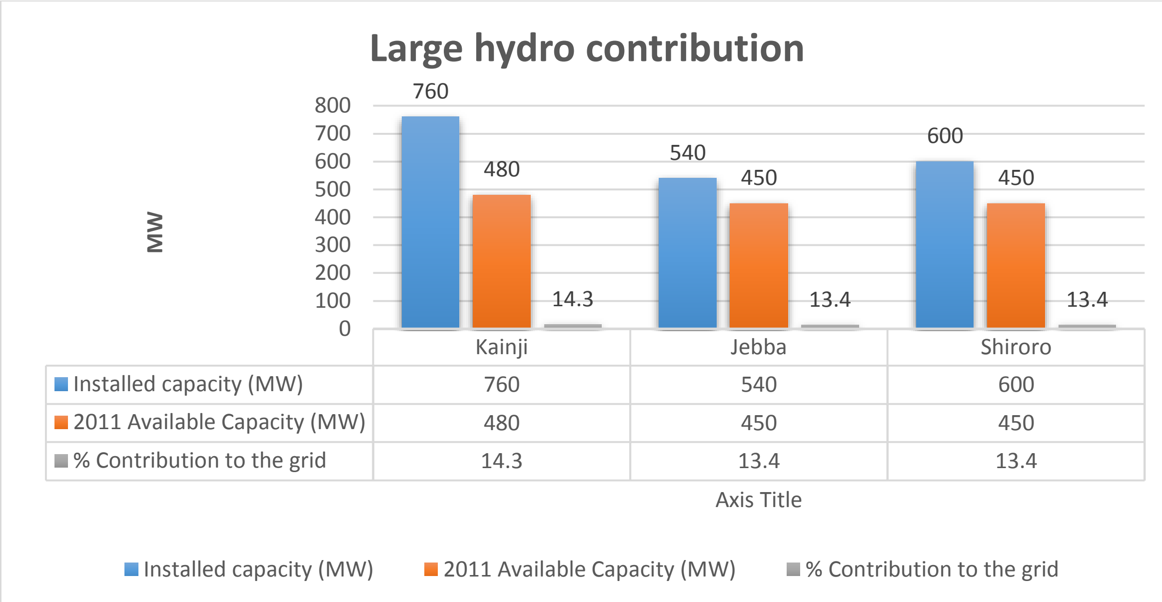

Figure 5. Contribution of hydro to the grid (Okoro, O.I., and Chikuni, E., 2007.)

Estimations by the ECN have determined that Nigeria has the potential to generate 14750MW from a combination of large and small scale hydro projects (ECN, 2012). Table 1 below gives a more details.

RESOURCE	POTENTIAL	REMARK
Large Hydropower	11250MW	1900MW exploited
Small Hydropower	3500MW	64.2MW exploited

Table 1. Current and potential hydro capacity (source; ECN)

If this potential is well harnessed to its peak capacity, it can generate more than one-third of the current deficit in demand based on the 2015 stats. Current contribution for installed hydro varies as even the available capacity is held ransom to poor maintenance policies in practice. As of 2005, the hydro contribution has fallen to an unimpressive 7% (Oyedepo, S.O., 2012).

2.2.1.4. Biomass potential

Nigeria has always relied on biomass as a source of energy in urban and rural households across the country. The country's biomass resource is predicted to be at $8x20^2$MJ (Sambo, A.S., 2005). Research in 2013 carried out by the U.S. Energy Information Administration (USEIA) estimates that the energy generated from biomass consisting of wood, manure, charcoal and residue accounted for 74% of the total energy consumption in the country. The primary use of biomass in the country is for cooking and heating purposes, most especially in rural communities that have no access to electricity.

There is presently low research being done for expanding the numerous potentials associated with biomass. Steps that could further initiate biogas production and anaerobic ingestion for fuel and power are not necessarily in practice as sufficient data required for this technology's implementation is still being observed.

2.2.2. Non-renewable resource

Non-renewable resources associated with Nigeria are vast in quantity, there are huge deposits of fossil fuels in the country with more discoveries being made. Most popular fossil fuels associated with the country are; Oil, coal, and natural gas.

2.2.2.1. Crude oil resource

Nigeria is popular for its crude as it is the 2nd largest producer of oil in Africa and 13th in world rankings. The World energy Resources estimates recoverable reserves at 5billion tons with a production rate of 120million tons per year. Contribution to the grid in 2005 was estimated to be 57% of the total energy supply of the country.

2.2.2.2. Coal resource

Since the discovery of oil in 1950, coal mining has received little or no attention in its exploration and use. It is estimated that there are recoverable reserves of 90.2Mtoe in the country which is equivalent to 1049TWh of power unassessed.

2.2.2.3. Natural gas resource

The Estimated amount of recoverable reserves is placed at 4.39thousand Mtoe with a production of 24.9Mtoe annually. Natural gas contributes about 36% to the electricity grid based on 2015 data (Oyedepo, S.O., 2012). This reserve is harnessed could generate about 51TWh of electricity.

Although vast potentials in renewable and non-renewable power generations have being identified, it is quick to note that most of these technologies will not be implemented on within the space of 5 to 8 years. This realization makes it imperative for the government to discover a solution that will tackle the current issue. For any technology to be implemented it must have 3 criteria's which are;

- Speed of implementation (roughly 6months to maximum of $1\frac{1}{2}$ years)
- Availability
- Consistency

With this mind, it is safe to say that an existing and proven technology meets the requirements. This would be hybrid energy systems.

2.3. Review of hybrid energy systems

A hybrid system is one that uses more than one energy source to generate power. It involves the combination of renewable technologies such as PVs and Wind turbines with fossil based equipment to generate constant power to isolated or off-grid communities (Rashid, M.H. ed., 2014, p 1-38). Interactions between system components are controlled and regulated by multiple ICs to allow the constant functionality of the system. Components that make up a hybrid system are described below.

2.4. Components of a Hybrid system

The components that make up a hybrid system constitute of renewable with fossil-based technologies and smart integrated ICs. The ICs are responsible for power conversion, inversion and regulation in the system as their detailed function is keeping all components inputs in synch with each other. Most popular renewable and fossil components include;

2.4.1. PV panels

Photovoltaics are panels that convert solar radiation to energy. It is made up of solar cells which function by converting energy received from the sun into electricity via the help of a semiconductor. Current produced by panels are DC which is converted to AC for use or stored in batteries until required.

2.4.2. Wind turbines

A wind turbine is a device that converts the kinetic energy from fast moving air (wind) into electricity via rotation of its motor to produce electricity.

2.4.3. Diesel generators

This component plays a major role in any hybrid design due to its consistency. Most generators have a specific power output and this characteristic solves the intermittencies associated with renewables.

2.4.4. Inverters

The function of the inverter is to convert current from DC form to AC. In hybrid connections, most inverters are directly connected to the batteries where it can easily convert or rectify in order to charge the batteries.

2.4.5. Storage

The most common form of storage used is batteries. Excess energy generated during the day from renewables can be stored in batteries for later use when there is a demand for it (Manwell, J.F., 2004). Storage plays a very important role in the system design as it gives leverage to the system should technical issues or maintenance disrupt electricity generation.

2.5. Classification of hybrid system

Hybrid systems are of multiple types which are based on their functionality. The purpose of any hybrid system influences the design of that system as well as the source of energy present at where it is despatched (Manwell, J.F., 2004). There are 3 classifications of hybrid systems that are based on their configuration which is described below.

2.5.1. Series hybrid system

For a hybrid system to be in series, all generation by components must be fed to the storage units. The output from the diesel generators is passed through a rectifier down to the battery banks while PVs and Turbines have charge controllers that regulate their output to the batteries as well. For reliable operation of the system, generator and inverters are sized to meet peak loads. This type of configuration allows a large fraction of energy pass through the storage unit, in turn, increasing the cycling but reducing the systems efficiency (Nayar C, et al 2011). This is described in figure 6 below.

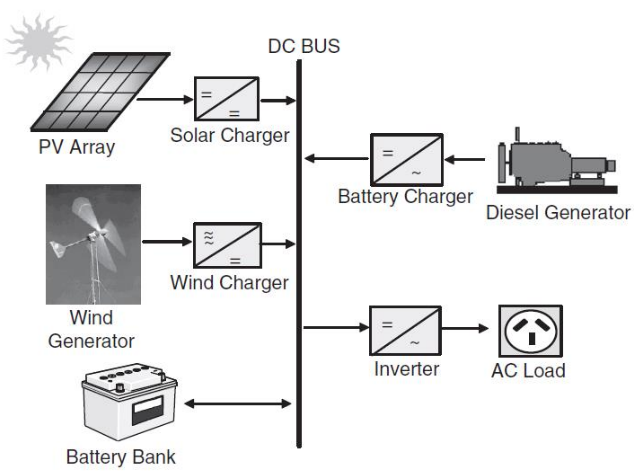

Figure 6. Conventional series hybrid configuration (Nayar C, et al 2011).

2.5.2. Switched configuration

A switched hybrid configuration involves the use of fossil fuels (diesel generators) to match peak demands day and night. Battery storage charging is handled by the renewables and any excess power from the generators. The stored power is then used to match the load during low demand at the night period (Nayar C, et al 2011).this process is described in figure 7 below.

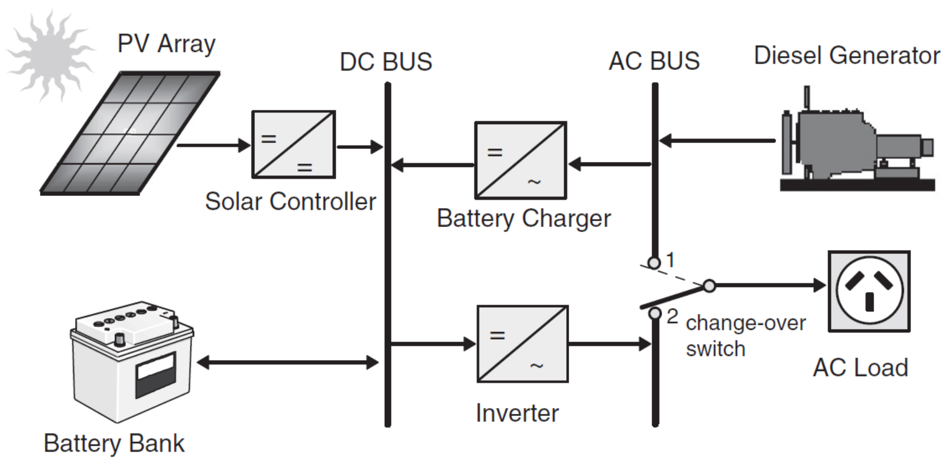

Figure 7. Switched hybrid configuration (Nayar C, et al 2011)

A major disadvantage with this configuration is the interruption of power that occurs during a change over as it is a manual system in place.

2.5.3. Parallel hybrid system

Parallel configuration involves dual supply to AC load by the diesel and renewable sources. Both components run in parallel to each other and supply a portion of the demand directly. Excesses from either of them are stored in the batteries for later usage. Figure 8 gives a schematic to the operation of the configuration.

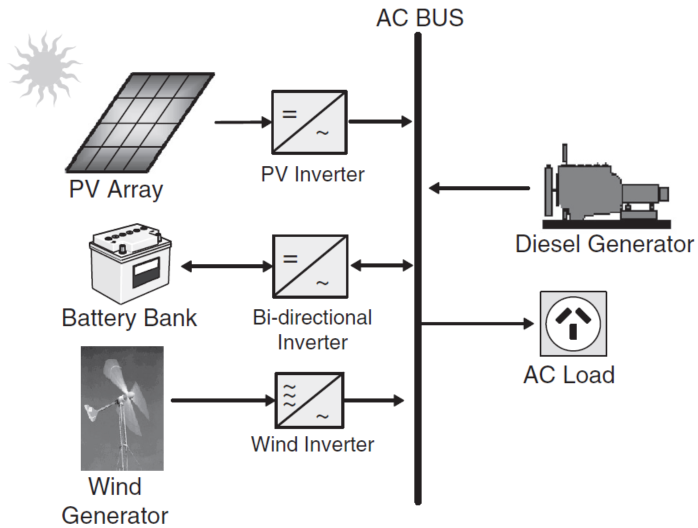

Figure 8. Parallel hybrid configuration (Nayar C, et al 2011)

3. Approach and Methodology

The aim of this project is to realize an ideal technological platform that will be suitable for providing uninterrupted power to the urban and rural communities in the FCT. The methods approached to achieving this are listed in a series of steps below;

- Creating a demand profile for the communities
- Estimate demand and supply matching via the use of a software (HOMER)
- Study outcomes of scenarios (possible best 3 scenarios)
- Financial analysis of these scenarios
- Select the best possible option available (on technicality and finance)

At the end of this process, it is hopeful that the results that are obtained are positive enough to be implemented not just in the country's capital city, but also other regions tackling similar issues.

3.1. Demand profile

The demand profiles generated for the rural and urban communities in the FCT. A description of their individual details is given below.

3.1.1. Rural communities

The rural area under consideration is that of Abuja's GWA GWA Lada area council. It is among one of the 6 major councils with a population estimated to be around over 1 million people since the creation of the FCT. It is described as a rural-urban fringe which is located 40kilometers away from the capital (Nicholas, E.O., and Patrick, D.D. 2015). The **Gwako** ward of the GWA GWA Lada are council is the location of interest as it has a high rural density.

The present condition and description of this ward are;

- No access to power
- Use of generators to meet demands
- Individual houses with electrical equipment rating <300W
- Single room housing structure
- Occupied 100% of the time of use
- No access to heating equipment's

Table 2 provides data on the list of appliances and their rate of consumption in the area. This assumption is based on an average estimate of the list of equipment acquired by most of the populous with a housing population ranging from 60 – 100 houses.

Appliance	**Rating (W)**	**Quantity**	**Hours daily (generator) pm**	**With grid**	**Total (Wh)**
15-inch TV	90	1	5	0	450
Table top refrigerators	35	1	5	0	175
Ceiling fans	100	1	5	0	500
Phone chargers	4	3	5	0	60
Light bulbs	40	2	5	0	400
TOTAL	**269W**				**1.6 KWh**

Table 2. Appliance in use and daily consumption for rural communities

100% of all heating demands are handled by burning biomass. Most rural communities in the country do not have access to gas and burn firewood and charcoal instead as it is easily accessible and very affordable. Presently, the daily 5 hours of electricity are provided by generator sets which are very costly for the communities. Generator sets of 800KW capacity are mostly used and frequently turned on at night when they are most needed.

3.1.2. Urban communities

The urban community under consideration is the **Lokogoma cadastral zone (**CO9**)** which is a district in the FCT and is considered a residential zone. There are numerous housing estates in this zone with the occupants consisting of mostly young families as well as retirees. Residents in this zone are considered middle-class citizens as they can afford certain luxuries compared to rural areas.

The present description and conditions include:

- 3 bedroom bungalow house designs
- 35 – 60 houses in total.
- Occupants present 80% of the time
- High use of electrical equipment’s
- Electricity supply guaranteed for 4 – 6 hours daily
- Remaining 8 hours are handled by 10KVA generator sets.
- Cooking is handled by 80% gas and 10% biomass

Consumption estimates are given in table 3 below for this zone.

Appliance	**Rating (W)**	**Quantity**	**Rat x Qty**	**Hours Via grid (am)**	**Hours via generator (pm)**	**Total hours of available power**	**Total (KWh)**
1.5hp Air Con	1300	1	1300	1	4	5	6.5
Microwave	1200	1	1200	1	1	2	2.4
Toaster	1000	1	1000	.30	0	.30	.50
Iron	1000	1	1000	1	1	2	2
1.hp Air con	1000	2	2000	1	4	5	10
Blender	300	1	300	1	1	2	.6
TV 45”	200	1	200	1	6	7	1.4
TV 25”	40	1	40	1	6	7	.28

Laptop	250	2	500	1	3	4	2
Stereo	120	1	120	0	3	3	.36
Cable	30	1	30	1	6	7	.21
Well pump	1000	1	1000	1	0	1	1
Lights	40	19	760	5	6	11	8.4
Freezer	51.6	1	51.68	5	8	13	.67
Fridge	50	1	50	5	8	13	.65
TOTAL	**7.6KW**		**9.6KW**				**36.97kwh**

Table 3. Consumption in urban areas.

Total daily consumption is estimated at 36.97KWh with 5 hours from the grid and 8hours from personal generators. Due to the inconsistency associated with the grid, more than 90% of homes use natural gas for cooking and heating which are sold in cylinders. Another reason for this is to reduce energy bills associated with electric cooking units as cylinders are cheaper. This adjusts the demand to be strictly electrical and cooling. The region itself does not require heating all year round as it has an annual yearly temperature of 25.7 degrees Celsius as seen in figure 9below.

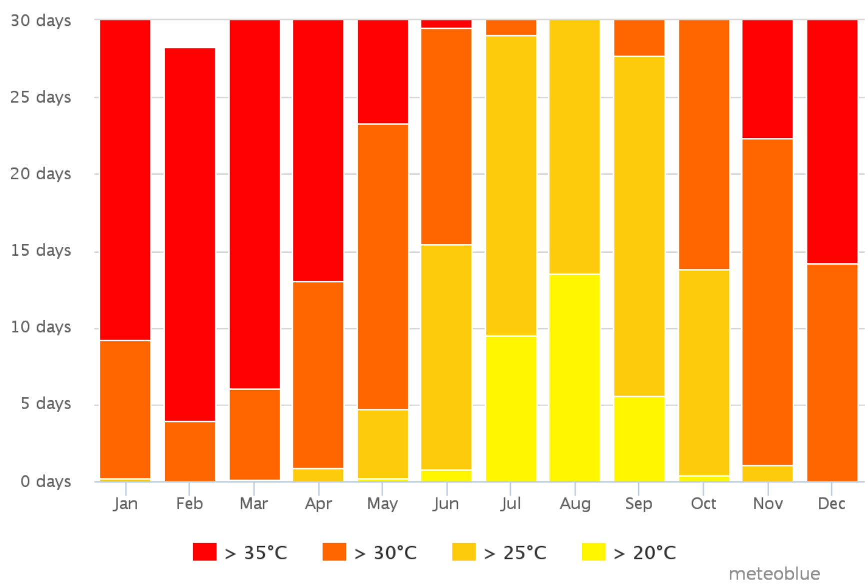

Figure 9. Temperature data for the FCT (source: meteoblue)

With this information, we could construct an annual demand profile and make considerations for periods when there are temperature drops. This, in turn, will reduce the use of cooling equipment as it contributes a huge chunk to the demand profile. Most houses use natural cross ventilation as this is current construction practice in the region.

3.2. Effects of current demand

As can be seen in table 2 and 3, the current demands are a product of the irregularity of power supply. For both the scenarios demand is not properly matched, therefore the next step is to estimate new demand profiles based on a 24hr consistent availability in power. This will be done by the use of HOMER simulation tool.

3.3. Simulation tools

The main simulating tool used for this thesis was the HOMER pro computer software. It is owned by HOMER energy and the full acronym stands for hybrid optimization model for multiple energy resources. This simulation tool can perform multiple tasks in relation to energy management with some key functions being that it;

- It can create detailed demand profiles
- Provides supply options for renewable and non-renewable technology
- Carries out demand and supply matching
- Sensitivity and economic analysis

Application of these functions have being implemented on table 2 and 3 to create a demand profile for the urban and rural communities in the FCT. Below is a guideline of the chronological process of the simulation function.

3.3.1. Demand profile

This function of the software allows the user to communicate the energy demands associated with the network being modeled. Information on equipment usage is analyzed on a time frame from hourly to monthly and yearly. The information that is supplied is then generated in a series of graphs which give a detailed outlook on the structures demand profile.

3.3.2. Supply Matching

Homer is already preinstalled with all the necessary demand and supply matching options and technology available. The program works by estimating a supply option either via renewable or non-renewable options to generate an adequate yearly supply for the demand profile in question.

3.3.2. Economic analysis

A cost analysis option is made available in the software to enable users to calculate the financial implications of any supply option that is eventually chosen for implementation. This includes detailed sensitivity analysis of the model in question and its feasibility. Other options include:

- Operation and management
- Initial cost of equipment.
- Payback period

4. SIMULATIONS AND RESULTS

The first step in the simulation phase was to derive information of the existing urban and rural dwellings and translate this information into the HOMER app to generate a demand profile for each dwelling. The first set of results is that of the urban areas which are described below.

4.1. Urban dwelling data

Metric	Baseline	Scaled
Average (kWh/d)	37.81	37.81
Average (kW)	1.58	1.58
Peak (kW)	8.23	8.23
Load Factor	.19	.19

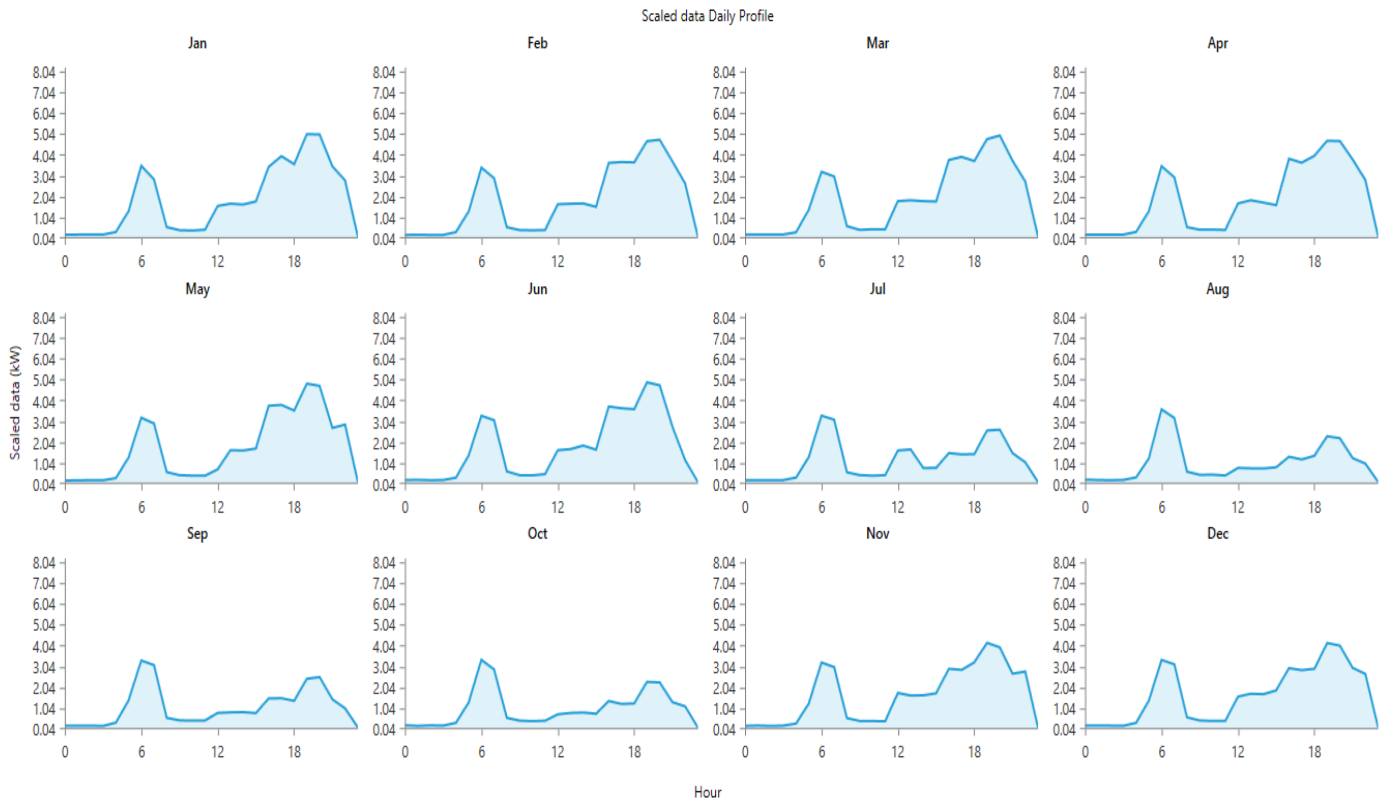

Figure 10. Annual demand profile of domestic residences

The figure above describes the annual demand profile for domestic dwellings in lokogoma. It can be observed that the average daily consumption is at 37.81KWh. Table 2 also gives a close estimate placing daily consumption at 36.97KWh. With this minimal difference of 2.4%, it is safe to say that the demand projection is relatively accurate. Another means of estimation is the use of current bills. Cost per KWh is =N=23.40 (NERC, 2015), with consumers spend an average of =N=25,000 monthly on electricity bills. Calculating this value will give a closer figure as shown;

$$\frac{monthly\ bills\ paid}{cost\ per\ kwh\ x\ days\ in\ a\ month} = \frac{25000}{23.40\ x\ 31} = 34.46\text{KWh}$$

Urban matching and supply

The next phase is to analyze multiple supply options that will match the annual demand. This includes a mixture of renewables and a fossil fuel generator which constitutes an ideal hybrid system. The components used are described below.

Components	**Size range**
Diesel Generator	10KW
DC Turbine	1KW
AC Turbine	10KW
PV panels	.250 – 25KW
Converter	8 – 25KW
Batteries	6V 230Ah

Table 4: Demand matching components

After the simulations completion, 3 specific matches stood out as they had a renewable penetration of 100%. Figure 11 gives their details with table 5 describing the quantity of technical components used for the first option.

PV (kW)	XL1R	XL10R	Gen10 (kW)	T-105	EnerSection® (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
15.0			10.0	120	25.0	CC	$0.713	$127,109	$3,790	$78,115	100
25.0	10		10.0	60	25.0	LF	$0.714	$127,426	$4,511	$69,115	100
25.0	1	1	10.0	60	25.0	LF	$1.01	$180,864	$4,486	$122,872	100

Figure 11. Best combinations

Although either design can generate power sufficient to cover the demand of the household, from the results of the simulation, the first hybrid design stands out due to its technical and financial possibility. Figure 12 gives a comprehensive outlook on the individual components contribution to the supply and demand matching. The first hybrid combination consists of;

Components	Size range	Quantity
Diesel Generator	10KW	1
PV panels	.250 KW	100
Converter	25KW	1
Batteries	6V 230Ah	120

Table 5: Combination based on technicality (1^{st} option)

Production	kWh/yr	%
Generic flat plate PV	24,688	100.00
10kW Genset	0	0.00
Total	24,688	100.00

Consumption	kWh/yr	%
AC Primary Load	13,800	100.00
DC Primary Load	0	0.00
Total	13,800	100.00

Quantity	kWh/yr	%
Excess Electricity	8,561.7	34.7
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	100.0
Max. Renew. Penetration	5,812.4

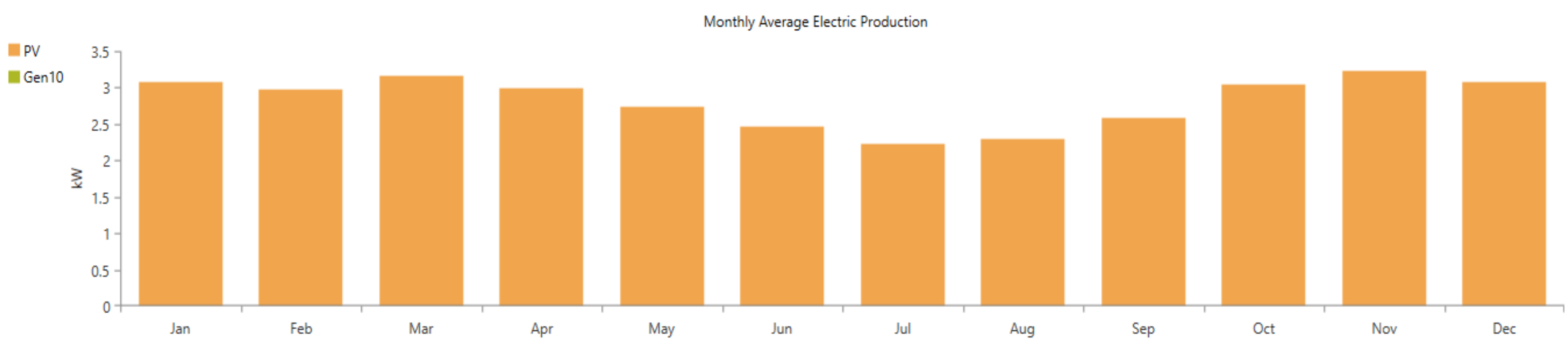

Figure 12. Individual component contribution to matching analysis

If this system is approved and implemented one of the major issues that would surface would be the wastage of excess energy being generated annually (8561.7KW/yr.). Although this could be fed back into the grid ideally, there is no feedback structure in place to realize this potential. Although the government is trying to create a feed in tariff structure, as of this time it is more of hearsay than realizable. If there was an available feed in tariff structure, a different option which would be profitable economically would have been chosen.

Financial analysis of urban areas

The system architecture as describes in table 5 is costly to implement with the total implementation of the system costing around $78,115.00 to assemble. The cost for a generator unit is not included seeing that it is already available. A summary of the cost of implementation is given below.

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
EnerSection®	$6,115.00	$0.00	$0.00	$0.00	$0.00	$6,115.00
Generic flat plate PV	$18,000.00	$0.00	$7,756.51	$0.00	$0.00	$25,756.51
Trojan T-105	$54,000.00	$47,705.63	$0.00	$0.00	($6,468.06)	$95,237.57
System	$78,115.00	$47,705.63	$7,756.51	$0.00	($6,468.06)	$127,109.08

Figure 13. Cost summary of components

There are no incentives associated with renewables in the country, thus the implementation of this technology is very costly especially on a large scale. Figure 14 shows a payback period of over 25 years with maintenance and replacement cost on the batteries between those times.

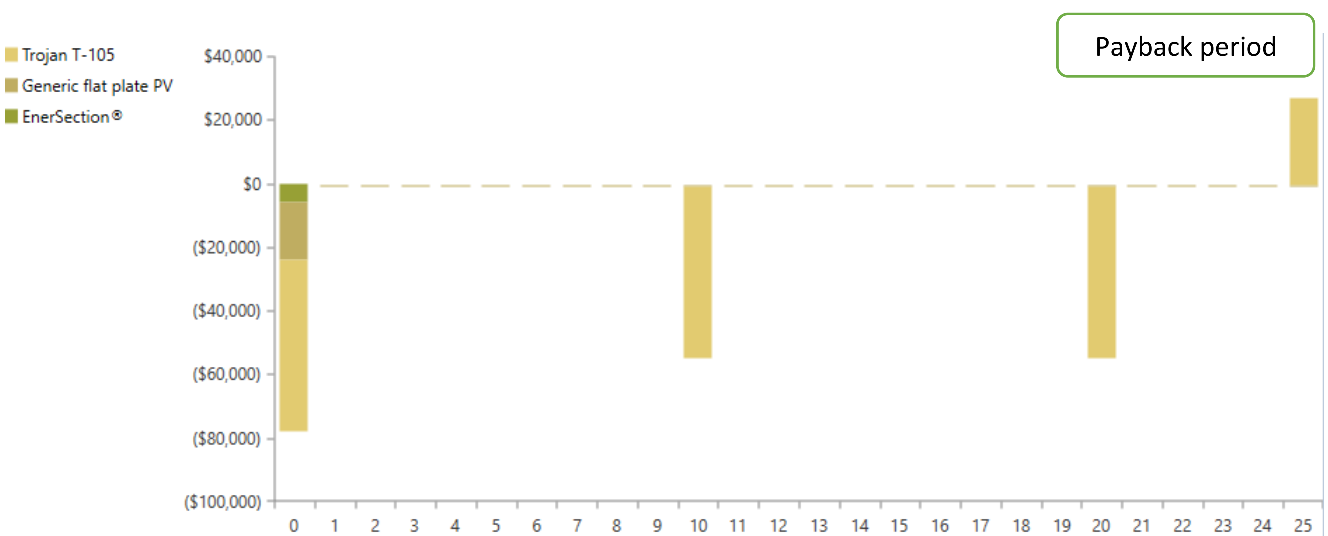

Figure 14. Payback period

In general, the Net present cost sums up the risk of implementing this technology as it looks set for only the financially capable in the society.

4.2. Rural dwelling data

The total capacity of most rural environments does not exceed 300Watts. Dependence on technology is not too common in this region and they have a relatively low energy demand.

Metric	Baseline	Scaled
Average (kWh/d)	5.76	5.76
Average (kW)	.24	.24
Peak (kW)	.6	.6
Load Factor	.4	.4

Figure 15. Rural demand data

Average consumption is estimated to be at 5.76KWh daily and this estimate is based on equipment size. Since this area is not connected to the grid, there are no forms of bills to make a proper estimation as to the real time demands. Equipment capacity is no subject to increase as the structure and present lively hood prevent noticeable electrical additions. There are about 80 houses within this area that meet the same demand specification.

Rural matching and supply

To achieve demand and supply matching, the same components described in table 4 were used in simulation runs on the present demand for the rural community. There were 3 stand our combinations based on technicality and cost as well. Figure 16 describes their result content.

PV (kW)	XL1R	XL10R	T-105	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Capital Cost ($)
3.00	1		15	1.00	CC	$0.695	$18,901	$591.82	$11,250	100	3,600
4.00			15	1.00	CC	$0.754	$20,519	$670.57	$11,850	100	4,800
2.00		1	10	1.00	CC	$2.66	$72,343	$463.02	$66,357	100	2,400

Figure 16. Technical combination for rural house

The top option stands out the cause of its technicality and cost implication. It is technically possible and would meet the required demand and do so at a lower cost compared to the other combinations. Details are given in figure 17 below.

Production	kWh/yr	%
Generic flat plate PV	4,938	93.58
Bergey Excel 1-R	339	6.42
Total	5,277	100.00

Consumption	kWh/yr	%
AC Primary Load	2,104	100.00
DC Primary Load	0	0.00
Total	2,104	100.00

Quantity	kWh/yr	%
Excess Electricity	2,720.9	51.6
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	100.0
Max. Renew. Penetration	6,718.5

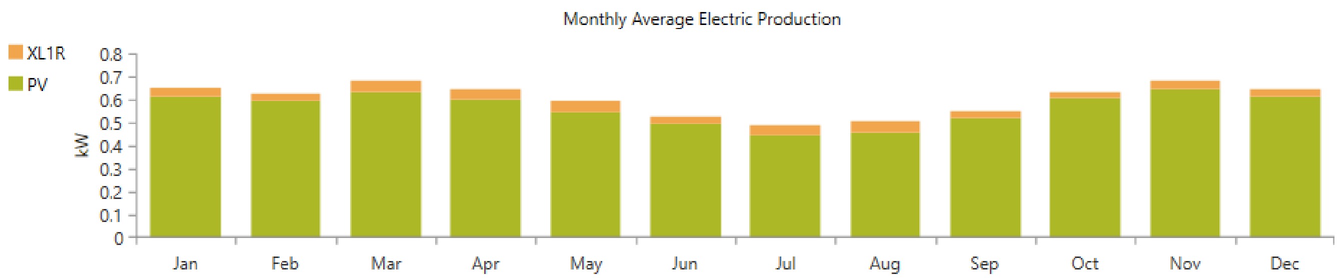

Figure 17. Component contribution to matching

From the graph, it can be noted that the region is well endowed with the potential to harness the vast resource of solar energy available to it. As explained in the urban scenario, not harvesting the excess electricity would be a problem.

Financial analysis of rural communities

The estimated cost of implementing a hybrid system in a single home in the rural community amounts to $11,250.00 which is astronomically high for most of the citizen living in Gwako ward where average citizens survive on less than $1 daily.

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Bergey Excel 1-R	$600.00	$0.00	$258.54	$0.00	$0.00	$858.54
Generic flat plate PV	$3,600.00	$0.00	$1,551.30	$0.00	$0.00	$5,151.30
System Converter	$300.00	$127.28	$0.00	$0.00	($23.96)	$403.32
Trojan T-105	$6,750.00	$6,269.15	$0.00	$0.00	($531.53)	$12,487.62
System	$11,250.00	$6,396.43	$1,809.84	$0.00	($555.49)	$18,900.78

Figure 18. Summary of Costs for Hybrid systems in rural communities

4.3. Community expansion

In order to meet the needs of multiple people in the rural community, another method is to create a community demand profile and carry out a supply matching to compare the cost summary that would be involved in powering these homes in the community.

Considering that there are at least 80 homes without connection to the grid presently, the initial rural household demand is then expanded upon to accommodate this number which is then matched to get details on the technical and economic summary of the combinations. This is represented in figure 19 below.

Metric	Baseline	Scaled
Average (kWh/d)	460.8	460.8
Average (kW)	19.2	19.2
Peak (kW)	47.84	47.84
Load Factor	.4	.4

Figure 19. Community demands data

Average demand is (X80) of the original demand profile. This data is then simulated to project a demand and supply matching option suitable for implementation. The result of best technical and cost effective option is described below.

Production	kWh/yr	%
Generic flat plate PV	82,294	41.64
50kW Genset	111,962	56.65
Bergey Excel 1-R	3,389	1.71
Total	197,644	100.00

Consumption	kWh/yr	%
AC Primary Load	168,192	100.00
DC Primary Load	0	0.00
Total	168,192	100.00

Quantity	kWh/yr	%
Excess Electricity	25,742.7	13.0
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	33.4
Max. Renew. Penetration	1,392.9

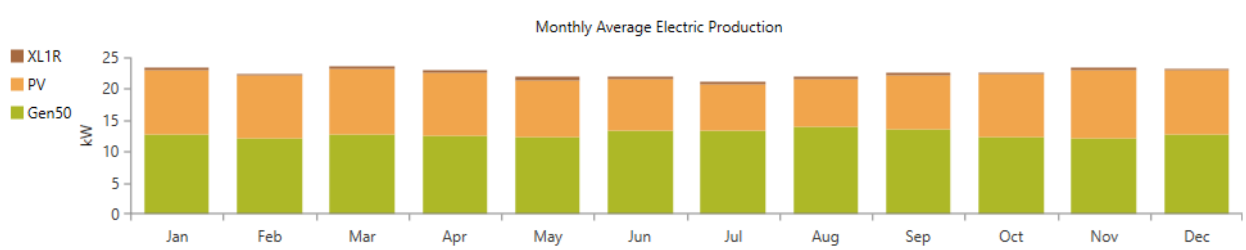

Figure 20. component contribution to the rural community

There is a massive contribution from solar and diesel generators with little input from wind turbines. Although demand is met, the cost of running such a system will take a huge toll on the financial investor in the project. All costs associated with the functioning of this system are well exaggerated. This can be seen in figure 20 below.

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
50kW Genset	$12,000.00	$0.00	$2,194.73	$603,539.38	$0.00	$617,734.11
Bergey Excel 1-R	$6,000.00	$0.00	$2,585.48	$0.00	$0.00	$8,585.48
Generic flat plate PV	$60,000.00	$0.00	$25,855.02	$0.00	$0.00	$85,855.02
Trojan T-105	$14,400.00	$25,719.73	$0.00	$0.00	($3,289.84)	$36,829.89
System	$92,400.00	$25,719.73	$30,635.23	$603,539.38	($3,289.84)	$749,004.50

Figure 21. Cost summary for community hybrid implementation

5. Discussion of Results

From a technical standpoint, most of the renewable components would function more than average in the conditions associated. It can be seen that one of the main resources is solar as most power generation was being done by the PV panels. Wind power is the least contributor among all available options, but that does not make it unimportant as it could be deployed to handle equipment that has smaller demands. Most buildings in the urban areas of the city have high power consuming equipment and this, in turn, affects the demand profile as well as an increase in the cost of operating hybrid equipment.

Most of the combination outcomes where all sufficient enough to power the households for 24 hours with different combinations subject to cost of deployment. Due to the fact that there is an absence of Feed in Tariff in the country, there are both financial end power losses associated with the system.

6. Conclusion

In order for Nigeria to develop, there has to be a diversification of the present power structure. There is almost absolute dependence on oil as the only source of the fossil-based generation system. More pragmatic approaches should be taken instead of constant policy creation with no peculiar aim or purpose. Although most policies look good on paper, the power sector has suffered from non-implementation of these policies.

Renewable energy should be vigorously investigated as there is vast potential to match the current demand that is associated with the country.

Abandoned projects especially those of renewable potential (hydro) should be looked into so as to reduce the dependency on fossil fuels.

More incentives should be given to renewables to enable them to flourish in the country as the present cost is too expensive for a vast majority of the population. There should be subsidies placed on renewable technology to increase their expansion all around the country.

Lastly, more research should be done on the implementation of hybrid systems in 50% of domestic homes to reduce the demand on the grid. The government could learn from pacesetters that generate a huge chunk of their supplies from renewables.

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8. Appendix

GENERATION BY NATURAL GAS

Power station	Type	Capacity	Status
AES Barge	Simple cycle gas turbine	270 MW	Operational
Aba Power Station	Simple cycle gas turbine	140 MW	Taking off (I quarter 2013)
Afam IV-V Power Station	Simple cycle gas turbine	726 MW	Partially Operational
Afam VI Power Station	Combined cycle gas turbine	624 MW Shell.	Operational
Alaoji Power Station(NIPP)	Combined cycle gas turbine	1074 MWNDPHC.	Partially operational(225MW)
Calabar Power Station(NIPP)	Simple cycle gas turbine	561 MWNDPHC.	Under Construction
Egbema Power Station(NIPP)	Simple cycle gas turbine	338 MW NDPHC.	Under Construction
Egbin Thermal Power Station	Gas-fired steam turbine	1320 MW	Partially Operational (994MW)

Geregu I Power Station	Simple cycle gas turbine	414 MW	Unknown
Geregu II Power Station(NIPP)	Simple cycle gas turbine	434 MW Siemens	Taking off (I quarter 2013)
Ibom Power Station(NIPP)	Simple cycle gas turbine	190 MW	Partially Operational (60MW)
Ihovbor Power Station(NIPP)	Simple cycle gas turbine	450 MW NDPHC.	Under Construction
Okpai Power Station	Combined cycle gas turbine	480 MW	Operational
Olorunsogo Power Station	Simple cycle gas turbine	336 MW	Partially Operational
Olorunsogo II Power Station(NIPP)	Combined cycle gas turbine	675 MW NDPHC	Partially Operational
Omoku Power Station	Simple cycle gas turbine	150 MW	Operational
Omoku II Power Station(NIPP)	Simple cycle gas turbine	225 MW	Under Construction
Omotosho I Power Station	Simple cycle gas turbine	336 MW	Operational
Omotosho II Power Station(NIPP)	Simple cycle gas turbine	450 MW	Operational fully by NDPHC
Sapele Power Station	Gas-fired steam turbine andSimple cycle gas turbine	1020 MW	Partially Operational (135 MW) Information Brochure
Sapele Power Station(NIPP)	Simple cycle gas turbine	450 MW	Operational The Nation

Delta - Ughelli Power Station	Simple cycle gas turbine	900 MW	Partially Operational(360 MW)

Hydro generation

hydroelectric station	Type	Capacity	Year completed
Kainji Power Station	Reservoir	800 MW	1968
Jebba Power Station	Reservoir	540 MW	1985
Shiroro Power Station	Reservoir	600 MW	1990
Kano Power Station	Reservoir	100 MW	2015
Zamfara Power Station	Reservoir	100 MW	2012
Kiri Power Station	Reservoir	35 MW	2016
Mambilla Power Station	Reservoir	3050 MW	2018

Coal generation

Power station	Type	Capacity	Status
Itobe Power Plant	Circulating Fluidized Bed technology	1200 MW	Planned