RURAL ELECTRIFICATION THROUGH RENEWABLE RESOURCES IN A RURAL/REMOTE AREA IN NIGERIA. DESIGN, OPTIMIZATION AND TECHNO-ECONOMIC EVALUATION

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I humbly dedicate this report to Allah. This report is also dedicated to my Parents, Wife, Children, brothers and sisters.

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ABSTRACT

The need for electricity generation in rural areas of Nigeria through renewable energy sources or grid extension is paramount in order to increase the rural electrification rate (35%) to an appreciable value. Electricity can be supplied through either the national grid being extended or through off-grid systems, grid extension cost depends on the location of the area, its terrain, the number of households, distance of the area from a grid point, the size of the land among others. However, based on these factors and inadequate supply of electricity to even the areas connected to the national grid, renewable energy sources may provide an alternative means of electricity generation in rural areas in Nigeria. This research designed and evaluated the techno-economic feasibility of providing electricity to rural Dilchidama in Nigeria through renewable energy source considering 77 households, 1 primary school, 1 primary health centre and 4 shops having an estimated load of 306 kWh/d and compared it with extending the national grid to the area using HOMER and RETScreen tools. The results obtained from the techno-economic design from HOMER tool showed that grid extension is much more cost competitive to the solar PV system for the study area and to other neighbouring villages with similar geographical data and settlement up to a distance of 9.99 km. The sensitivity analysis performed by varying several input parameters such as annual average load, scaled annual average solar resource, annual real interest rate and solar PV components prices indicated that, solar PV renewable resource has a high potential especially if the location is far away from a grid source.

ABSTRAK

Keperluan penjanaan elektrik di kawasan luar bandar Nigeria melalui sumber tenaga boleh diperbaharui atau sambungan grid adalah sangat penting untuk meningkatkan kadar elektrik luar bandar (35%) kepada nilai yang cukup besar. Elektrik boleh dibekalkan melalui sama ada grid nasional lanjutan atau melalui sistem luar grid, kos sambungan grid bergantung kepada lokasi kawasan, kawasannya, bilangan isi rumah, jarak kawasan dari titik grid, saiz tanah antara lain. Walau bagaimanapun, berdasarkan faktor-faktor ini dan bekalan elektrik yang tidak mencukupi untuk kawasan-kawasan yang berkaitan dengan grid kebangsaan, sumber tenaga boleh diperbaharui mungkin menyediakan alternatif penjanaan elektrik di kawasan luar bandar di Nigeria. Kajian ini merancang dan menilai kelayakan tekno-ekonomi untuk menyediakan tenaga elektrik kepada kawasan luar bandar iaitu Dilchidama di Nigeria melalui sumber tenaga boleh diperbaharui dengan mengambil kira 77 isi rumah, 1 sekolah rendah, 1 pusat kesihatan primer dan 4 kedai yang mempunyai anggaran 306 kWh / d dan membandingkannya dengan grid nasional lanjutan ke kawasan itu dengan menggunakan alat *HOMER* dan *RETScreen*. Keputusan yang diperoleh daripada reka bentuk teknologi dari alat *HOMER* menunjukkan bahawa sambungan grid jauh lebih kompetitif untuk sistem *solar PV* untuk kawasan kajian dan ke kampung-kampung lain yang mempunyai data geografi dan penyelesaian yang sama sehingga jarak 9.99 km. Analisis sensitiviti yang dilakukan melalui pelbagai *parameter* input seperti beban purata tahunan, sumber solar purata tahunan yang disingkat, kadar faedah tahunan sebenar dan harga komponen *solar PV* menunjukkan bahawa, sumber *solar PV* yang boleh diperbaharui mempunyai potensi tinggi terutamanya jika lokasi jauh dari sumber grid.

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LIST OF ABBREVIATIONS

STC	Standard Test Condition
PV	Photovoltaic
NOCT	Nominal Operating Cell Temperature
kW	Kilowatt
MW	Megawatt
CFL	Compact Fluorescent Lamp
HOMER	Hybrid Optimization Model for Electric Renewables
yr.	Year
V	Voltage
DC	Direct Current
AC	Alternating Current
d	Day
MIN	Minimum
Ah	Ampere Hour
h	Hour
Inv_T	Inverter
MPPT	Maximum Power Point Tracker
AGM	Absorbent Glass Material
kV	Kilovolt
LCC_{GEX}	Life Cycle Cost of Grid Extension
LCC_{Egen}	Life Cycle Cost of Electricity Generation
LCC_{GL}	Life Cycle Cost of Grid Line
D	Distance from Grid Point to the Load Centre
O & M	Operation and Maintenance
$ALLC_{GEX}$	Annualized Life Cycle Cost for Grid Extension
CRF	Capital Recovery Factor
PVC	Present Value Coefficient

COE	Cost of Energy (Electricity)
NPV	Net Present Value
NPC	Net Present Cost
SPB	Simple Pay Back
IRR	Internal Rate Of Return
B-C	Benefit Cost Ratio
NREL	National Renewable Energy Laboratory
PCS	Pieces

LIST OF SYMBOLS

PV_{RC}	PV array rated capacity	kW
PV_{DF}	PV array derating factor	%
$G_{i,PV}$	Incident radiation on the array at that time	kW/m^2
$G_{i,STC}$	Incident radiation on array at standard test condition	$1kW/m^2$
τ_p	Temperature coefficient of power	$\%/^0C$
T_{cell}	Cell temperature of PV	^0C
$T_{cell,STC}$	Cell temperature of PV at STC	^0C
T_S	Surrounding temperature	^0C
$T_{Cell,NOCT}$	Nominal operating temperature of the cell	^0C
$T_{S, NOCT}$	Surrounding temperature where NOCT is 20^0C	^0C
G_R	Radiation acting on array	kW/m^2
$G_{R,NOCT}$	Radiation at which NOCT is defined (800 W/m^2)	kW/m^2
τ_a	PV array solar absorbance	%
η_{mpp}	Efficiency at maximum power point	%
P_{pvao}	PV array power output	kW
L_{bb}	Battery bank life	yr.
N_b	Number of batteries	-
Q_{lt}	Lifetime throughput of a single battery	kWh/yr.
L_{bf}	Float life of the battery	yr.
V_n	Nominal voltage of a single battery	Ah
L_o	Other loads	kW
L_i	Inductive loads	kW
Q_{tp}	Annual battery throughput	kWh/yr.
C_n	Nominal capacity of a single battery	Ah
q_m	Minimum state of charge of the battery bank	%

L_{av}	Average primary load	kWh/d
δ	Solar declination	Degree
x	Day of the year	-
H	Hour angle	Degree
S_t	Solar time	h
θ	Incident angle	Degree
Φ	Latitude	^{0}N
γ	Azimuth angle	Degree
θ_z	Zenith angle	Degree
$\tau_{t\&d}$	Transmission and distribution losses	-
h’	Annual operation hours	h/yr.
n	Lifetime of the project	yr.
P	Present worth	$
C_{GL}	Cost of grid line	$/km
C_T	Cost of distribution transformer	$
β'	Fraction of capital cost for O&M of the grid	-
d’	Discount rate	%
$C_{T,NPC}$	Total net present cost of a power system	$
i	Real interest rate	%
$C_{P,grid}$	Cost of power from grid	$/kWh
E_{AD}	Summation of the annual demand for electricity	kWh/yr.
C_{CGEx}	Capital cost of grid extension	$/km
$C_{o\&m}$	Cost of operation and maintenance	$
R	Interest rate	%
i'	Inflation rate	%
C_v	Current value	$
C_{in}	Initial cost	$
C_R	Replacement cost	$
E_D	Load demand	kWh/d
C_{NPC}	Net present Cost	$
C_{ti}	Total cost of investment	$
$C_{n'}$	Net cash coming in during year n	$

V_{ig}	Incentive and grant	$
C_F	Fuel cost	$/L

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CHAPTER 1

INTRODUCTION

1.1 Background

The requirement for electricity in any community is paramount considering the high benefits that are derived from it which relate to the enhancement of man's quality of life. Electricity to some extent is a major issue in the characteristics of the gap between rural and urban communities in the developing world. It was estimated that about 1.2 billion of the world population have no provision of electricity grid [1]. Most of them reside in rural areas in Sub-Sahara Africa (about 0.590 billion), South Asia (about 0.610 billion), and East Asia (about 0.195 billion) [1]. Lack of access to reliable light source or electricity, means productive workday stops when it is dark. Most of the rural dwellers use kerosene lamps, which emit poor light, and very dangerous because they give off an irritating smoke that blackens the walls and fills up closed rooms. If mistakenly tipped over it can start a fire that could burn down houses, particularly in mud-thatched houses, which are commonly found in the rural settlements.

Furthermore, present scheme of provision of electrification to rural area via extension through grid lines of transmission didn't succeed in the provision of electricity to the numerous population of rural areas in Nigeria and the hope that many rural areas will be connected to an electric source in the near future is still not known because even those connected receive an epileptic supply. In order to reduce dependence on the conventional grid system and to reduce the number of people living without access to electricity, the design, cost implications and evaluations of renewable resources for rural electrification was considered together and compared with the conventional mode in this project.

However, it is also evident that about 1.2 billion people across the globe living in rural remote villages far from electricity grid have no access to electricity supply [1], despite the abundant renewable resources that are yet to be exploited or harnessed. Certainly, with these numbers of people living in darkness with no grid connection, it deemed necessary that off-grid based rural electrification will serve as a better option in providing power to the rural population. Nigeria has many villages including Dilchidama with such predicament.

The country Nigeria is in Sub-Saharan Africa (West Africa), it has $924{,}000\ km^2\ land\ area$, almost 3.1 % land area of Africa, it lies between 4.32 ^{0}N and 14 ^{0}N on the latitude and 2.72 ^{0}E and 14.64 ^{0}E on the longitude [2]. The country has abundant energy sources; ranging from coal, petroleum, natural gas, solar, small hydropower, large hydropower, and biomass. The economy of the country relies mostly on the revenue generated from the export of crude oil. The country depends largely on fossil fuel to achieve her energy demand. The generation of electricity in Nigeria obtained from hydro power and fossil fuel is 38.1 % and 61.9 % respectively. The estimated reserve of some fossil fuel types as obtained from Sambo [2] are 36.2 billion barrels of crude oil, 18.7 trillion SCF of Natural gas, 2.7 billion tonnes of coal & lignite and Tar sand of 31 billion barrels of oil equivalent. However, with the gains in the sales of crude oil and the abundant reserves of fossil fuel couple with the dependence of products of petroleum for the provision of electricity, there are the possibilities that fossil fuel usage may continue to be the most suitable means of energy resources in Nigeria for some time [3,4]. Table 1.1 below gives an overview of the fossil fuel resources in Nigeria.

Table 1.1: Overview of Fossil Fuel Resources (Source BP, 2013)

Resources	Reserve	Production	Years of extraction remaining (yrs.)
Oil	37.2 billion barrels	2417000 barrels/day	42
Gas	5.2 trillion cubic metre	43.2 billion m^3/yr.	120

Nigeria has an estimated overall population of 188,375,518, it was estimated that only 40 % (75,350,207.2) of Nigerians are connected to the national grid and even these connected populations experience frequent power outages [5]. This means that about 60 % (113,025,310.8) of these populations live without electricity; this population constitutes mostly the rural settlers who mostly use kerosene lamps or corn stalks for night reading/activities, which may likely have an adverse effect on health and risk of spread of fire.

A good number of Nigerian researchers made a lot of study and research work in order to consider the possibility of harnessing renewable energy sources in the country noting that solar radiation received in the country and other renewable sources can be gainfully utilized. The yearly solar radiation recorded was 5250 Wh/m^2/d. This varies between 3500 Wh/m^2/d around the coastal areas of the south and 7000 Wh/m^2/d in the northern area [4,6,7]. Estimated result of the average period of hours of sunshine across the country was 6.5 hours with an average yearly intensity of solar radiation at 1.935 MWh /m^2/yr. and an approximated solar energy of 1,770,000 GWh/yr. This result equates to multiples of 120,000 total yearly average energy generated by the electricity distribution company of Nigeria called Power Holding Company of Nigeria (PHCN) [7]. Agbo and Oparaku [8] indicated that some of the policy factors hampering the deployment of some energy technologies and alternative fuels include poor research and development (R&D), lack of pilot and demonstration projects, institutional framework, investment promotion, incentives, and protections.

However, a techno-economic analysis conducted by Chaurey, A. and Kandpal, T.C [9] based on Photovoltaic micro grid and solar home systems for rural electrification. They reported that the micro grid might the best option economically (in terms of cost) for the energy company and the user (community) having many households especially if the terrain is flat and the population is densely situated. In the case of a spread or sparse population, they reported that the best option might be the solar home system due to the absence of distribution cost.

A study by Mahapatra S, and Dasappa S [10] on the optimization for the selection between grid extension and off -grid non-centralized renewable resources using photovoltaic and biomass gasification and applying cost assessment on the life cycle concluded that renewable energies for electricity generation could be cost competitive. They also reported that the perception of renewables having the huge initial cost of investment is not always the case especially for a rural area with low energy requirement and far from where a grid source can be tapped. Generation cost for grid electricity is low but incurred substantial amount due to transmission and distribution losses as the distance between the grid point and its destination (village load) is wide. However, life cycle costs for biogas came from cost of fuel, the cost of maintenance and cost of operation. As the hours of operation of biomass gasification increases, the life cycle cost of energy from the system decreases, while for a system of photovoltaic, it approximately maintains its value for different times (hours) of operation [10].

Shaahid, S.M and El-Amin [11] carried out a techno-economic assessment of off-grid hybrid PV-diesel-battery power system for electrification of a rural area in Saudi Arabia with a view of analysing solar radiation data of Kafha to examine the viability of hybrid-diesel-PV-battery system to accommodate the load needed for a rural area that has a yearly energy need of 15.943 GWh. Their findings from the simulation indicated that for hybrid components comprising 4.5 MW diesel system, 2.5 MWp PV system and 1-hour battery system autonomy, 27 percent PV penetration was obtained and that the energy cost (COE) of the hybrid system was $0.17/kWh at $0.1 per litre. However, with this hybrid configuration, maintenance in the diesel system is greatly reduced and the efficiency increased. There is also a reduction in the diesel and battery capacities and a consequential decrease in the percentage of carbon emissions.

Electrification of rural area is mostly associated with many challenges that include bad terrain, low load demand, the huge cost of investment, inadequate load factor, the cost of maintenance and operation [12]. However, some factors such as irrational renewable energy policies; non-availability of subsidies for renewables militates or hampers the use renewable resources and this contributes to making the conventional system more affordable than the renewable resources [13]. In Nigeria, the basic challenges faced for renewable energy resources are; the master plan and energy policy law need to be reviewed, lack of manufacturing companies/industries for components of renewable system to be produced locally, no enough incentive for the development of renewable energy, insufficient studies on biomass and hydropower requirement [2].

Rural electrification is obtainable through either grid extension strategy to remote/rural settlements, or by design using the decentralized systems often called ”off-grid” systems of electrification [14,15]. However, the study area currently relies on generators for their means of providing electricity, and to a large extent on kerosene lamps, hand held torch and rechargeable lanterns. Therefore, in other to make the population of Dilchidama feels the benefit and impact of having electricity through the adoption of renewable resources, this study investigated the techno-economic evaluation of the potential of renewable resources and technology for electrification of Dilchidama in Hong local government of Adamawa State in Nigeria. Furthermore, to examine the viability of rural electrification through off-grid renewable energy options, this work determined the technology configuration with the use of HOMER tool and finally its financial acceptability with the aid of RETScreen tool. HOMER tool (Hybrid Optimization Model for Electric Renewables) is a micro power optimization software used in evaluating designs of both off-grid and grid-connected power systems for a variety of applications. This software was developed by Mistaya Engineering, Canada for the National Renewable Energy Laboratory (NREL) USA so as to assist in the design of a power system, sizing of components used and other parameters involved. Its optimization and sensitivity algorithm simplifies the evaluations of several system configurations and stimulates the operation of energy balance calculations sorted by the net present cost that can be used to compare system design [16].

RETScreen tool is a software developed by CANMET Energy Diversification Research Laboratory (CEDRL) that is based on Microsoft Excel spread sheets, consisting of a standardized and integrated renewable energy project analysis [17]. As stated above this tool will also be employed for the project financial viability such as Cost of Energy (COE), Net present Value (NPV), Internal rate of return (IRR) and Benefit to Cost Ratio (B/C). This tool also enables the researcher to assess energy production, reduction in greenhouse gas emission and life cycle cost of renewable energy technologies [17].

However, this research work compared off-grid options (microgrid) with grid extension (conventional) to the study area and indicated the most economically competitive method of providing electricity access in the rural area of Dilchidama.

1.2 Problem Statement

Many rural/remote areas in Nigeria are living without access to electricity. The wide gap between electricity demand and supply is increasingly growing, as the expected demand in 2015 was targeted to approach 31,240 MW. Reports from the Federal ministry of Power showed that the national grid generated 4,389 MW and delivered 4,038 MW as at December 2014, and data gotten from the Energy Commission of Nigeria (ECN) showed that the power generated in 2015 was not close to that of the national need expected to be 31,240 MW at GDP of 11 % growth rate.

In many developing countries, projects of renewable energy sources (hybrid systems) have been implemented for rural electrification [18] . Although, a lot of researches have been conducted and still on-going for the viability and reliability of renewable energy for rural electrification projects in various rural communities around the world, so far, no research has been conducted for electrification through grid extension or off-grid options for Dilchidama. The provision or access to power to that area is still a dream despite the fact that national grid is just a few kilometres (3.02 km) away from the village.

To attend to the problem of rural electrification in rural Dilchidama, this project designed and evaluated the possibility of providing power through a Solar (PV) renewable energy source and compared it with that of the conventional means (National grid and Diesel Generator) of electrification and gave the optimum design and techno-economically feasible source for providing electricity to the rural area of Dilchidama.

1.3 Objectives of the Study

The aim of the present work is to design and optimize the electrification system in Dilchidama village and conduct the techno-economic evaluation of the proposed systems. The specific objectives of this project work are:

(i) To perform design, optimization and sensitivity analysis of a renewable source of electrification system in Dilchidama.

(ii) To obtain the economic evaluation and feasibility of rural electrification using renewable resources, and comparing it with that of the conventional system (national grid) being used in Nigeria.

(iii) To evaluate and examine the least-cost technology options for providing electricity access in the rural area of Dilchidama.

1.4 Scope of Study

HOMER and RETScreen tools were employed for the solar PV renewable energy technology configuration (design), financial viability and reliability of electrifying the study area.

Estimated load demand, climatic data and average market prices were used for the design and evaluations.

The electricity design, distribution and cost analysis was limited to only for the provision of electricity for lighting, ventilation, and few domestic appliances having low power ratings.

1.5 Significance of Study/Research

The major significances of this project are:

(i) It provides data for the design of renewable resource for the electrification of Dilchidama because presently the village is without any source of electrification.

(ii) It will give the techno-economic advantage of a renewable energy source as compared to other types that provide the same service.

(iii) It evaluates and promotes the use of renewable resources, and a consequential mitigation of greenhouse gases.

(iv) It evaluates and investigates installation cost and financing problems with rural electrification.

(v) It gives knowledge and awareness in the aspect of renewable rural electrification and provides better life/development for the rural dwellers if implemented.

1.6 Research Outline

This project work is discussed in five chapters. Chapter 1 highlights the introductory part, in-adequacy and in-accessibility of rural electrification in most rural communities around the world. It also gives some of the objectives and limitations of this study.

Chapter 2 discussed the literature on work performed by other researchers and the technology options in order to have adequate information on methods and technology options used by previous researchers. It also provided the energy scenario in Nigeria and highlighted some of the renewable energy options that can be explored in the study area.

Chapter 3 considered the basic components used in solar renewable and hydro energy technology systems and the necessary formulas that will be applied in the design and costing analysis. This chapter also provided the input data required for the design and financial viability of the electrification system.

Chapter 4 presented the design results of different configurations performed, it also provided some sensitivity results conducted for a different range of input parameters and stated the most economically competitive option of providing electricity to the study.

Chapter 5 provided the summary of the project design and evaluation, it also suggested some future work that can be conducted for the same case study and ways that can make the study area have adequate electricity supply if implemented.

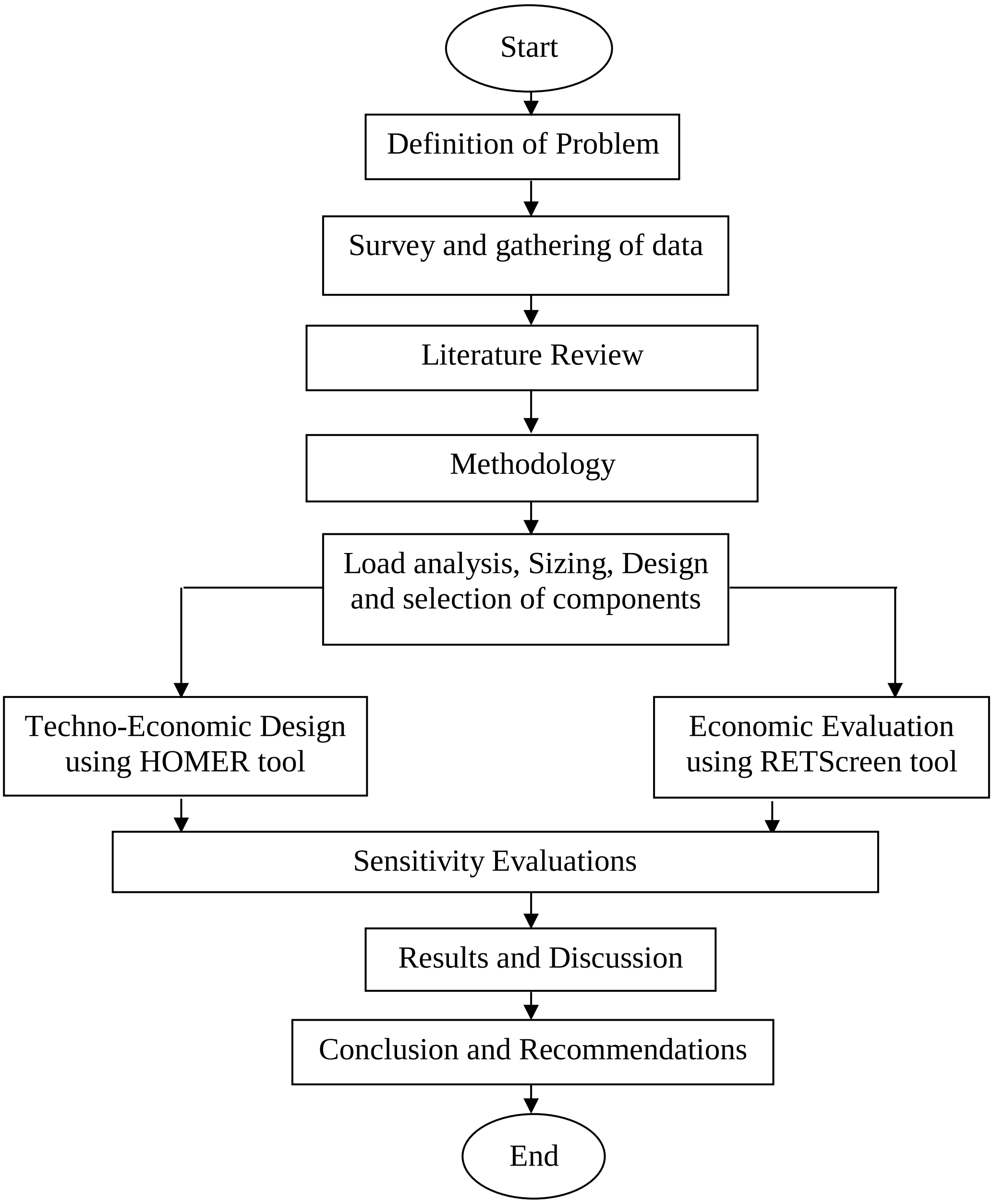

Figure 1.1: Project Outline

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