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RENEWABLE ENERGY TECHNOLOGIES ASSESSMENT IN PROVIDING SUSTAINABLE ELECTRICITY TO NIGERIAN RURAL AREAS

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DEDICATION

To my Mum for her support, prayers and words of encouragement

To my kids (Nusaybah, Haneefah, Maryam, Rahmah and Abdulhakeem (Jr)) for my absence during the course of the study

ABSTRACT

The research work that underpins this thesis aims to investigate the viability of renewable energy technologies (RETs) and to develop a RETs implementation framework for providing sustainable electricity to Nigeria's rural areas. As a result of electricity supply deficiency in Nigeria, rural communities have been negatively affected in their socio-economic activities. A strength, weakness, opportunity and threat (SWOT) analysis in combination with an assessment of sustainability indicators of RETs, identified the most appropriate technology for providing sustainable electricity in Nigeria's rural areas. Biomass energy technologies (BETs) are the most appropriate RET given significant resource availability. However, cost has been identified as the major barrier in adopting BETs. Both BETs and grid extension (GE) systems have been assessed. Whole Life Costing (WLC) and interview methods have been used to evaluate the economics of various capacities of BETs and GE systems, and assessed suitability of BETs respectively. Typical findings revealed that all the BETs capacities evaluated other than a 50kW direct combustion system are currently cost-competitive with existing fossil fuel (FF) sources used in generating electricity in Nigeria (US$0.13/kWh without incentives). BETs are identified as the preferable option than GE system for electricity provision to communities of demand capacity less than 50kW and distance less than five kilometre from load centres. Similarly, the interview method confirmed that BETs utilisation in the country's rural areas are suitable and desirable. For implementation, all the identified drivers and enablers of BETs should be considered, along with the identified constraints to the adoption and development of BETs, some of which should be addressed before implementation. Further, a BETs implementation framework for sustainable electricity provision in rural areas has been developed through the selection of appropriate biomass feedstock and conversion technologies, and support through suitable incentive strategies. The framework was then evaluated and validated using six villages as case study. The benefit of the framework is ensuring successful electricity provision in rural areas. Thus, this study recommends that the existing rural areas energy policies be reviewed to include incentive strategies like economic subsidies in order to encourage investors' participation given lack of energy infrastructures in rural areas.
***Keywords**: Decentralised sustainable electricity, Feed-in-tariff, Nigerian rural areas, Renewable energy technology, SWOT analysis, Whole life costing*

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Energy is a key factor for any form of socio-economic development and electrical energy has proven to be important among factors of production which include land, capital and labour (European Commission 1993; Mandelli et al. 2016; Chineke & Ezike 2010). In Nigeria 80% of organizations may rely on self-generated electricity (Sanyaolu 2008). Accessibility to electricity and the socio-economic growth of a nation are connected (Ikeme & Ebohon 2005; Ohunakin et. al. 2011) and is an essential factor in controlling the extent of rural-urban migration (Ajayi et. al 2011). Any nation with an electricity supply deficiency will experience declining economic growth, social problems and a low standard of living.

Following the failure of the national utility company (Power Holding Company of Nigeria), the country has been experiencing energy shortages for over three decades (mid 1980s –date), resulting in an unfavourable environment for both foreign and local investors, businesses and domestic users. Many multi-national companies have relocated to neighbouring countries, and large numbers of local manufacturers have switched to trading as a result of an inability to compete with technologically advanced corporations that do not suffer from electricity supply problems in their country. This problem has caused businesses closures and job losses (Ikeme & Ebohon 2005).

Nigeria is endowed with both fossil fuel and renewable energy sources, and the country is the seventh largest member of Organisation of Petroleum Exporting Countries (OPEC) (Energy Commission of Nigeria (ECN) 2005). Nonetheless, Nigeria remains unable to meet the electricity needs of its citizens, with over 85% of its secondary energy being imported (Oseni 2012). Nigeria's power generation installed capacity was approximately 6500 mega-watt (MW) in 2005 but only 3959 MW of this was available (Ibitoye & Adenikinju 2007). Nigeria's electricity output still remains around 4,000MW or less for a population of over 180 million despite completion of the power sector privatisation in 2013 (Garba &

Kishk 2015; Garba et al. 2016c; Central Intelligence Agency (CIA) 2016). This capacity does not compare well with countries such as South Africa and Egypt (Nnaji 2011; CIA 2016), particularly with Nigeria being the largest African economy (Obiakor 2016). See table (1.1).

Given the shortage of commercial energy in Nigeria, the majority of rural communities and some fractions of urban dwellers utilized fuel wood and charcoal (FWC) to meet nearly all their energy needs. Sambo (2009) declared that FWC usage constitutes between 32%-40% of Nigeria's total primary energy consumption, with approximate annual consumption of 50 million metric tons of fuel wood alone. Also, self-generation of electricity is generally common and represents between 4,000 and 8,000 mega-watt (MW) (Eberhard & Gratwick 2012). This capacity exceeds the gridline source.

Table 1.1: Watt/Capita Data for Sample African Countries (Nnaji 2011; CIA 2016)

Country	**Population (million)**	**Installed Capacity (GW)**	**Electricity Production (kWh)**	**Watt/capita**
Nigeria	181	6.09	27.27 billion	40 (25 available)
South Africa	54	44	239 billion	826
Egypt	88	27	155 billion	259

The causes of this situation can be classified as either technical or human factors. Technical factors include but are not limited to:

- Power generation stagnation,
- Dilapidated power plants,
- Transmission and distribution losses.

Human factors include:

- Insufficient funding,
- Leadership change,
- Electricity theft by ghost customers,
- Non-payment of electricity bills by customers,
- Corruption (Adenikinju 2003; Sambo 2009; Sambo et al. 2010).

A recent human factor that has contributed to this condition is persistent vandalism/sabotage of energy infrastructures and gas supply pipelines (Al-chukwuma & Sunday 2013; Garba et al. 2016a).

1.2 PROBLEM STATEMENT AND RATIONALE FOR THE STUDY

Nigeria has consistently low electricity supply at both national and rural areas levels; electricity accessibility remains at 34% and 10% respectively (Ikeme & Ebohon 2005; Sambo 2009; Shaaban & Petinrin 2014; Garba & Kishk 2015), a situation that is worsened by rural communities representing over 60% of the country's total population (Bugaje 2006; Ogwueleka 2009; National Population Commission 2006). Consequently, Nigeria consistently has the highest gap (globally) between electricity demand and supply (Nnaji 2011). In rural areas the energy supply problem has subdued the local economy and constrained the development of cottage industries and small businesses (Ikeme & Ebohon 2005). The consequences of this problem are endemic rural-urban migration, unemployment, poor health (particularly to women using FWC for cooking), social-cultural stagnation and depletion of forest and woodland in the country (over 90% of rural dwellers depend on fuel wood and charcoal) (Sambo 2009).

Previous Nigerian energy policies have targeted rural communities, with a view to improving their energy access: Consumer Assistance Fund and Rural Electrification Fund are two examples (Ikeme & Ebohon 2005). Similarly, initiatives such as subsidising kerosene (cost Nigerian government over US$20 billion between 2010 and 2013) have had little or no impact (Garba & Kishk 2014).

Rural areas electricity problems are connected with the high cost of centralised electricity supply system using fossil fuel sources and grid network system, as they are typified with low capacity utilisation and are far from the grid, making it unappealing to private investor in providing electricity to these communities (Mahapatra & Dasappa 2012; Garba & Kishk 2015; Sambo 2009). (See also section 1.3 for more details). Thus, a sustainable means of electricity provision that is not fully reliant on expensive grid extension systems (to reach rural villages) and fossil fuel (non-sustainable) sources is required. Hence, rural communities' electricity needs have to be met through sustainable and economical means; typically decentralised renewable energy technologies (RETs) have been used in providing sustainable electricity to rural areas in developing countries. This approach represents the most suitable alternative to fossil fuel-based systems, provides a foundation for future grid growth (Mandelli et al. 2016), has merits in determining when and where power energy is truly required, helps in mitigating greenhouse gas (GHG) emission associated with FF sources, and creates more employment (Evans et al. 2010; Shunmugam 2009; Kaundinya et al. 2009). The most used RETs are solar PV, biomass and small hydropower systems (Mahapatra & Dasappa 2012). However, high capital cost has been identified as a major constraint on RETs adoption (Alazraque-cherni 2008; Frondel et al. 2010; Otitoju 2010), particularly for people in developing nations; and members of Nigeria's rural communities typically earn less than $1.25/day (UNICEF 2011).

This study builds upon Garba & Kishk's (2014) and Oyedepo's (2012) recommendations that an economic evaluation of RETs in Nigeria should be conducted in order to address the lack of reliable cost data which has affected modern RETs and constrained their inclusion in the country's energy mix.

1.3 CAUSES OF ELECTRICITY SUPPLY DEFICIENCY IN NIGERIAN RURAL AREAS

The following factors represent the major causes of Nigeria's rural areas electricity provision shortage problems. See Table (1.2) and figure (1.1).

Table 1.2: Causes of Electricity Supply Deficiency in Nigerian rural Areas (Adopted from: Iwayemi 1994; Mahapatra & Dasappa 2012; Sambo 2009, Eberhard & Gratwick 2012; UNICEF 2011; World Bank 2005; Dasappa 2011)

Problems	Causes
Investment Pattern	• Limited investment by the Nigerian government (prior to full privatisation in 2013) and commercial investors (since 2013) • Allocation of investment has favoured generation over transmission and distribution (See figure 1.1)
Electricity Infrastructure Economy	• High cost of grid network extension to rural areas • Electricity generation using fossil fuel equipment capital cost in excess of US$ 1,000
Economy of Rural Communities	• Nigerian rural communities live below US$ 1.25/day • Largely agriculture base • Long distance from the load centres • Bad road condition • Low energy consumption pattern
Climate Change Effect	• Declining rainfall in Nigeria, affecting water level in dams
Grid Network Losses	• High transmission and distribution losses of around 40% due to obsolescence of energy infrastructure

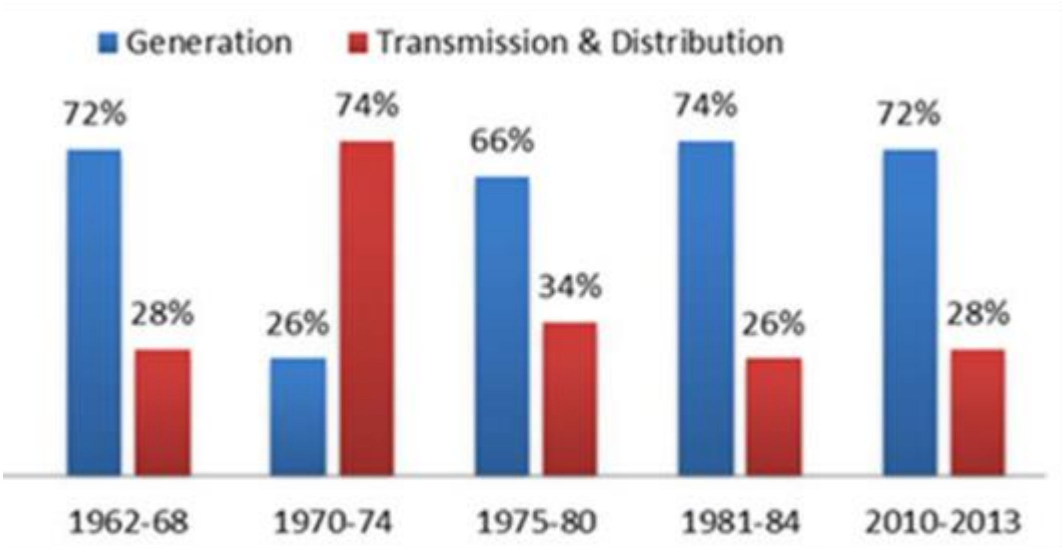


Figure 1.1: Sectoral Allocation of Investment in the Nigerian Power Sector (Iwayemi 1994; Nnaji 2011; Garba & Kishk 2014)

1.4 RESEARCH AIM AND OBJECTIVES

Aim

The aims of the research is to investigate the viability of Renewable Energy Technologies (RETs), and to develop RETs implementation framework in providing sustainable electricity to Nigeria's rural areas.

Objectives

Specific objectives of the research are:

- To carry out an extended literature review of various RETs and their application in Nigeria
- To examine the state of RETs development in Nigeria
- To investigate suitability of various RETs in provision of sustainable electricity to Nigerian rural areas with a view to identify a subset of technically viable options.
- To outline a whole life costing (WLC) model suitable for evaluating the sustainability of energy sources in Nigeria's power sector.
- To evaluate the economic viability and optimise the identified subset of RETs in provision of sustainable electricity to Nigeria's rural areas.
- To propose a framework for implementing RETs in Nigeria's rural areas.
- To evaluate and validate the proposed framework developed.

1.5 Research Questions

Can RETs provide sustainable electricity to Nigeria's rural areas?

- What are the RETs resources potential in Nigeria?
- Can RETs be affordable to rural communities over their life cycle?
- Can existing energy policies support the delivery of affordable and sustainable electricity to Nigeria's rural areas?
- What are the constraints on implementation of RETs in Nigeria?

Can the proposed RETs implementation framework guarantee sustainable electricity provision in rural Nigeria?

1.6 SIGNIFICANCE OF THE STUDY

The impacts of the research work are to:

- Overcome affordability obstacles of RETs through assessing and optimising their economic viability using whole life costing (WLC).
- Identify an alternative means of providing sustainable electricity to rural areas.
- Guide policy makers, investors and consumers' decision-making.
- Help with the elimination/reduction of national resources wastage
- Provide empirical data to support RETs inclusion among the national energy mix.

1.7 INITIAL METHODOLOGY

A combined qualitative and quantitative methodology will be used to achieve the research objectives. The literature review method will take the lead by reviewing: the current state of RETs globally and Nigeria; energy policies; RETs types; the knowledge gap and what sort of primary data will be collected. Interview method will be used to collect qualitative primary data, while whole life costing (WLC) data will be collected directly from the market (particularly biomass fuel and labour cost), manufacturers (conversion technologies) and Central Bank of Nigeria (discount rate). The qualitative data collected using both exploratory and semi-structured interview methods will be analysed using content analysis. A whole life costing (WLC) approach will evaluate and optimise the economic viability of the selected RETs. Finally, an implementation framework will be developed, evaluated and tested using a case study approach. This will be reported in full in chapter 5.

1.8 RATIONALE FOR RETS APPLICATION

The World Commission on Environment and Development (WCED) called for RETs to be adopted as a means of meeting global energy needs in 1987. Perhaps this could be because of the global prospect of this energy system's sources, projected to be 3.36×10^4 and 7.04×10^4 TWh/annum by the year 2030 representing economic and technical potential respectively (Akinbami et. al. 2001; Akinbami 2001). The estimated economic potential above is approximately double the global electricity generated from fossil fuel (FF) and nuclear sources by the end of 2014 representing 18, 125 TWh (REN21 2015).

There are basically three sources of commercial energy production currently available: FF, nuclear and renewable energy systems, with FF (coal, oil, natural gas) being the most established and commonly available (Kaundinya et al. 2009; Evans et al. 2009; REN21 2015; Moriarty & Honnery 2011). Regarding commercial energy requirements approximately 77% of global and 75% Nigerian requirements respectively are met through FF production but this energy source is finite (Sambo et al. 2010; Ohunakin et al. 2011; REN21 2015). The finite nature of FF energy source has generated debate among stakeholders concerning the extent of future discoveries of oil, etc., but there is general agreement that relatively few discoveries will be made in the future (Moriarty & Honnery 2011). Perhaps somewhat perversely, a reducing rate of increase in energy demands, particularly in developed countries, is emerging as energy efficiency measures take effect, thereby arguably extending the life of present and future discoveries. Thus Moriarty and Honnery's (2011) assertion that "Given declining reliance on fossil fuels because of both their greenhouse gas emissions and depletion of reserves, renewable energy will need to become the main energy form" could be argued to be partially accurate as a prediction. The search for alternative energy sources has become more connected to threats such as climate change effect (rather than depletion of reserves), as global energy and electricity production are contributing around 75% and 37% of greenhouse gas (GHG) emission respectively (Sopian et al. 2011; Manish et al. 2006).

Furthermore, the volatility of oil pricing, rising supply disruption (particularly regarding 'volume' producers such as the Middle East and Nigeria's Niger delta region), and health hazards (e.g. fuel wood causing lung problems to over 1.5 million women and children annually in developing countries (Sopian et al. 2011)) are among the reasons for emphasising the development of alternative and sustainable sources of energy (Shunmugam 2009; Kaundinya et al. 2009)

1.9 THE BENEFITS OF RETS FOR SUSTAINABLE ELECTRICITY

Fossil-fuel (FF) systems have, to varying degrees, failed to deliver sustainable and affordable energy to rural communities in developing countries (1.6 billion people without access to electricity) (World Energy Outlook 2004; Mahapatra & Dasappa 2012). As the world's population grows this situation will worsen and for this reason, amongst others, RETs sources are attracting growing attention.

In comparison with FF sources, RETs sources are globally available in abundance; 1000 times more solar energy reaches the surface of the earth than the daily energy provided through FF (Augustine & Nnabuchi 2009). Sources of energy to 'power' RETs are not uniformly distributed throughout the world; every region has some form of renewable energy resource or the other (Bull 2000). Also, RETs can generate more employment opportunities, thereby promoting socio-economic cohesion, than FF due to the decentralised nature (Sopian et.al. 2011; Owen et al. 2013), which also assists in income generation and protecting local environments (Karekezi & Kithyoma 2003). Furthermore, it is possible to integrate RETs sources into a centralised grid system in addition to operating as a decentralised system (as mini-grids or as individual home system) (Alazraque-Cherni 2008). RETs are modular in nature, permitting load growth flexibility (Bull 2000), which is a possible benefit from both economic and risk-management perspectives especially in third world nations.

RETs present a strategic value of identifying where and when electricity is actually required, thereby eliminating/reducing additions to a gridline network, albeit at high initial capital cost, this can be offset in the long term due to characteristics such as zero fuel cost for wind and solar sources. There is also a social benefit arising from the supply of electricity to the vulnerable rural poor, especially in remote communities in developing countries (Alazraque-Cherni 2008; Bull 2000). Taking a long-term perspective on such social benefits allows for a possible enhancement arising from most RETs producing relatively little impact on the environment (little waste or pollutants) and eliminating/reducing CO2and GHG releases to the atmosphere. For example, wind technology and PV/biomass electricity generation can reduce GHG emissions by 880g/kWh (around 98%) and 850g/kWh (around 95%) respectively when compared with coal-based electricity generation (Manish et al. 2006; Evans et al. 2009; Evans et al. 2010).

Slightly more peripheral benefits can be identified in terms of increased energy security and mitigation of the economic and political power of organisations such as OPEC (8 nations have 81% of all world crude oil reserves and 6 nations hold 70% of all the natural gas reserves) (Ajayi & Ajayi 2013). Both benefits are realistic in that as every region/country has some form of RETs 'fuel' source available. Typically, increasing attack on the energy infrastructure as result of instability in the Nigeria's Niger delta region, resulted to Egbin thermal power station could not generates up to 40% of its capacity in 2008 as result of Niger delta youths unrest (Eberhard & Gratwick 2012). Similarly, from 1999 to 2012, incidences of energy infrastructure vandalism increased exponentially where over 1,600 cases were witnessed annually (Al-chukwuma & Sunday 2013).

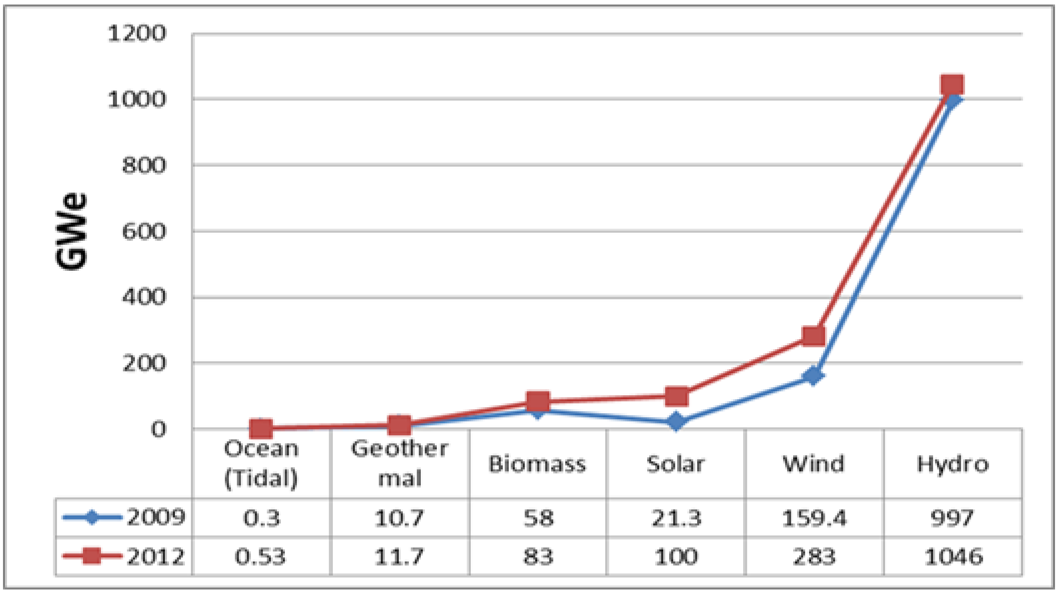


Figure 1.2: Comparison of RETs Contribution to Global Electricity Generation

RETs sources combined contribution to meeting energy demands is improving globally, see figure 1.2 for details, particularly the increased contribution by solar and wind between 2009 and 2012 (Martinot 2013; Wiese et. al. 2010). REN21 (2015) reported that modern RETs contributed 10.1% to the global total energy consumed by the end of 2013. Also, by the end of 2014, RETs have contributed approximately 23% of global electricity generated.

RETs are not without shortcomings, and these barriers are classified under deployment, utilisation and resource. Mature RETs such as large hydro and geothermal have shown some forms of environmental problems (Evans et al. 2009); and there can be limited potential for some RETs as result of intermittency of resources and location specific issues (Moriarty & Honnery 2011). The challenges of using RETs include inaccessibility to know-how and financial resources (Sopian et al. 2011), apathy to gather feedback, investment deficiency, inadequate policy framework and high initial cost (Alazraque-Cherni 2008). More so, unregulated production of electricity from biomass sources may lead to food and materials crises affecting vulnerable populations in developing countries (Shunmugam 2009 & Kaundiya et al. 2009).

Considering the deposit of FF sources in the country, Nigeria may not need to entirely replace its current energy sources with RETs sources at least not over the coming decades. However, strategic planning to reduce dependence on FF energy sources will be vital for sustainable development principles. As such, both sources should complement each other, thereby mitigating the effect of FF energy sources on climate change, given that Nigeria is the second-largest gas-flaring country globally (Oseni 2012).

Resources, land, and water availability may constrain large scale application of some RETs, such as with electricity production from biomass. According to Manish et al. (2006) it would have required approximately 7.7 million km2 (around 50% of the global total arable land) of planting for biomass to fully meet world electricity demand in 2003. Along with an increased electricity demand (2016) requiring even more land to be planted with 'fuel', there is a need to meet the world's food and fabric needs. Such competition (grains and vegetable oil are used in production of ethanol and biodiesel respectively (Renewable Fuels Association 2009)) has put pressure on grain prices; 75% of the food price increase in 2008 was a result of ethanol production from grains (Ngo 2008). Moriarty & Honnery (2011) opined that "Wind turbine output in 2008 was less than one EJ globally, but turbines are today already counted in the tens of thousands."

1.10 SCOPE OF THE RESEARCH

Based on the above argument (e.g., (90%) of Nigeria's rural communities without electricity), along with the need to address GHG production, this research will explore flexible and sustainable means of electricity provision. In addition, the lack of interest exhibited by investors in extending the gridline network to poor low consumption communities due to high cost of gridline network, evidences the need to examine the economics of modern and sustainable alternative means of electricity provision. Without this examination of the economics of sustainable and flexible alternatives there is a risk that such alternatives will not be dealt with realistically when making decisions concerning national energy strategies and policies. By focusing on evaluating the economics of RETs in providing sustainable electricity to Nigerian rural areas, and evaluating the relative suitability of decentralised RETs and extensions to the gridline network (in relation to the distance of the villages from load centres) the study supports the development of a RETs implementation framework. Such a framework will make a significant contribution to ensuring successful sustainable energy provision in rural areas by decision makers, investors or other stakeholders (communities). Also, the proposed RETs implementation framework shall only be limited to Katsina state, northwest Nigeria, especially from two local government councils (Funtua and Dandume).

1.11 THE STRUCTURE OF THE THESIS

A summary of how this research has been conducted is presented in Chapter One, which includes the following: background, rationale, aim and objectives, and research questions and scope of the study. The chapter also includes justification of adopting RETs, benefits of RETs utilisation and identification of RETs barriers.

Chapter Two presents a critical evaluation of RETs commonly utilised, using strength, weakness, opportunities and threats (SWOT) analysis. Also, sustainability indicators of individual RETs are assessed.

Chapter Three illustrates biomass resources suitable for electricity generation and various biomass conversion systems.

An assessment of various Nigerian energy policies and of approaches for evaluating economics of energy systems, along with previous empirical studies are been presented in Chapter Four.

Chapter Five presents the research methodology identified as appropriate to answering the stated research questions. Firstly, it reviews the difference between research methodology and research method, followed by the philosophical stand underpinning the study. Research design and the implementation process are presented. Research methods for collecting and analysing data are discussed. Validity and reliability, and ethical consideration of the research methodology are also addressed.

In Chapter Six, whole life costing (WLC) analysis has been undertaken and presented.

Qualitative (interview) analysis is presented in Chapter Seven.

Chapter Eight presents RETs implementation framework as developed, evaluated and tested. The framework will serve as a guide to decision makers, investors and other stakeholders in implementing RETs (biomass energy technologies BETs) in rural areas.

Finally, Chapter Nine presents a thesis summary of findings, conclusions reached, recommended strategies for advancing RETs in Nigeria, and suggestions for further research.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter critically evaluates, using a SWOT analysis, six major renewable energy technologies (RETs): wind, solar, hydro, biomass, geothermal and ocean energy. This analysis will assist in determining the strengths and weaknesses of individual RETs, along with identifying opportunities to break the dominance of fossil fuel (FF) energy systems in the context of rural Nigeria. The sustainability indicators of each RET source are assessed with a view to enabling the selection of appropriate technologies for adoption in Nigerian rural areas.

Bull (2001) defined Renewable Energy as "energy derived from a broad spectrum of resources, all of which are based on self-renewing energy sources such as sunlight, wind, flowing water, the earth's internal heat, and biomass such as energy crops, agricultural and industrial waste, and municipal waste. These resources can be used to produce electricity for all economic sectors, fuels for transportation, and heat for buildings and industrial processes". In other words they are energy "sources that involve the harnessing of natural energy flows (e.g. sunlight, wind, waves, falling water, ocean currents, and tides) or the tapping of natural stocks of energy whose rates of replenishment are comparable to or greater than the human use rates (such as ocean thermal gradients, biomass, and hydropower reservoirs)" (Akinbami 2001).

RETs are classified differently by different authors; Moriarty & Honnery (2011) classified RETs based on their availability: continuous available technologies (biomass, geothermal, and partially some hydro) and intermittent available technologies (wind, solar, wave and tidal energy), while Evans et al. (2009) classified them as originating from combustible and non-combustible sources.

2.2 RENEWABLE ENERGY TECHNOLOGIES (RETS) ASSESSMENT

This section seeks to assess the commonly utilised RETs using the principle of Strength, Weakness, Opportunity and Threat (SWOT) analysis and assess their sustainability indicators in the context of Nigerian rural areas.

2.2.1 Wind Energy

Sambo (2009) described wind as "an effect from the uneven heating of the earth's surface by the sun", while wind power "converts the kinetic energy of the wind into other forms of energy such as electricity" (Bull 2001). From this process clean energy is produced (Varun et al. 2009).

Bull (2001) identifies commercially available wind turbines as mostly using a "horizontal-axis configuration with two or three blades, a driven train including a gearbox, generator, and a tower to support the rotor". Early wind turbines produced in the range of few kilowatts (kWs), while contemporary wind turbines produce up to 6 mega-watt (MW) plus per unit source (Martinot 2013). However, unit output of wind turbines is largely dependent on the related energy infrastructure. Countries with good energy infrastructure may produce between 2MW and 3MW from onshore wind turbines, while countries with poorer infrastructure could produce only up to 1.5MW and mainly from larger farms (Wiese et. al. 2010; Moriarty & Honnery 2011).

Wind Energy Strengths

Wind power is now a significant source of renewable energy globally (about 100 countries) and is typically the major source of electricity among RETs excluding very large hydropower facilities; in 2009, for example, the 38 giga-watt (GW) of the annual wind capacity surpassed the 31GW of hydro capacity in the same year (Wiese et. al. 2010), becoming competitive with Fossil Fuel (FF) energy sources in term of affordability and reliability. The World Wind Energy Association (WWEA) (2013) reported that, by the end of 2012, total global installed capacity was around 282 GW, with over 44GW capacity added in 2012 (see figure 2.1). This capacity can provide up to 580 tera-watt hour (TWh)/year; representing 3% of electricity demand globally (WWEA 2013). Wind is therefore the second energy system in term of the total installed capacity among RETs after all (including very large) hydro sources (Martinot 2013).

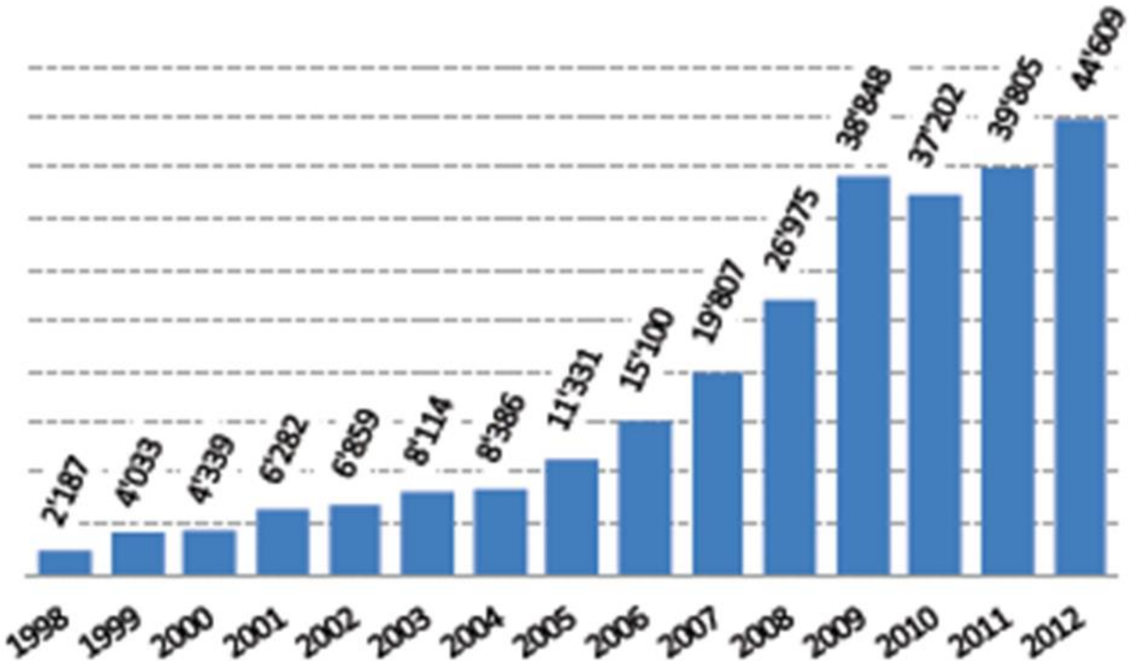


Figure 2.1: Annual wind installed capacity (MW) (WWEA 2013)

Table 2.1*:* Mean price of electricity and average greenhouse gas emissions (Evans et al. 2009)

	US$/kWh	gC02-e/kWh
Photovoltaic	$0.240	90
Wind	$0.070	25
Hydro	$0.050	41
Geothermal	$0.070	170
Coal	$0.042	1004
Gas	$0.048	543

Despite the global economic downturn experienced since 2008, WWEA (2013) projected wind energy global capacity to increase to 500GW by 2016 and around 1000GW by 2020. While Sopian et al. (2011) projected global wind capacity to exceed 1,900GW by 2020. The greatest strength of wind energy lies with its cost/kWh; the second lowest among RETs after hydro, whilst emitting the lowest CO2 levels among all the power energy sources (see Table 2.1). Further, the total wind energy resource has been estimated to be approximately 115,000 exajoule (EJ) equal including jet stream source and around 30,000 EJ available over land (Moriarty & Honnery 2009) (*joule – equal work of watt/second*). In view of the above, it implies wind energy resources alone are far more than the annual global primary energy requirements of approximately 500 EJ (Moriarty & Honnery 2011).

Wind Energy Weaknesses

Wind energy cannot realise its full potential unless environmental constraints are relaxed; no restricted sites for wind energy projects (Moriarty & Honnery 2011; Moriarty & Honnery 2009). See figure (2.2) for details.

Wind energy resources also suffer intermittency and idleness problems; scenarios where turbines cannot operate because of wind speed design constraints. "Turbines must not operate when wind speeds are too high (>25 m/s) as turbine damage may result and will not turn when wind speeds are too low (<3 m/s)" (Evans et al. 2009). Hence, potential energy at such moments cannot be considered part of the total available base resources; wind energy systems cannot produce a base load (Evans et al. 2009). There also problems regarding low energy efficiency and low capacity factor (Garba & Kishk 2014). See Table (2.9) and (2.10) for details.

There is also a need to consider the economics of distribution of power through centralised energy systems; constraints affecting electricity supply to rural areas may be experienced due to the relatively high costs of transmission (Evans et al. 2009). The cost of long transmission routes adds to the high capital cost associated with wind energy system as its best resources are located in the countryside, thereby reinforcing one of the major wind energy drawbacks.

In OECD countries social problems associated with wind energy include visual intrusion of the tall turbines, landscape distortion, likelihood of impacts on property prices etc (Moriarty & Honnery 2011), along with adverse effects on 'aerial' wildlife such as birds and bats, which are typically the most affected (Kerr 2006; Moriarty & Honnery 2011) not just in terms of impacts with windmills but also "displacement due to disturbance, barrier effects and habitat loss" (Drewitt and Langston, 2006)

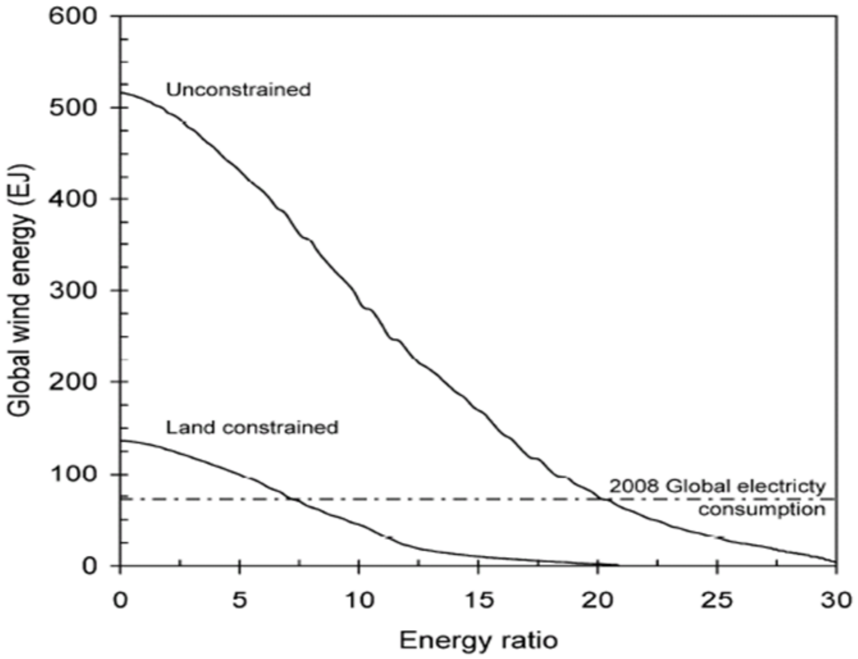


Figure 2.2: Global wind potential (EJ/year) with location factor (Moriarty & Honnery 2011)

Wind Energy Opportunities

Considering wind energy's environmental and social problems and intermittent nature, the following 'solutions' have been proposed:

- Wind speed in the jet stream is approximately 10 times faster than at ground level and is dependable. Moriarty & Honnery (2011) claimed the use of Kites which are connected to ground turbines, each having an area of 100m2 could generate 0.1MW electricity per kite, this power is more than double the ground turbine per unit (Brooks 2008).

- Wind power could be generated through rotorcraft secured with aluminium conductor cables. Each rotorcraft would have four rotors mounted on it with the rotors providing lift and electricity up to 40MW (Moriarty & Honnery 2011; Archer & Caldeira 2009; Roberts et al. 2007). This pioneering technology has been tested at a small scale (Moriarty & Honnery 2011).

- Edmond et al. (2007) suggested that combating the intermittent nature of wind energy technology could be achieved through the smoothening effect – a scenario where capacity, either of the same or different technologies, could be distributed throughout the country to ameliorate the effect of intermittency of RETs and this will reduce/eliminate Back up (batteries and inverters) costs (Esteban & Leary 2012; Evans et. al. 2009).

- Wind farm location should be carefully selected to reduce problems for wildlife.

- Actions such as closing down the turbines during periods of bat activity, which turn out to be when wind speeds are low are beneficial to wildlife and have minimal impact on generation (Evans et al. 2009).

The earnings from wind energy continue to expand; the turnover of global wind energy reached US $ 75 billion by the end of 2012 as against US $ 3.9 billion in 2000 (WWEA 2013). There is also a significant difference between the turnover of 2012 and US$ 65 billion of 2011, despite the decline in installed capacity between 2009 and 2011.

Europe leads the drive to produce wind-based energy, accounting for 38% of the total installed capacity, closely followed by Asia (35%), and North America (23%), while the balance goes to the rest of the world. Furthermore, top wind markets of 2012 were China, USA, Germany, Spain and India, accounting for 207GW in 2012 (73% of global wind capacity). Also, by the end of 2012, China was the leading country in the world in terms of total capacity (WWEA 2013; Martinot 2013).

Wind Energy Threats

The global market growth rate of wind energy declined between 2009 and 2011 and, although in 2012 a record level of newly installed capacity was achieved, the growth rate dropped by 19.1%; the lowest in fifteen years (see figure 2.3 for details). "For the first time, the longer-term trend discontinued that the installed wind capacity doubles every third year. In 2009, there was a global total installed capacity of 160 GW of wind energy compared with 282 GW in 2012"

(WWEA 2013). This discontinuation will, to some extent, be connected with the global economic meltdown that started in 2008. This economic problem continues to constrain the development of all RETs.

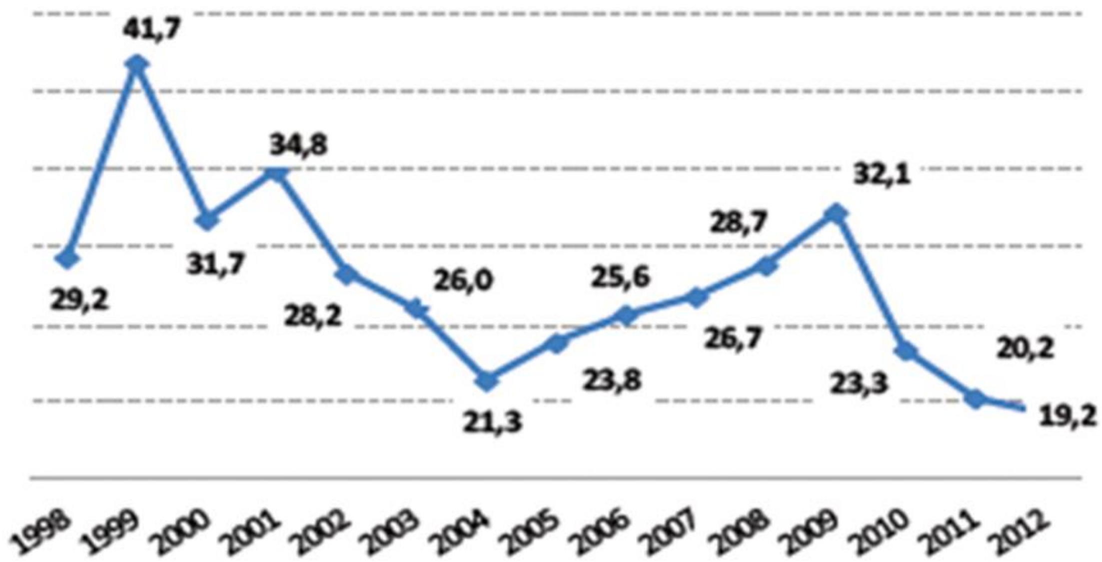


Figure 2.3: Wind World Market Growth Rates (%) (WWEA 2013)

2.2.2 Solar Energy

Solar energy uses the sun's radiation for generating electricity and heat using basically two types of technologies: solar photovoltaic (PV) and solar thermal. Both technologies are generating energy at a commercial level globally, but solar PV is the most popular technology. Solar PV system is categorised as follows: single crystalline, polycrystalline and amorphous (Moriarty & Honnery 2011; Suberu et al. 2013; Evans et al. 2009). Solar PV generates electricity directly via semi-conductor materials that convert heat energy (Bull, 2000), comprises no moving parts and emits no CO2 during operation. PV devices are exceptionally modular in nature, being used in small cells, panels, and arrays (Evans et al. 2009). While solar thermal system generate electricity indirectly by trapping the heat from concentrated sunlight in the conversion system (Varun et al. 2009). Pillai and Banerjee (2009) stated that power energy from solar thermal uses "solar radiation to heat water or a heat transfer fluid and then operate a power cycle with the fluid".

Solar Photovoltaic (PV) Energy Strengths

Considering that solar energy has the highest global potential of any renewable source (170,000 TWh/year), it is feasible for solar PV to significantly contribute to global power energy production and the decarbonisation of energy (Evans et al. 2009). A PV system requires little or no maintenance, has no fuel dependence, and typically has a lifetime of 20 to 30 years, although maintenance costs can increase when inverters and batteries are utilised (Bull 2001; Evans et al. 2009; Renewable energy handbook 2010).

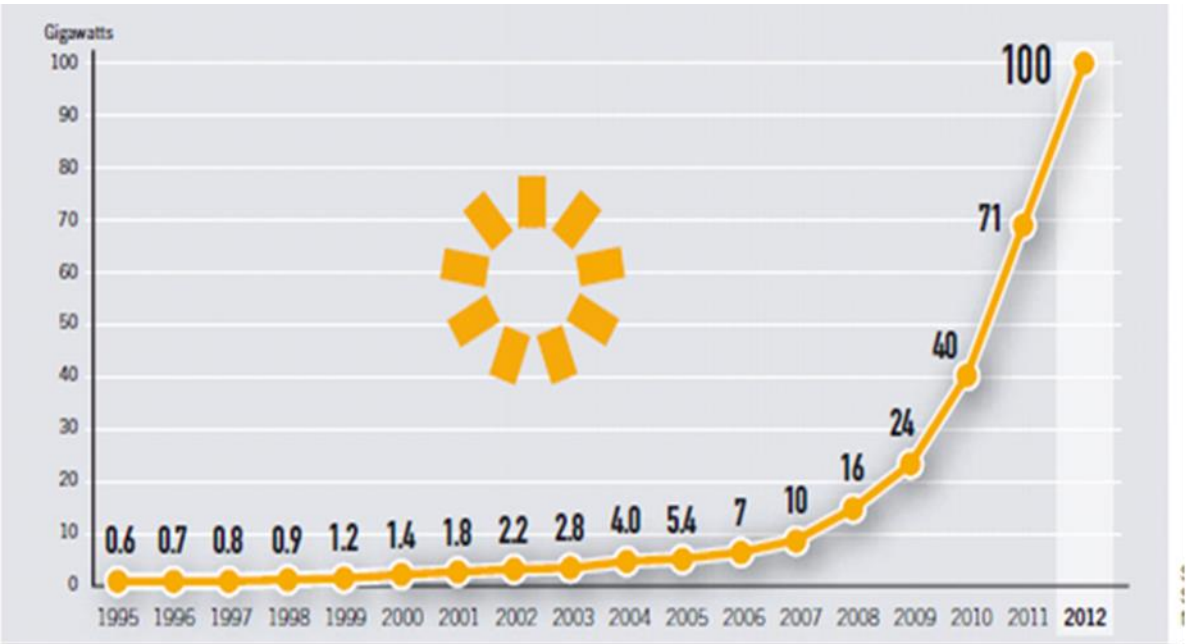


Figure 2.4: Solar PV Global Capacity- 1995-2012 (Martinot 2013)

Solar PV is exhibiting a trend of increasing capacity, which is expected to continue over the coming years. The PV global cumulative installed capacity by the end of 2014 is 177 GW, with the newly installed capacity (in 2012) representing 40GW (REN21 2015). There is reasonable capacity increase compared to 2012 with 100 GW (cumulative capacity) and 29.4GW annual capacity added in 2012. See figure 2.4 for details. Solar PV system can be either grid connected or stand-alone, with the latter making it suitable for rural electrification, particularly where there is electricity deficiency and/or low grid penetration.

Europe continues to dominate the solar PV market as the traditional leader in 2012 with about 70% of the total global installed capacity and more than half of newly installed capacity representing (70GW) and 57% (16.9GW) respectively (Martinot 2013). The top markets in 2012 and also the leading countries in terms of total installed capacity were: Germany, Italy, China, the United States, and Japan. The growth of solar PV between 2007 and 2012 was approximately 10 fold (see figure 2.4) and some growth is expected over the coming years but how much is uncertain due to factors such as the decline of incentives and general energy policies uncertainty (Martinot 2013), although the, falling prices of modules, innovative financing and ownership models, especially in the USA, China and lately in Africa (Sherwood 2012; Bowden 2012), along with a rapid increase in energy demand is driving solar PV use in the Middle East and Northern Africa (MENA) particularly in Saudi-Arabia (Martinot 2013).

Solar PV Energy Weaknesses

Despite solar radiation being more predictable than wind speeds, there remains a problem of intermittency in energy generation which limits the technology's ability to produce base load (Evans et al. 2009). Solar radiation is never available after sunset, partly available on cloudy days, and at some latitudes during the winter months there is a need to alter the angle of panels' exposure to the sun (most energy being produced around midday). This latter requirement is a serious drawback for all forms of solar energy systems in countries along high latitudes, a situation made worse by such countries usually experiencing below-zero temperatures for months. Energy storage facilities (batteries, converters (inverters) and molten salt) help to store energy produced during the sunny hours and allow its discharge later for continued supply of energy. However, in higher latitude locations there may be insufficient solar radiation to merit the additional cost of such storage devices (as insufficient electricity may be produced to 'fill' them) (Moriarty & Honnery 2011).

Furthermore, solar energy systems have the lowest energy efficiency and capacity factor of all RETs, contributing to them being the most expensive cost/kW technology (see tables 2.1 and 2.9). Both total installed capacities added in 2012 and 2014 (see details under solar PV energy strengths) are quite small considering the high global potential (170,000 TWh/year), particularly when compared with other RETs such as wind and hydro energy systems (44.6GW and 30GW 2012 newly installed capacity respectively) (WWEA 2013; International Hydropower Association 2013).

Solar PV Energy Opportunities

Solutions to the weaknesses of solar, particularly intermittency, are suggested by researchers:

- Desertec -the proposed project is to build solar thermal plants in the desert of North Africa to generate and transmit electricity to Europe using high voltage DC lines (thereby total transmission losses not exceeding 10%), the aim being to provide 15% of Europe's electricity demand by 2050 at an estimated cost of € 400 billion (Moriarty & Honnery 2011; Czisch et al. 2003; Pearce 2009). However, the project has been argued as too expensive considering its benefit: "we will need more than a minor dent in fossil fuel use by 2050, for both climate and fossil fuel depletion reasons" (Moriarty & Honnery 2011).

- Moriarty and Honnery (2011) reported the proposal to place a network of seven large solar farms in the desert areas of both hemispheres of the world, thereby solving the problem of intermittency and providing 2.63 tera-watt (TW) of electricity power annually at its completion by 2020. The high voltage transmission line required is also major problem in that it will consume an estimated 63% of the total project cost (Seboldt 2004).

The major opportunity for solar energy system is the cost reduction experienced per unit price of the components representing approximately 25% in 2012 alone (Martinot 2013). This is on-going every year and can serve as the biggest breakthrough for the adoption of solar.

Solar Energy Threats

The biggest threat of solar PV market is the removal of incentives, especially the feed-in-tariff (FIT) in Europe. The impact of diminishing incentives became more apparent in 2008 as result of the global economy's downturn particularly in Spain, which was then the market leader in both solar PV and solar thermal. This problem affected Italy in 2011. Although Germany in 2009 replaced Spain's PV market position (Wiese et al. 2010; Martinot 2013).

A second factor is uncertainty concerning general policies affecting the solar and wind energy markets. Murphy (2013) reported that, as the PV share of generation increases "PV is starting to affect the structure and management of Europe's electricity system, and is increasingly facing barriers that include direct competition with conventional electricity producers and saturation of local grids". This has made some countries either remove or reduce subsidies, particularly FIT, and reduce their obligation for some RETs (given the level of development and deployment achieved). The UK government, for example, has cut 65% of the solar FIT incentive to households using rooftop models for small generation. However, this is affecting the proposed new capacity from this source. For instance, between March 2015 and March 2016 only 25% of the expected capacity has been installed (DECC 2016).

A third factor is China's aggressive build-up of capacity, resulting in excess production and saturation of the solar energy market. The implication of this situation has been fierce competition among manufacturers, thereby driving solar PV components prices further down (crystalline silicon modules and thin film dropped by 30% and 20% respectively), resulting in marginal profit for manufacturers. In terms of production, China's solar PV capacity alone exceeded the global market demand and, by the end of 2012, China was producing two-thirds of the total global solar PV needs (Martinot 2013). This issue of over-capacity of modules led to a (quickly resolved) bilateral crisis between the EU and China in the second and third quarters of 2013.

Martinot (2013) reported that the solar PV components over-production problem resulted in a series of failures, bankruptcies, and debts restructuring between 2011 and early 2013. This problem was global and forced around 100 companies to exit the industry, and some companies in Asia have commenced buying-up promising companies who went bankrupt, such as Q-cell (Germany). The worst case scenario was exit of some major companies like Siemens (Germany) from the solar business.

2.2.3 Hydropower Energy

Hydropower generates electricity by the application of gravitational force of flowing or falling water (Sopian et al. 2011) which turns the turbine thereby converting running water into mechanical and electrical energy (Varun et al. 2009).

Hydropower energy strengths

Hydropower is the largest single RET for electricity generation; cumulative installed capacity of 1055GW and newly installed capacity of 37GW represent 73% and 27% of overall RETs contribution at the end of 2014 (REN21 2015). Hydropower source is the third largest commercial energy source after coal and gas (Moriarty & Honnery 2011).

This technology is very flexible and reliable compare to other technologies and is highly available (Egre 2002), the most efficient among all the technologies currently generating electricity including fossil fuel sources (energy efficiency in excess of 90%) (Garba & Kishk 2014), and it can supply base load and peak load power, because of its ability to quickly convey on line (Evans et al. 2009; Moriarty & Honnery 2011). It can reduce GHG emissions (CO_2) by approximately 96% when compared with coal based electricity generation (Sopian et. al. 2011). (See Table 2.9). Given that hydropower is a mature technology and, if located at a good site, it can generate electricity at a price competitive with FF energy sources, and has the cheapest electricity cost/kWh among RETs (see table 2.1). Balat (2006) opined that hydropower has a global economic potential of over 8,100 TWh/year, while Moriarty & Honnery (2011) reported that hydropower has a technical potential of 50 EJ/year, somewhat more than the 30EJ suggested by (Hafele 1981).

Hydropower Weaknesses

This technology has been responsible for the displacement of between 40 to 80 million people, mostly in developing countries (Moriarty & Honnery 2011), declining fisheries and the deterioration of freshwater eco-systems (Sims 2007), and may be responsible for earthquakes resulting from the ground pressure caused by damming huge quantities of water (Moriarty & Honnery 2011).

Seasonal variations from dams in tropical countries cause them to be regarded as intermittent sources (as with wind and solar) in comparison to continuous sources in high precipitation regions (see Table 2.8 for details). Typically, the level of intermittency of hydropower energy sources are high in Nigeria; during the rainy season the generating capacity of the dams increases significantly and immediately after the rainy season the capacity output of the dams declines.

Large hydropower construction is declining in comparison to other RETs, given that wind energy's newly installed capacity exceeded hydropower energy in 2009, 2012 and 2014 with more than 7GW, 14GW and 14GW respectively (Wiese et. al. 2010; Mortinot 2013; REN21 2015). Similarly, solar power exceeded hydropower capacity by 3GW by the end of 2014 (REN21 2015). This declining share of capacity for large hydropower may not be unconnected with resistance from people and pressure groups as result of environmental and social impacts across the world.

Given the projection of IEA (2009) (cited in Moriarty & Honnery 2011 p.83) that "by 2030 global hydropower production will be 17.2 EJ, a rise of 42 % on 2008 levels" in conjunction with its contribution by the end of 2014 of approximately (1055GW) (REN21 2015) hydropower will only make a lesser contribution to meeting the future world power energy demand than other RETs sources such as wind energy, which has been projected to exceed 1,900GW by 2020 (Sopian et al. 2011). See figure 2.5 for details.

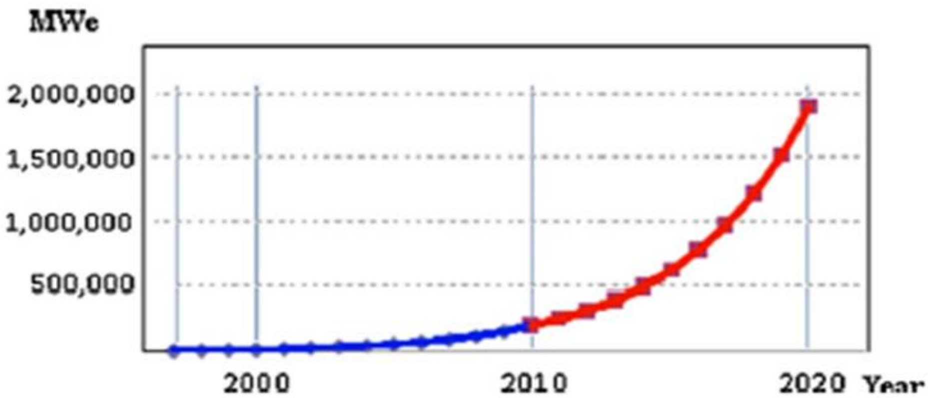


Figure 2.5: Total worldwide installed wind capacity 1997–2020 (MWe): Development & Forecast (Sopian et al. 2011).

Hydropower Opportunities

According to Evans et al. (2009) hydropower plants can be started and stopped at any time, and they are modular in nature. Hydropower has opportunity of producing no direct waste once the reservoir is constructed and filled up.

In terms of turbine capacity, Chinese (Tianjin Alstom) and Russian (Power Machines) manufacturers are installing four of the biggest ever turbines (capacity of 1,000MW each) to the Xiangjiaba plant in China (Martinot 2013). Similarly, REN21 (2015) reported that there is emerging demand for refurbishment of existing power plants, especially in Europe and North America, with a view to increasing their outputs, efficiency and environmental performance. Furthermore, given hydropower's high efficiency and flexibility, any decrease in component costs serves as an opportunity for innovation.

Hydropower Threats

The social and environmental effects of large hydropower projects include among others: increased sediment transport, biodiversity damage, land-use change, water quality and hydrological regimes, with the effect or severity of each differing between projects, and so the opportunities to realise greater positive effects also differs between sites (Martinot 2013).

Following the resistance to the construction of new large hydropower station in industrialised countries, most new projects will be in the tropical and Amazonian regions, and particularly in emerging economies (BRICS). See figure 2.6 for details.

Moriarty and Honnery (2011) reported that the biggest threat of hydropower energy is changing rainfall patterns resulting from climate change, which contributes to the on-going debate regarding hydropower's sustainability credentials. Precipitation is expected to reduce in cooler regions, while extreme rainfall is expected to increase in other regions, leading to increased soil erosion and dam sedimentation. Surface evaporation is also expected to increase from large hydropower dams, as a result of higher temperatures which will be generally higher in all regions.

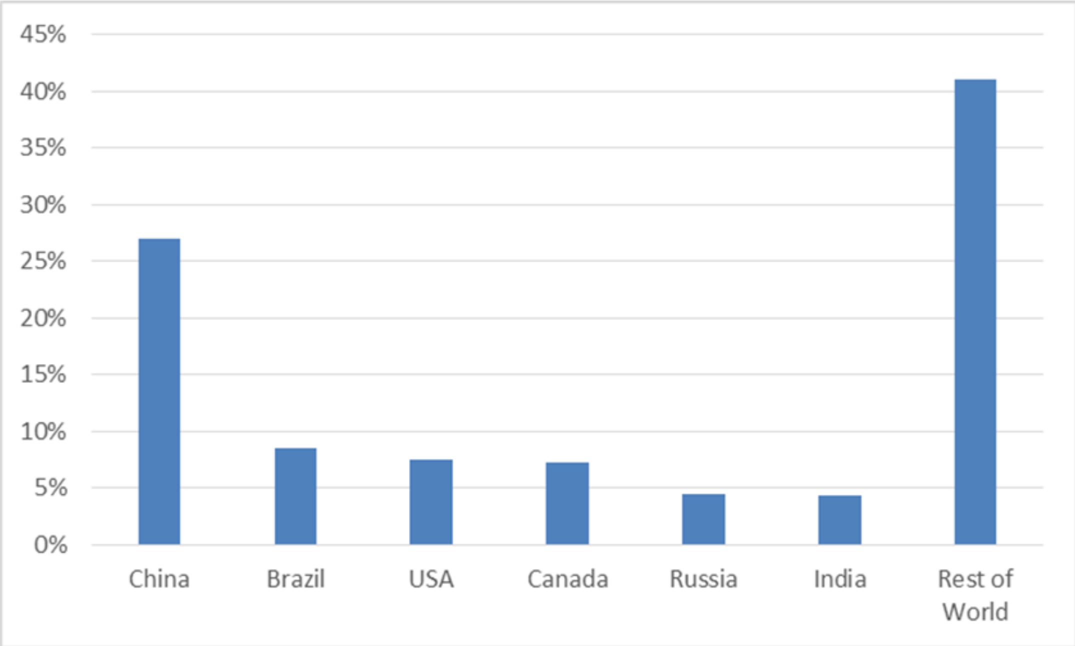


Figure 2.6: 2014 Hydropower Global Capacity (REN21 2015)

During dam construction, the type of terrain undergoing inundation appreciably affects CO_2 emissions; the higher the biomass present during inundation, the higher the emissions. The decaying biomass may emit CO_2 or methane (aerobic systems produce CO_2, while anaerobic systems produce methane) for several years after reservoir filling. During this period CO_2 emission can exceed that of conventional energy sources (gas-fired) of the same power output (Evans et al. 2009; Moriarty & Honnery 2010) due to "methane has a global warming potential, 25 times higher than CO_2, over 100 years. Therefore, small changes in methane emissions will result in large changes to CO_2 equivalent emission" (Evans et al. 2009). Higher emissions are mostly experienced in Amazonian and tropical reservoirs as result of the higher biomass intensities flooded; while dams in cooler climates tend toward lower biomass levels (Evans et al. 2009).

2.2.4 Geothermal Energy

Geothermal energy (GE) is energy stored as heat below the surface of the earth and can be used for generating electricity (Bertani 2012). The heat has its origin from the internal structure of our earth and the physical processes taking place inside it (Barbier 2002).

Twenty four (24) countries are using geothermal energy resources for both heat and electricity generation, despite its limitation of being location specific.

Table 2.2: Geothermal plants installed capacity and annual electricity generated in 2010 (Bertani 2010)

Country	Units	Installed Capacity MW	Produced energy GWh/year
Australia	2	1.1	0.5
Austria	3	1.4	3.8
China	8	24.2	150
Costa Rica	6	165.5	1131
El Savador	7	204.4	1422
Ethopia	2	7.3	10
France	3	16.2	95
Germany	4	7.1	50.2
Guatermala	8	52	289.2
Iceland	25	574.6	4597
Indonesia	22	1197.3	9600
Italy	33	842.5	5520
Japan	20	535.2	3063.5
Kenya	14	202	1430
Mexico	37	958	7047.4
New Zeland	43	761.6	4055
Nicaragua	5	87.5	310
Papus (NG)	6	56	450
Phillipines	56	1904.1	10311
Portugal	5	28.5	175
Russia	11	81.9	440.7
Thailand	1	0.3	2
Turkey	5	91.1	489.7
USA	210	3098	16603.4
World total	**536**	**10897.8**	**67246.4**

Geothermal Energy Strengths

GE systems provide a continuous source of energy, therefore as long as the geological conditions do not change, natural steam or hot water can be sustained. The stored thermal energy below the earth surface can be used for several decades to come. Considering the total amount of heat of approximately $42x10^6$ EJ in the high enthalpy regions of around 10% of the Earth' surface, geothermal heat can meet world energy demands (Bertrtani 2012). Another view was that energy flows will continue for hundreds of millions of years before coming to an end (Moriarty & Honnery 2011). Stefansson 2005 (cited by Bertani 2012) stated that "the rate at which the heat is continuously replenished from the higher temperature regimes below the 3–5 km depth is about 65 MW/m2, which corresponds to an average thermal energy recharge rate of about 315 EJ/year".

By the end of 2010, the growth rate exceeded 10% in many regions and this technology has a cumulative installed capacity around 11GW producing in excess of 67 TWh. The planned capacity for 2015 and 2050 could be around 19GW and 140GW respectively; and these are expected to generate electricity around 140 TWh/year and 1200 TWh/year for year 2015 and 2050 respectively (Bertani 2012; IGA 2010; Chamorro et. al. 2012). Figure 2.7 illustrates this trend of evolution, along with the varying developmental rate (1GW in every five years from 1980-2005, and approximately 2 GW between 1975-1980 and 2005-2010).

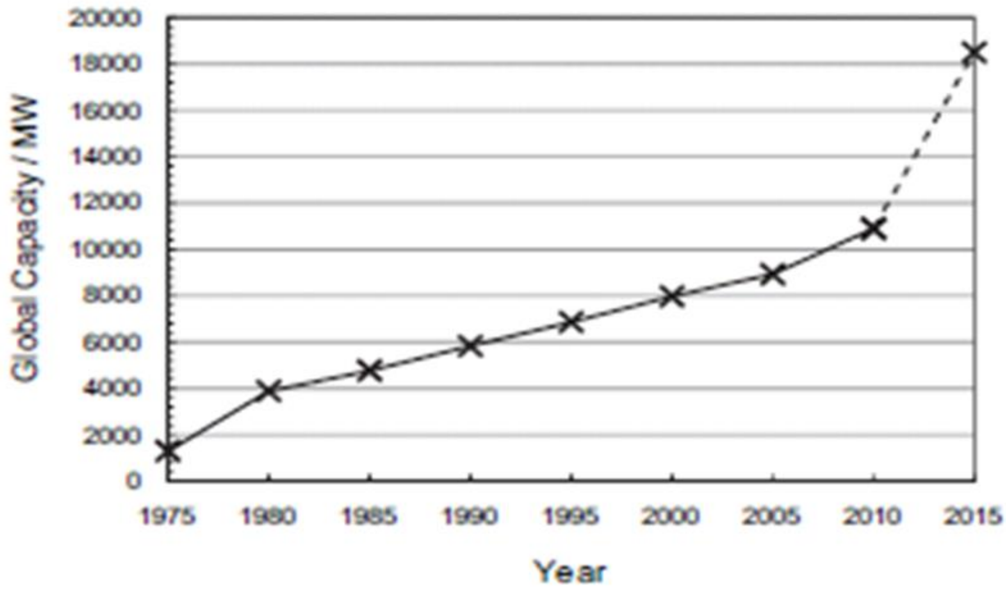


Figure 2.7: Evolution of installed geothermal power (Chamorro et al. 2012).

The capacity factor of GE plants is higher than any other form of power plant (both FF and RETs sources); in excess of 90% reliability, as against biomass (25-80%), wind (20-20%), solar photovoltaic (8-20%),, solar thermal electricity (20-35%), and tidal (20-30%) (Fridleifsson 2003).

Fridleifsson (2003) opined that geothermal energy is "independent of weather, as opposed to solar, wind, or hydro applications. It has an inherent storage capability and can be used both for base load and peak power plants. However, in most cases, it is more economical to run the geothermal plants as base load suppliers".

Application of geothermal energy resources for electricity generation is estimated to save approximately 200 million barrels of fuel oil or 30million tonnes of oil annually (Lund et al. 2011). Also, when used for energy generation it can save substantial CO_2 emission (up to 1000 million tons/year if 140GW projected target is met by 2050) (Bertani 2012).

Geothermal Energy Weaknesses

Based on 2050 projection of 140GW installed capacity from both traditional and Enhanced Geothermal System (EGS), it is indicative that the growing capacity of this technology is still low compared with other forms of RETs such as wind energy, which is estimated to reach 1,900GW by 2020 (Sopian et al. 2011). This suggests that geothermal energy will contribute less than 10% of the projected capacity of wind energy by 2020. Geothermal energy technology has the lowest global potential compared to other RETs. Also, unlike solar, wind, and hydro energy resources that are adequately distributed globally, geothermal energy system is location specific (Garba & Kishk 2014).

The low capacity problem of GE system may be connected with the inherent small potential for further expansion in electricity generation, especially in the leading countries of OECD (Moriarty & Honnery 2011). In combination, these factors suggest that conventional geothermal power may not be able to deliver significant electricity in terms of future energy needs.

Despite the high capacity factor of geothermal energy systems (the highest among all energy forms of power plants), it has the lowest electricity generation efficiency among RETs (10-20%) (Barbier 2002). The reason for this is because of the use of low temperature steam, which is mainly less than 250°C (Evans et al. 2009). Similarly, Evans et al. (2009) reported that GE systems have the highest CO2 emission among all the RETs plants, with emission levels approximately six times that of wind energy sources per kWh of electricity generated. Its emission pattern critically depends on the type of technology adopted; Wairakei, The Geysers (USA) and Larderello (Italy) geothermal plants with CO_2 emission values of 13, 33 and 380 g/kWh respectively (Barbier 2002). However, compared to FF energy sources emissions, it is insignificant (Barbier 2002). (See table 2.9 for details).

Geothermal Energy Opportunities

Conventional techniques of geothermal energy exploitation are inefficient, and further expansion is possibly limited to traditional geothermal power in the leading countries that use it. These factors are the cause of increasing interest in how to improve efficiency of both existing and new sites.

Consequently, the Enhanced Geothermal System (EGS) is the most favoured to improve efficiency through exploitation of hot dry rock reservoirs. This system has the ability to drill far below the earth's surface (several km downward) and achieve higher temperatures (200^0 C and up to 4000^0 C at the outer core of the Earth) (WEC 2007). Hence, EGS could provide a reasonable contribution to the world energy mix when fully developed.

Geothermal Energy Threats

Pollution of air and water bodies such as rivers and lakes is the major environmental impact of geothermal exploitation. Depending on the geothermal plant technology adopted, steam gases can contain various pollutants (CO_2, H_2S, NH_3, CH_4, H_2 & N_2) and are non-condensable, giving pollutants in emitted gases of between 1 to 50 g/kg of steam (Barbier 2002).

Another major threat of geothermal energy source is land subsidence. "The weight of the rocks above a reservoir of groundwater, oil or geothermal fluids is borne in part by the mineral skeleton of the reservoir rock, and in part by fluids in the rock pores. As fluids are removed, pore pressure is reduced, and the ground tends to subside. Less subsidence is expected with harder reservoir rock" (Barbier 2002). Water-dominated fields subside more than vapour-dominated fields (Allis et al. 1998; Dini et al. 1995). Subsidence can be controlled or prevented by the reinjection of spent fluids. Reinjection could, however, induce micro seismicity (Barbier 2002).

2.2.5 Biomass Energy

Biomass is another form of RETs, 'fuelled' from various natural and derived materials such as agricultural and forestry residues, wood and wood wastes, animal dung, Municipal Solid Wastes (MSW) (Zheng et al. 2010). Biomass resources can be converted to electricity through thermo-chemical processes (gasification, direct combustion and pyrolysis) and biological process (anaerobic digestion) (Demirbas et al. 2009; Demirbas 2001, Garba et al. 2016b; Shunmugam 2009; IRENA 2012). Biomass accounts for around 14% of global primary energy (Sopian et al. 2011), while Martinot (2013) claimed it provides over 10% of world energy and is the fourth largest source of energy after coal, oil and natural gas. Also, over half of the global population get their energy from biomass energy sources (Zheng et al. 2010), but mostly in traditional form such as wood fuel and charcoal etc. Biomass resources are largely plant based materials, and can quickly be renewed in different environments (Evans et al. 2010).

Biomass Energy Strengths

The application of biomass as a source of energy has advantages such as the ability to convert, with varying level of effort into three states of matter: solid, liquid and gas, and with many modes of conversion into useful energy (Martinot 2013). They are more sustainable in nature than fossil fuel (FF) energy sources, as they can be restored immediately after utilisation. Biomass either in solid, liquid or gas form can be used for electricity generation, heating and fuel (Evans et al. 2010; Moriarty & Honnery 2011).

Biomass energy (BE) resources are universally available in the world and allow energy needs to be met at all times as there is seldom a supply problem; a wide network of retailers covers the supply chain, particularly in developing countries. In comparison unreliable FF sources, particularly LPG supply, are undermined in terms of regular use (Owen et. al. 2013).

Researchers have argued that use of biomass could serve as a means to achieving negative GHG emissions. Shunmugam (2009) stated that a BE system is carbon-neutral: biomass combustion emits CO_2 during conversion processes; however, plants subsequently absorb an equivalent amount of CO_2 as they grow (carbon capture and storage) which eventually reduces the global warming effect (Haberl et al. 2010). Mann & Spath (1997) claimed that only 95% of the emitted carbon dioxide is absorbed by the plants when grown renewably. Similarly, Manish et al. (2006) reported that biomass power generation can reduce GHG emission by approximately 95% when compared with coal-based power generation. More so, it is cost competitive with FF energy systems particularly in developing countries and for rural application (Mahapatra & Dasappa 2012; Garba & Kishk 2015, Garba et al. 2016b, Dasappa 2011).

BE systems can be used as a means of improving energy security, particularly if sourced domestically and renewably. This is because FF importation could be reduced through biomass diversified production and application. Volatile crude oil prices can be a threat to the majority of developing countries, thereby presenting socio-political risks to their economy (Owen et. al. 2013; Shunmugam 2009).

Application of both traditional and modern biomass can generate employment, particularly in local communities, at a higher level than the majority of fossil fuel energy systems (Owen et al. (2013). BE systems have a good capacity factor of up to 70%, with the second best energy efficiency among RETs after hydropower system (Garba & Kishk 2014). See Table (2.9) and (2.10) for further details.

REN21 (2015) reported that by the end of 2014, bio-power global capacity was around 93GW and 75% of electricity generated from biomass was from solid biomass fuel, biogas (17%), MSW (7%) and biofuel (1%). Also, in the same period, all the existing bio-power systems together produced around 1.8% of global electricity. In that period, USA remained the leading bio-power nation with a total installed capacity of 16.1 GW (18%-generating 69.1 TWh electricity); followed by Germany and then China, Brazil and Japan (Martinot 2015).

Biomass Energy Weaknesses

The major problem of BE system is the use of food crops for energy generation. Food crops for fuel cannot be expanded further, as increasing grains diversion has put pressure on grain prices. The growth in food for fuel was responsible for 75% of the food price increase globally in 2007 (Ngo 2008) and also it has sparked a debate of food versus fuel end use internationally (Moriarty & Honnery

2011). Typical of this problem is a scenario where "feed use of maize, which accounts for 65% of global maize use, grew by only 1.5% per year from 2004 to 2007 while ethanol use grew by 36% per year within this period" (Mitchell 2008). Also, pressure has mounted in tropical forest in South-East Asia (Malaysia and Indonesia) against palm oil plantations for biodiesel production (Moriarty & Honnery 2011). From the above, it is indicative that BE systems that compete with increased food demand are unsustainable. Thus, biomass energy source could only provide a fragment, rather than the total, of global electricity demand.

According to FAO (2006) the world has 15 million Km2 of arable land and assuming 14 ton/ha/year biomass productivity, approximately 50% of this land would have been required by 2003 to meet global electricity needs; such a change of use would seriously affect food crop production (Manish et al. 2006). Similarly, International Energy Agency (IEA, 2011) (cited by Miyake et al. 2012) estimated that 65 million hectares (ha) of land will be required by 2030, and 105 million ha by 2050 to meet global electricity demand. The land availability poses a great problem to BE system.

Return on investment (ROI) in using biomass for energy production is marginal. Also, the application of modern fertilisers (Nitrogen fertiliser) releases GHG (N_2O) thereby working further against the marginal ROI mentioned above (Moriarty & Honnery 2011).

Given that a biomass energy system consumes considerable water to generate a kWh of electricity (between 150 and 260 kg), this energy system may be confronted with a water scarcity problem, as 17% of the potential bio-energy sites are situated in severely water-scarce regions such as Middle East and North Africa (MENA) and western USA. Also, 6% of global potential lies in modestly water-scarce zones (Van Vuuren et al. 2009). Future biomass production may be affected because of the continuous energy cost for providing underground water (Moriarty & Honnery 2011).

Expansion of natural reserves for biomass plantations could affect flora and fauna causing deforestation and changing the eco-system, particularly impacting on plants as they tend to affect soil nutrients (soil carbon); while arid land plantation could raise the soil carbon level (Moriarty & Honnery 2011).

Biomass Energy Opportunities

Given land availability and food versus fuel crisis poses a great problem to BE system, organic materials such as Microalgae and Jatropha can be grown by the seaside and arid land respectively for energy production. These can support or replace the first generation biomass as they have advantages of having already made oil in them which can be used purely or blended with other products (e.g. petrol), and they are less competitive with grains in term of human consumption (Shumnagam 2009). Also, cellulosic materials such as grasses, agricultural residues, animal waste and municipal solid waste can replace grains (food crops or first generation biomass) for energy production. Application of green fertiliser from biogas energy can replace Nitrogen fertiliser and this can reduce GHG emissions (Moriarty & Honnery 2011).

Following a lack of acceptance of BE system by the majority of governments, particularly in Sub-Saharan Africa (SSA), in their national energy policies, it will be appropriate to replace the traditional form of biomass with a modern and sustainable form, providing improved efficiency of fuel, cleanliness, safety and simplicity of application (Owen et al. 2013). To achieve sustainable biomass production and application Miyake et al. (2012) suggested the following strategies:

- Give high priority to none or less land bioenergy feed stock,
- Develop sustainable land-use options for bioenergy crop production,
- Develop agreed international policy mechanisms and instruments for sustainable land-use options for bioenergy crop production and
- Strengthen sustainability requirements and certification schemes.

In line with the universal availability of biomass resources particularly in developing countries, it can serve as an opportunity for electricity utilisation in line with substantial universal shift as especially developed economies return to organic and low carbon renewable energy sources (biomass based), with a view to achieving a sustainable energy strategy (Owen et al. 2013). Similarly, biomass conversion technologies are improving, resulting in the generation of approximately 93 GW by the end of 2014, indicating the growth of biomass system adoption (REN21 2015). Both biomass conversion technologies and growth in developed countries can serve as drivers for biomass utilisation.

In addition, arid land plantations could raise the soil carbon (Moriarty & Honnery 2011), creating opportunities for biomass plantations in desert areas and regions. Removal of subsidies by a majority of countries in sub-Saharan Africa such as Tanzania, Madagascar, Senegal and Nigeria with a view to encouraging investors and increasing accessibility to electricity and petroleum products, can serve as an impetus for BE utilisation in developing countries (Owen et al. 2013). Furthermore, the application of modern biomass technologies such as wood pellets, chips and briquettes is increasing because of domestic and industrial application for heating and electricity generation, particularly in the USA and EU. The reason for this increase may be connected with a high energy density and lower moisture content of pellets compared to other wooden energy sources and other biomass resources (Martinot 2013).

On the technological side, the improved wood and charcoal stoves, such as micro-gasifiers that use volatile gases, should replace the traditional three stone stove which leaves charcoal behind instead of ash for efficient utilisation (Roth 2011; Owen et al. 2013). Finally, further modernisation of BE systems will assist technology developers to produce BE machines that will be more economical and worthwhile for application.

Biomass Energy Threats

Despite the fact that bioenergy systems are a continuously available and largely emerging technology for electricity generation, there are limitations in term of expansion for energy production regarding its resources. Among all the available RETs, bioenergy systems are the only technology for which resources have to be procured (not available free of charge such as sun and wind).

Biomass system application could result in "social polarisation (between large land holders and smallholder/landless farmers), displacement of communities, and the disregard for local land rights have been reported in developing countries" (Miyake et. al. 2012), and the continuous application of traditional BE system could worsen the global climate change effect (Moriarty & Honnery 2011)

Also, in developing countries approximately 1.6 million women and children die yearly from indoor air pollution produced by traditional biomass stoves (Sopian et al. 2011), along with such stoves preventing the children from going to school as result of assisting their parent in scavenging for wood fuel; hence, increasing the illiteracy level in these countries (Garba & Kishk 2015; Kennedy-Darling et al. 2008).

2.2.6 Ocean Energy

Ocean energy includes: Ocean Thermal Energy Conversion (OTEC), tidal and wave energy (Moriarty & Honnery 2011), osmotic energy (Esteban & Leary 2012) and ocean circulation (Bahaj 2011). The application of ocean energy is negligible compared to other forms of RETs. Despite ocean energy resources being available to many countries, the technologies to generate electricity from it are either at pilot or prototype stage due to a lack of operational experience from real world scenarios. Commercial ocean energy technologies are required with a view to understanding its sustainability, efficiency and test survivability (Westwood 2004). According to World Ocean Review (WOR) (2013) "Ocean energy contains 300 times more energy than humans are currently consuming", but because of economic and technical limitations relatively little energy can be generated.

However, ocean energy's cumulative installed capacity by the end of 2012 was approximately 527 MW, and around 255 MW capacity was added in 2011(Martinot 2013). From the 527 MW total installed capacity by the end of 2012, two plants were responsible for around 94% of this capacity, with the majority coming from tidal energy sources: South Korea's Sihwa tidal power plant (254 MW) and France's Rance tidal station (240 MW); Sihwa commenced operation in 2011 and Rance in 1966 (Moriarty & Honnery 2011; Martinot 2013).

In spite of being the lowest capacity energy source among RETs, there are new proposed projects coming up globally, such as the 6.5 GW tidal barrages across the 18 km Severn estuary south of Cardiff, which will be privately funded and is expected to deliver around 7% of UK electricity demands after completion (Martinot 2013; WOR 2013). Recent achievements and on-going related projects in South Korea, along with some pilot and soon to be delivered projects in the USA and Europe ocean energy industry, have shown signs of huge commercialisation of this energy source particularly for tidal energy (Martinot 2013; Esteban & Leary 2012).

Due to factors of maturity, in terms of technology and commercialisation, good predictability, consistency and excellent potential of tidal energy over other forms of ocean energy (Bahaj 2011) it will be the only ocean energy system to be assessed using SWOT analysis in this section.

Tidal Energy Strength

Tidal energy (TE) is another form of RETs offering a continuous source of energy due to tidal streams offering dependability, predictability and consistency, "as tides can be accurately predicted weeks or even years in advance" (Esteban & Leary 2012). A TE system operates based on a consistent source of kinetic energy as a result of tidal cycles, allowing TE to operate like dams except that the waters are allowed to flow in both directions (Pelc & Fujita 2002; WOR 2013; O'Rourke et al. 2010). However, if it is tidal turbines, they work like an underwater windmill where the blades are driven with fast-moving currents and they can be installed on the seabed where strong tidal streams are located (Marine Current Turbine (MCT) 2013).

Ocean energy technologies are clean, produce no GHG emissions and have insignificant visual impact compared with onshore wind and hydropower energy structures, as long as they are located far from the coastline (Ladenburg 2009).

Also, the reliability of a TE system removes the need for energy storage devices (battery and inverter and fossil fuel back-up plant system) thereby offering an excellent source for a grid network. TE system consists of three types of technologies: tidal barrages, fence, and turbines. Tidal barrages represent around 94% of the current cumulative capacity of the ocean energy, and the technology is fully commercialized; unlike tidal fence and turbines that are either under research and development or at pilot stages (Pelc & Fujita 2002; MCT 2013).

The global potential of TE system is estimated to be between 500-1000 TWh/year, with Europe's potential to be approximately 105.4 TWh/year (Pelc & Fujita 2002). Moriarty & Honnery (2009) claim that tidal energy has a total annual potential for electricity of about 2 EJ. While MCT (2013) estimated global TE capacity is in excess of 120GW, with the UK projected potential in excess of 10GW representing 50% of TE of Europe. See table 2.3 for global major tidal barrage sites.

Esteban & Leary (2012) claimed that it appears realistic that the TE energy system can provide 7% of total global electricity by 2050. Also, it is expected that employment generation through this energy system will increase substantially throughout the globe; possibly one million persons by 2030. According to MCT (2013) "tidal energy has the potential to power 15 million homes, save 70 million tonnes of carbon and create 16,000 jobs in the United Kingdom alone". The UK has one of the best tidal resources in the world (MCT 2013; WOR 2013).

Table 2.3: Major world tidal barrage sites (Twidell & Weir 2006)

Location	Mean range (m)	Basin area (km2)	Potential mean power (MW)	Potential annual production (GW h/year)
North America				
Passamaquoddy	5.5	262	1800	15,800
Cobscook	5.5	106	722	6330
Bay of Fundy	6.4	83	765	6710
Minas-Cobequid	10.7	777	19,900	175,000
Amherst Point	10.7	10	256	2250
Shepody	9.8	117	520	22,100
Cumberland	10.7	73	1680	14,700
Petitcodiac	10.7	31	794	6,960
Memramcook	10.7	23	590	5,170
South America				
San Jose, Argentina	5.9	750	5870	51,500
United Kingdom				
Severn	9.8	70	1680	15,000
Mersey	6.5	7	130	1300
Solway Firth	4.5	60	1200	10,000
Thames	4.2	40	230	1400
France				
Aber-Benoit	5.2	2.9	18	158
Aber-Wrac'h	5	1.1	6	53
Arguenon	8.4	28	446	3910
Frenaye	7.4	12	148	1300
La Rance	8.4	22	349	3060
Rothenuf	8	1.1	16	140
Mont St Michel	8.4	610	9700	85,100
Somme	6.5	49	466	4090
Ireland				
Srangford Lough	3.6	125	350	3070
Russia				
Kislaya	2.4	2	2	22
Lumbouskii Bay	4.2	70	277	2430
White Sea	5.65	2000	14,400	126,000
Mezen Estuary	6.6	140	370	12,000
Australia				
Kimberly	6.4	600	630	5600
China				
Baishakou	2.4	No Data	No Data	No Data
Jiangxia	7.1	2	No Data	No Data
Xinfuyang	4.5	No Data	No Data	No Data

Tidal Energy Weakness

Unlike intermittent energy sources such as wind and solar that are ubiquitously available, TE system availability are site specific (Pelc & Fujita 2002).

Generally, an ocean energy system has many problems that deter their deployment on a large scale: financial, technical, environmental and legal difficulties. This type of technology is generally more expensive than other RETs, and presents some engineering challenges (Esteban & Leary 2012). The biggest barrier hampering development of TE is the high initial cost (O'Rourke et al.

2010). Also, it is difficult or impossible to install marine devices at greater sea depth, along with the cost of transmitting the generated electricity to onshore grid being exorbitant (Moriarty & Honnery 2010, WOR 2013).

On the environmental side, several projects are either paused or abandoned because of pressure from environmental campaigners (eg the Severn estuary South of Cardiff in the UK which has been reassessed, and currently has related prototype projects either completed or on-going, such as 1.2 MW SeaGen devices in Strangford Lough in Northern Ireland (MCT 2013)). Similarly, "many of the potential locations in coastal areas can be ruled out because they are either reserved for the fishing industry, shipping, or they are protected areas" (WOR 2013).

The intermittent nature of some RETs sources (wind and solar) poses a problem to grid networks , and the generation of power from the ocean can also experience this problem because energy production depends on tidal waves at a given location, therefore supply to the grid network will also be affected. However, tidal energy is better predicted and consistent than wave and OTEC energy system (Esteban & Leary 2012).

Tidal Energy Opportunities

Despite the high capital cost of TE, there are new projects, either on-going or soon to be deployed, particularly in UK and more than 60 different projects are to be delivered soon globally (Khan et al. 2009). For a significant future development of ocean energy, there is the need for government to support the sector with favourable policies. In line with the above, "the UK Government has indicated that it will offer 5 Renewable Obligation Certificates (ROCs) to TE projects that are installed and operational by 2017. This government backing will be crucial in attracting the necessary private investment to ensure that the UK retains its position as the global leader in the tidal energy sector" (MCT 2013). Also, Portugal's government has set feed-in-tariffs for ocean energy to encourage delivering significant energy (Esteban & Leary 2012). These forms of incentives have encouraged substantial deployment of some of RETs capacities globally.

Currently, there are a few companies researching and developing an ocean energy system receiving support from the UK government and other regional governments. Typically, the Scottish government has an investment fund of £130million to support ocean energy development (Martinot 2013).

Tidal Energy Threats

Despite the huge potential associated with the TE source and its ability to reduce effects of global climate change, there is some opposition to its application; in South Korea the hindrance of TE has been from the public, based on ecological concerns, while high costs and effects on wildlife were concerns in the UK (Martinot 2013). "The environmental impacts of these structures have generally hindered their wide scale application, and they have been known to have some impacts on marine biodiversity" (Esteban & Leary 2012). Also, they have potential to affect the ocean ecosystem and kill fish and ocean mammals if tidal barrages or fence technology are used. Therefore tidal turbines could be the most environmentally benign form of this RET (Pelc and Fujita 2002).

2.3 NIGERIAN RETS RESOURCES, DEVELOPMENT AND CHALLENGES

Given this study aims to examine sustainable means of providing sustainable electricity to Nigerian rural areas, this section assessed RETs commonly utilised for the purpose of distributed generation of electricity in Nigerian rural areas. According to Energy Commission of Nigeria (ECN) (2005), Nigeria has plentiful RETs resources but few are currently being used: hydropower and traditional biomass (Akinbami 2001), and recently solar, in decentralised used but with capacity less than 1 MW (Clean Technology Fund Investment Plan (CTFIP) for Nigeria 2014).

2.3.1 Wind Energy in Nigeria

Wind energy (WE) technology has experienced significant global growth over the last decade, with its installed capacity doubling every three years (WWEA 2012) and by the end of 2014 reached a capacity of 370 GW (REN21 2015). Unfortunately, this is not the case in Nigeria. The country is categorised under a poor-moderate wind regime, so, consequently wind energy cannot be applied on a bigger scale than for irrigation and village electrification.

According to Ajayi (2007), WE resources are very poor in the southwest and south onshore regions of the country, but offshore areas of the same zones bound by the Atlantic Ocean have excellent WE resources. However, while authors tend to recommend its application for specific locations (Ojosu & Salawu 1990; Ohunakin et al. 2011; Ngala et al. 2007; Fagbenle et al. 2011). Based on the study by Ohunakin (2011), using 36 years of wind speed data (1971-2007), at 10m height with wind turbine in the Northwest, Northeast and the mountainous areas of North central Nigeria, wind resources in these regions have a minimum yearly average wind speed above 4.8 m/s. Kano and Katsina having yearly average wind speeds above 7.0 m/s. Annual average power density and mean energy produced across the regions range from 100 W/m2 - 369 W/m2 and 900 KWh/m2/year- 3230 KWh/m2/year respectively.

Currently there is no official record of any significant WE application in Nigeria. Sopian et al. (2011) claimed that 2.2MW of electricity has been generated by WE in Nigeria, but reality suggests that it has been abandoned due to the lack of maintenance and technical knowhow. Also, the WE source is the least exploited RET for power generation in Nigeria. According to Akinbami et al. (2003), there were small applications of WE in Nigeria before independence in 1960, mainly in far northern Nigeria for water pumping. Also, there are recent few wind energy pilot projects in the country which include Sayyan Gidan Gada-5 KW capacity, 0.75KW (Danjawa village), Goronyo and Kedada (Bauchi) (Mohammed et al. 2013; Ohunakin 2011; Ajayi 2009).

Other obstacles facing sustainable WE utilisation in Nigeria include the lack of a corresponding market, general apathy towards the development of wind technology, and poor budgetary allocation (Ajayi & Ajayi 2013; Oyedepo 2012).

Wind, solar and hydro resources of electricity generation suffer intermittency; but in Northern Nigeria there are particular locations that can provide 100% power generation from wind technology. Typically, Kano and Katsina experienced only 1% and 8% yearly drop respectively (Ohunakin 2011). However, differences could occur within the same zone, therefore, it will be appropriate to site wind farms in good locations spread over different regions (see table 2.4).

Consequently, considering good wind speed availability in excess of 5m/s at 10m height in Kano and Katsina, and the offshore area of the country spanning from

Lagos to Akwa Ibom throughout the year, suggests that 100% wind energy production is feasible. However, as locations change from far north, down to north central, turbines will need to be installed higher than 10m for better power generation (Ajayi 2007). The economic implication of additional height of wind turbine is marginal considering the life span of the components and expected power generation. However, given the locations this study is assessing for electricity generation, it may be difficult for this energy system to be adopted. This is because of intermittency and highly unpredictable nature of wind resources, but may be suitable for grid application. This may be connected with the on-going 10MW project in Katsina presently.

Table 2.4: Seasonal variations of wind characteristics for the six sites for the period between 1971 and 2007 (Ohunakin 2011)

Season	Mean wind speed (10m)	Annual power density (W/m2)	Monthly seasonal duration range
Gusau			
Rainy season	5.45	120.83	June-September
Dry season	6.42	207.31	October-May
Kaduna			
Rainy season	4.78	74.61	June-September
Dry season	5.52	126.7	October-May
Katsina			
Rainy season	7.96	391.31	June-September
Dry season	7.19	314.13	October-May
Kano			
Rainy season	7.81	371.03	June-September
Dry season	7.74	367.86	October-May
Bauchi			
Rainy season	4.39	80.37	May -September
Dry season	5.16	149.17	October-April
Potiskum			
Rainy season	4.02	46.31	September - Deceber
Dry season	5.2	89.57	January - August

Power generation through wind technology is higher during the dry season (November-May) than in the rainy season (June-September) particularly in most part of the northern Nigeria. However, intermittency associated with the majority of RETs can be resolved through Smoothening effect. See further details in section (2.2.1-under wind opportunities). More so, Nigeria's wind energy resources are naturally distributed from the far north through the central zone up to the coastal area of the southern region. See figure 2.8 for details.

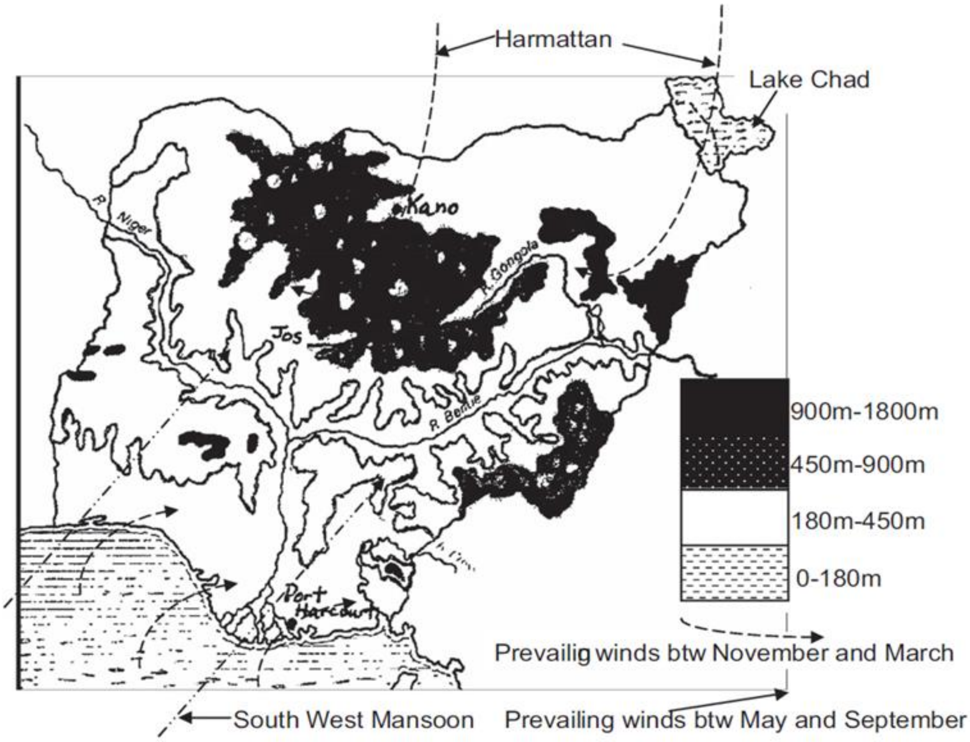


Figure 2.8: Map of Nigeria showing relief and prevailing winds (Ajayi 2009)

2.3.2 Solar Energy in Nigeria

Nigeria is located in the tropical zone and geographically is situated between 4^0 N and 13^0 N, thereby providing opportunity to receive high levels of solar energy. Sambo (2009) reported that "The mean annual average of total solar radiation varies from 3.5 kW/m2/day in the coastal latitude to 7 kW/m2/day along the semi-arid areas in the far Northern Nigeria. On the average, the country receives solar radiation at the level of 19.8 MJ/m2/day". Similarly, Shaaban and Petinrin (2014) reported that Nigeria averages 6.5 hr/day of sunshine and mean solar radiation of 5.535 KWh/m2/day. Table (2.5) details some Nigerian' cities solar radiation. Solar energy that falls on Nigeria daily is approximately 16.7 EJ and has capacity of generating 4.2×10^5 GWh electricity annually (Akinbami 2001). The solar potential is 27 times greater than that of the nation's fossil fuel resources and in excess of 115,000 times greater than the electricity generated by the end of 2008 (Augustine & Nnabuchi 2009).

Table 2.5: Maximum, minimum and yearly average global solar radiation (kWh/m2/day) (Okoro et al. 2007)

Stations	Location Lat. °N	Location Long °E	Altitude (m)	Max[a]	Min[b]	Monthly Average
Abeokuta	7.25	3.42	150	4.819	3.474	4.258
Abuja	9.27	7.03	305	5.899	4.359	5.337
Akure	7.25	5.08	295	5.172	3.811	4.485
Azare	11.8	10.3	380	6.028	5.022	5.571
Bauchi	10.37	9.8	666.5	6.134	4.886	5.714
Beni City	6.32	5.6	77.52	4.615	3.616	4.202
Calabar	4.97	8.35	6.314	4.545	3.324	3.925
Enugu	6.47	7.55	141.5	5.085	3.974	4.539
Ibadan	7.43	3.9	227.23	5.185	3.622	4.616
Ilorin	8.48	4.58	307.3	5.544	4.096	4.979
Jos	9.87	4.97	1285.58	6.536	4.539	5.653
Kaduna	10.6	7.45	645.38	6.107	4.446	5.672
Kano	12.05	8.53	472.14	6.391	5.563	6.003
Katsina	13.02	7.68	517.2	5.855	3.656	4.766
Lagos	6.58	3.33	39.35	5.013	3.771	4.256
Lokoja	7.78	6.74	151.4	5.639	4.68	5.035
Maiduguri	11.85	13.08	383.8	6.754	5.426	6.176
Makurdi	7.73	8.53	112.85	5.656	4.41	5.077
Minna	9.62	6.53	258.64	5.897	4.41	5.427
New Bussa	9.7	4.48	152	5.533	4.15	4.952
Nguru	12.9	10.47	342	8.004	6.326	6.966
Obudu	6.63	9.08	305	5.151	3.375	4.224
Oweri	5.48	7.03	120	4.649	3.684	4.146
Port Harcourt	4.85	7.02	19.55	4.576	3.543	4.023
Serti	7.5	11.3	610	4.727	3.972	4.488
Sokoto	13.02	5.25	350.75	6.29	5.221	5.92
Wari	5.52	5.73	6.1	4.237	3.261	3.748
Yola	9.23	12.47	186.05	6.371	4.974	5.774

Note: (a) represents average for the months of March, April and May; while (b) represents average for the months of July and August.

Considering all the RET forms in Nigeria, solar energy (SE) is the most abundant and promising source, but also the most expensive technology (Evans et al. 2009; Moriarty & Honnery 2011). Current development indicates the capital cost of solar PV modules is reducing (20-30% in 2012) (Martinot 2013). Solar PV components cost reduction results from significant decreases in silicon prices, increased production capacities, improved efficiencies and particularly growth in the technology market (Renewable Handbook 2010; Wiese et. al. 2010). The reduction in capital cost of PV modules combined with a newly incentivised

(Feed-in-tariff) Nigerian market offer an opportunity for investors to deliver sustainable electricity in the country, particularly in the rural areas. Also, wealthy households in the cities can use this source for their power needs, as it is becoming affordable.

The historic deficiency of local technical knowhow and components production in Nigeria are both being overcome, through the establishment of a 7.5MW manufacturing plant in the capital Abuja. The plant is a joint venture project between federal government of Nigeria (through National Agency for Science and Engineering Infrastructure (NASENI)) and foreign partner, with objectives of capacity building, business creation and technology development. The plant has since commenced operation since 2011. Furthermore, considering the available solar energy in Nigeria in the context of the approximately 2.33 kWh/day requirement for average Nigerian household, it is feasible to use SE to generate enough electricity to meet the needs of all Nigerians throughout the year (Adeoti et al. 2001).

Currently, SE systems are used in Nigeria for small and medium-sized power applications including street lighting, domestic/office powering, water pumping, rural electrification, rural health centres (e.g., refrigeration of vaccines), powering of telecommunication booster stations and ATM machines. Further development of SE technology requires the following problems to be addressed: creating a reliable policy framework; reducing the costs of components; stopping the use of sub-standard components; strengthening the poor maintenance culture, and improving the lack of statistical data and capacity utilisation (Shaaban & Petinrin 2014; Mohammed et al. 2013; Oyedepo 2012).

2.3.3 Hydropower Energy in Nigeria

Nigeria's hydropower source has been the largest contributor in the provision of sustainable electricity in the country, particularly from 1973-1978 (approximately 46% more than other sources) (Akinmami 2001). Nevertheless, there has long been a bias toward fossil fuel (FF) electricity energy sources (see figure 2.9), despite the reform in the country's energy sector of Energy Power Sector Reform Act (EPSRA) 2005. This is evident in the proposed power generation plants; of 28 licenses issued to Independent Power Provider (IPP) for electricity generation as at February 2009, only 1 provider is expected to generate electricity from a renewable source (Sambo et al. 2010; Ohunakin et al. 2011).

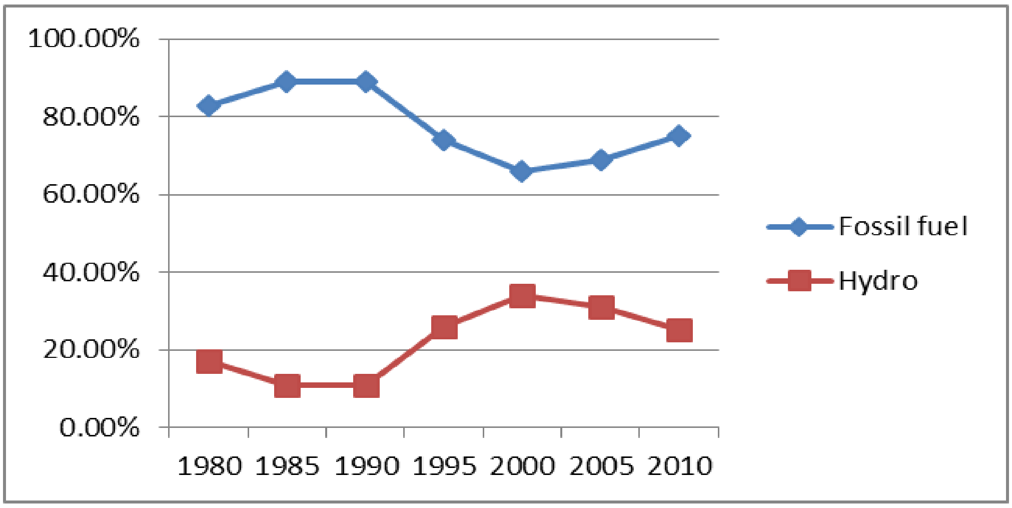


Figure 2.9: Nigeria Electricity Generation Fuel Share between 1980 and 2010

The disparity indicates that government is comfortable with the use of FF in delivering electricity in the country despite the greater sustainability credentials of renewable energy sources, and the National Energy Policy (2003) setting the expectation that the country's electricity needs shall be met through both FF and renewable energy sources.

Support for FF energy sources by government may not be unconnected with the abandonment of RETs resources in Nigeria. However, this may not be the only problem facing hydropower in the country; climate change has affected annual rainfall in Nigeria and other Sahel countries so that the River Niger (provides Nigeria's main three dams) now only provides a low level of dam water. Also, stagnation of hydropower capacity development is a source of concern as for over two decades there has been no meaningful development after the Shiroro dam was completed.

Nigeria has a hydropower potential of approximately 14,735 MW with 11,235 MW and 3,500MW for large scale and small hydropower (SHP) respectively (Oseni 2011; Sambo 2009; ECN 2005) from waterways in excess of 3,000KM (Tunde 2005). Despite the hydropower resource in the country, only a total of 1,960 MW has so far been exploited, representing 14% of total capacity (i.e, 1930MW for large hydro and 30MW for small hydropower) and contributing around 25% to the total available national grid capacity (4,000MW). Also, Nigeria's hydropower resources have a feasible potential of about 32,000 GWh/year (Shaaban & Petinrin 2014; Mohammed et. al. 2013; Ohunakin et. al. 2011; Adewumi 2006).

Nigerian hydropower technology has been developed and used since the 1960s. However, the established sites of SHP based on 1980 surveyed were 277 and they have capacity representing approximately 734.2MW, of which only 30MW are currently exploited, i.e. less than 5% of established capacity; hence they could be utilised in rural areas to address the 90%+ electricity deficiency (Tunde 2005, Sambo 2009; Mohammed et.al. 2013; Manohar & Adeyanju 2009-Mohamed et.al. 2013; Shaaban & Petinrin 2014; REMP 2005). See table (2.6) for further details. SHP are suitable for rural areas based on their features: no need for transformers, high tension lines, or reservoirs (Garba & Kishk 2014). In addition, they provide readily available power, require no fuel, limited maintenance needs, application of local skills and materials during construction, sustainable energy source, and a competitive price vis-à-vis FF energy source (Bugaje 2006; Adeoti et.al. 2001; Tunde 2005). However, the main constraint of this source is the displacement of inhabitants. This can be mitigated through informed consent from local communities along with economic compensation.

Table 2.6: Small hydro (developed and underdeveloped) potential in Nigeria (Renewable Energy Masterplan 2005)

			Hydropower Potential		
State (Pre 1980)	**River Basin**	**Total sites**	**Develpoed (MW)**	**Undeveloped (MW)**	**Total capacity MW**
Sokoto	Sokoto-Rima	22	8.0	22.6	30.6
Katsina	Sokoto-Rima	11		8	8
Niger	Niger	30		117.6	117.6
Kaduna	Niger	19		59.2	59.2
Kwara	Niger	12		38.8	38.8
Kano	Hadeija-Jamare	28	6.0	40.2	46.2
Borno	Chad	28		20.8	20.8
Bauchi	Upper Benue	20		42.6	42.6
Gongola	Upper Benue	38		162.7	162.7
Plateau	Lower Benue	32	18.0	92.4	110.4
Benue	Lower Benue	19		69.2	69.2
Cross River	Cross River	18		28.1	28.1
Total		**277**	**32**	**702.2**	**734.2**

Inconsistency by the Nigerian government policies has affected hydropower source uptake, particularly for SHP which was projected to contribute to the energy supply mix (by the Federal Ministry of Power and Steel in 2006 under its Renewable Energy Action Program) by "190, 490, 1280 and 3315MW by 2000, 2010, 2020 and 2030 respectively and yet only 30MW capacity is being harnessed, representing approximately 16% of the 2000 demand indicating a wide disparity and deficiency in supply relative to demand" (Ohunakin et. al. 2011).

In spite of favouring FF, such sources have failed to deliver the expected electricity. According to Ohunakin et al. (2011) "natural gas supply to Nigeria's thermal power stations has been grossly inadequate; it is less than one-third of the needed 1.2 billion standard cubic feet of gas per day. However, to increase the energy production, there is need for enhancement of the existing sources and full exploitation". Hence, this research is recommending the need for sustainable and alternative means of generating electricity in the country, given the significant resources available for RETs.

The Energy Commission of Nigeria (ECN) is now collaborating with international organisations such as United Nation Industrial Development Organisation (UNIDO) and Ministries, Departments and Agencies (MDA) in the country on how to develop and create awareness on the enormous benefits of renewable energy in the country, particularly SHP for provision of sustainable electricity to rural areas. The goal of this cooperation is to develop rural areas through establishment of cottage industries (small and medium enterprises) with a view of creating employment and eventually mitigating ongoing rural-urban migration (Sambo 2009). However, progress has been made as a Memorandum of Understanding has been signed between ECN and UNIDO-IC-SHP, China for exploitation of identified SHP sites. Nonetheless, at present there is no official record showing any capacity increase from this source of electricity. Hence, there is the need for strong political will to develop this source for sustainable electricity generation. Also, it is worth noting that SHP has been in use since 1923, approximately four and half decades before large hydro become operational in Nigeria.

2.3.4 Biomass Energy in Nigeria

Nigeria's biomass resources include agricultural residues, forest biomass, municipal solid waste (MSW) and animal dung (ECN 2005). The country's vegetation arrangement dictates the availability of these resources, with the major forms of vegetation in Nigeria being savannahs and forests representing approximately 80% and 20% respectively of Nigeria's total area of around 923,768km2 (Sambo 2009; Akinbami et al. 2003). The majority of the savannahs (northern) are cultivatable and largely the people in the region earn their livelihood through farming. The region produces large quantities of agricultural products and modest quantities of fuel wood, while large quantities of wooden biomass are produced in the south (the forest region) (Garba & Kishk 2014). Also, urban areas are the major producers of MSW; and all these biomass resources can be converted to power energy. Some of the benefits of using biomass resources for energy generation, specifically forest and agricultural residues, include procurement of the resources at little or no cost, and designated landfill waste redirecting (Evans et al. 2010).

Approximately 50% to 60% of energy needs of developing nations are met through traditional biomass sources, particularly fuel wood; this phenomena is increasing specifically in Sub-Saharan African (SSA) countries where most of their energy policies are either unrealistic or conflicting (Owen et. al. 2013; Akinbami et. al. 2003). According to IEA (2010), by the end of 2030, the number of SSA citizens depending on biomass consumption will increase by 60%. In Nigeria over 60% of rural people and a fraction of urban people depend on fuel wood for their energy needs, and the country is consuming in excess of 50 million metric tonnes of fuel wood annually; in excess of afforestation replenishment programmes in the country (Sambo 2009). Sambo (2009) claimed that the deforestation rate is around 3.6% per annum. In line with the above, fuel wood has really proven to be an alternative source of energy to petroleum products, which, despite Nigeria being a member of OPEC, can be difficult to obtain. The rate of consumption, particularly of FWC, is alarming, and there is necessity for modernising the use of this energy source to prevent depletion.

Nigeria's Biomass Resources

Biomass resources in Nigeria are available in quantities which the citizens can convert for their energy use. The four major forms of biomass sources as highlighted above include: agricultural residues, animal residue, forest biomass and municipal solid waste. Nigeria has biomass resources potential of approximately 1.2 Petajoule (PJ) as at 1990 (Akinbami 2001) but this does not include MSW, biogas and other few sources (see table 2.7). ECN (2005) projected the resources to be around 144 million tonnes per annum. Garba & Kishk (2014) stressed that it is feasible to generate electricity up to 68,000 GWh/year using approximately 30% of the biomass resources in the country for the rural communities. Dasappa (2011) forecasted Nigeria's biomass resources (30% forest and agricultural residues) availability as capable of generating approximately 15,000MW. The forest resource is the largest biomass utilised in Nigeria for energy purposes. Biomass resources can be used to provide electricity in rural areas without a supply chain issue. However, the biomass resources supply chain should be given emphasis before adoption in these communities, as it determines energy cost (IRENA 2012). If this source is going to be utilised in the country, the resources availability, development and sustenance have to be planned in a sustainable way.

Table 2.7: Nigeria Bioenergy potential (Akinbami 2001)

Biomass Resources	Animal Residues	Agricultural Residues	Wood Residues (industrial, fuelwood, charcoal)	Total
Potential (PJ)	47,718	325,822	805,580	1,179,120

Forestry biomass

Large areas of Nigeria's forests are owned by the government but its use is unregulated and unguarded, that giving opportunity to individuals and lumber merchants to encroach the forests and harvest forest trees unabatedly. There is the need for an appropriate biomass resource policy such as adopted by EU, USA and Asia in Nigeria and sub-Saharan African countries to prevent this economic sabotage and environmental degradation. According to Nigeria's Ministry of Agriculture (1997), between 12% and 13% of the country's total land area

(923,768km2) is projected to be covered with woodland and forest, and about 61% of the area is set as reserve-(see figure 2.10 for details).

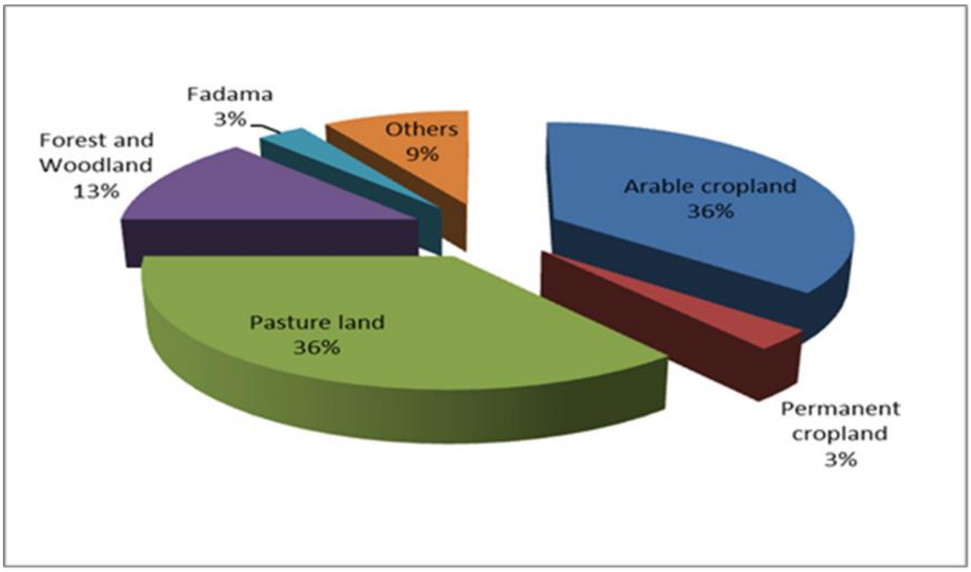


Figure (2.10): Nigeria Land use estimate (Federal Ministry of Agriculture 1997)

Agricultural residues

Nigeria is a developing country and approximately two-thirds of its population in the rural areas largely depend on farming. According to Mohammed et al. (2013) "the most important source of agricultural residue in Nigeria is cereal crop residue". From cereal cultivation, a significant amount of processing residues such as stalk, straw, shell, bagasse, husk, and off-cuts from grain, rice, vegetables, and cotton are generated during the harvest seasons. The majority of these residues end up as waste being burnt to allow for the following year cultivation, or as MSW. This practice may be connected to a lack of awareness of the benefits of using these residues in modern power generation through thermo-chemical and biological conversion processes which eventually can meet the rural communities' energy needs. However, these residues are also required by other applications such as for thatched roofing, livestock feeding and stabilisation for local laterite (mud) blocks etc. which may create competition among these applications, especially in the Northern part of the country.

Nigeria's agricultural residues energy potential, based on FAO estimates in 2010, is around 700 TJ/year, i.e. equivalent of approximately 194 GWh/year.

Conversely, agricultural residues are location specific, may be insufficient quantities and in terms of power generation are not usually the best alternative (Thornley 2006). Also, wastes are generally of less value when long transportation distance are involved and usually of low density (Evans et al. 2010).

Animal residues

The majority of Nigerian rural communities and some substantial amount of urban dwellers are farmers. It is noteworthy that 94% and 68% of Nigerians households are engaged in crop farming and livestock farming respectively (ECN 2005). In northern Nigeria, average households practice animal husbandry thereby giving the region opportunity to produce substantial amounts of livestock including: cattle, sheep, and goats; while chickens and a large fraction of pigs are produced from the southern region. The waste of such livestock is referred as animal dung and can be used for energy production through biogas system. However, the quantities of waste produced by these animals differ based on the animal body size, and frequency and quantity of feeding (Malau-Aduli et al. 2003; Mohammed et al. 2013).

ECN (2005) reported that, from Nigeria's livestock in 2001, it was possible to produce 285.1 million tonnes of dung to generate over 3 billion m3 of biogas annually (equivalent to over 1.25 million tonnes of fuel oil equivalent per annum). "The dry dung output in kilograms per head per day are 1.8 (cattle), 0.4 (sheep), 0.8 (pigs), 0.4 (goats) and 0.06 (chicken)" Hemstock (1995) (cited by Mohammed et al. 2013 p6). It is possible therefore for Nigeria to generate 456 PJ annually (FAO 2010), which corresponds to an energy potential of 126,667 GWh/annum, but at 30% availability around 38,000 GWh per annum can be achieved. This estimate is far above the total given in table (2.7). From the available animal resources in the country, it is possible to use biogas energy systems for all capacities of family and community.

Municipal Solid Waste (MSW)

MSW is defined as "refuse from households, non-hazardous solid waste from industrial, commercial and institutional establishments (including hospitals), market waste, yard waste, and street sweepings" (Ogwueleka 2009). While

Mohammed et al. (2013) describe it as materials emanating from human daily activities. There are two basic forms of solid waste management systems in Nigeria: open dump and structured sanitary landfill, with the open system being the most common scheme in Nigeria. This form of disposal system has implications such as polluting the atmosphere and groundwater, disease, foul odour, toxic smoke etc. While the structured sanitary landfills are situated in major cities the majority have now been abandoned due to lack of appropriate regulation of waste management in the country (Ogwueleka 2009; Mohammed et. al 2013). The only city in Nigeria with a central sewer system is Abuja (the nation's capital), this gives the city opportunity to utilise household waste to produce energy subject to political will being in place.

However, the effects of the open dump system can be mitigated through appropriate conversion of the waste to energy. Ogwueleka (2009) reported that Nigeria generates in excess of 25 million tonnes of municipal solid waste (MSW) yearly, at a rate of 0.44 to 0.66 kg/capita/day from rural persons to urban dwellers respectively. The rate of generation differs from individuals and locations based on the following factors: economy size of the nation/city, population, social behaviour and events (particularly feasts), extent of urbanisation and level of any re-use/recycling system.

The rate of waste generation in developing nations is far below the generation rate in developed countries, which range between 0.70 and 1.8 kg/capita/day (Ogwueleka 2009). Waste streams in developing countries comprise in excess of 50% organic material (Hoornweg et al. 1999), which may be a blessing in disguise if biogas systems are to be utilised.

Furthermore, the volume of waste continues to increase every year at the rate exceeding the aptitude of the Nigerian government to handle, and it has now become a nuisance to the streets and roads of Nigeria's major cities. Given that it is possible to generate electricity from the waste, action should be taken to achieve appropriate conversion to energy. From the study by Suberu et al. (2013), it was estimated that Lagos state (former capital of Nigeria) has a power potential of 442 MW from MSW. Also, based on the 2006 population census in Nigeria, Lagos state contained approximately 6.5% of total Nigeria population

(National Population Commission 2006), so by extrapolating based on the subsequent increase in the national population (currently over 170 million), it is possible for Nigeria to generate in excess of 6,000 MW of electricity from MSW. Also, conversion of 25 million tons of MSW to electricity (over 29,000 GWh/annum) can be generated. Thus, at 30% availability, producing around 7,800 GWh of electricity is feasible annually through biological processes such as biogas system. Biogas system is one of the methods of converting waste to energy, most especially the biodegradable part of the MSW. While from the portion of non-biodegradable matter recyclable materials should first be separated to prevent GHG emission during conversion to energy process.

Biogas

Biogas is created from decomposition of organic matter through the process of anaerobic respiration (in the absence of air) (Shaaban & Petinrin 2014; Mohammed et al. 2013; Poschl et al. 2010). Biogas can be used for different energy purposes, such as agriculture, industrial and household sectors, and can replace unsustainable use of fuel wood, charcoal, kerosene and diesel, thereby reducing GHG emissions and the subsidy for kerosene (over US$ 20 billion between 2011 and 2013 utilised in Nigeria) (Garba & Kishk 2014). Also, "it exhibits no risk to health; does not have offensive odour and it burns with a clean bluish, spotless flame thereby making it non-messy to cooking utensils and kitchens" (Akinbami et. al. 2001; cited by Shaaban & Petinrin 2014 p8) as witnessed with traditional biomass and FF energy systems. The majority of biomass resources have issues with energy balance.

Following the available records that Nigeria has huge resources for generating electricity from different forms of biomass resources, and in line with the socio-cultural setting of citizens practicing extended family system (over 9 persons/family), it is possible to generate electricity at family, community and centralised levels using biogas system. The cost implication of the family-size biogas plant of around 6m3 capacity that can produce 2.7m3 of biogas/day is around US$500 initial capital cost (equivalent to NGN 85,000 at February 2014) with running cost of NGN 11,970/annum and cost benefits (savings) by each household of NGN 26,750/annum (Adeoti 1998).

Nigeria produces large quantity of livestock (FAO 2010) and based on approximately 150-180 kg/capita/annum of MSW, with every 1 kg of fresh animal waste can generate around 0.03m3 of gas, Nigeria can generate multi-millions m3 of biogas/day (Shaaban & Petinrin 2014). Currently, Nigeria has in excess of 30 biogas plants of between 10 – 30 m3 capacity across the nation applying various substrates such as human excreta, cow dung, pig waste etc (ECN 2005 & Field survey 2013) for cooking gas and laboratories in the prisons and secondary schools. Also, a community-based 35 kW electricity biogas project has been initiated in Ibadan (Oyo state capital, southwest Nigeria) to utilise abattoir waste resources (Mohammed et al. 2013).

The major constraints identified in the utilisation of these pilot biogas plants were lack of planned maintenance, inadequate feedstock sources, lack of budgetary allocation, lack of appropriate records of these pilot biogas projects (even the Energy Commission of Nigeria do not have records of the total national biogas plants). Thus, the application of biogas system will solve many issues pertaining to environmental pollution noticeable in developing country cities, and offer better alternative for replacement of application of FWC and conventional energy system.

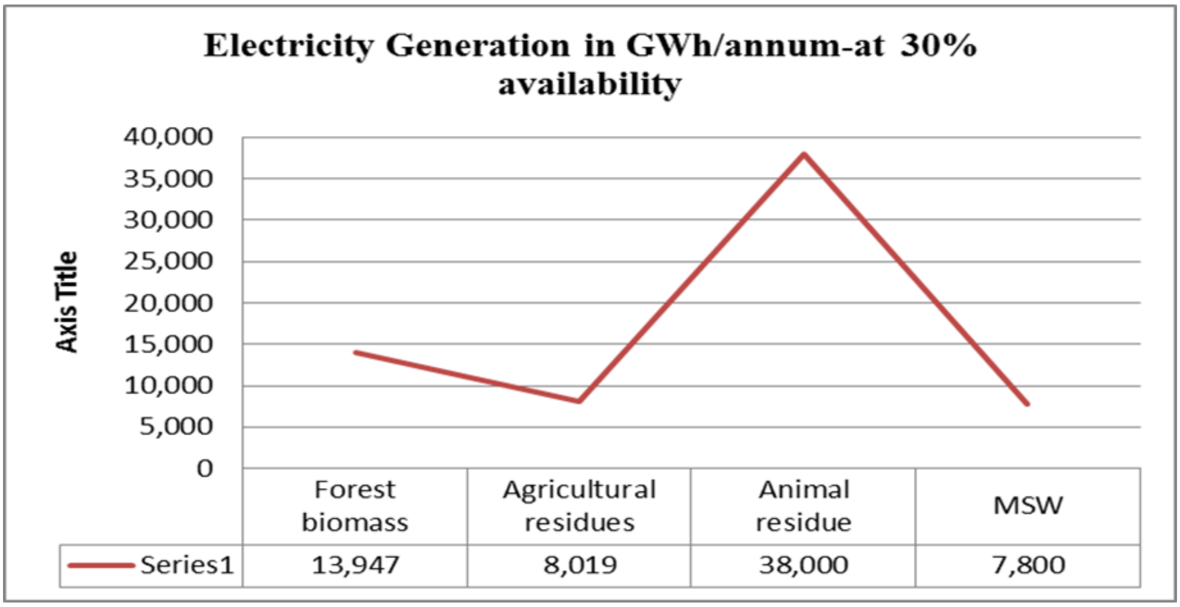


Figure 2.11: Nigeria Biomass Electricity Potential at 30% resource Availability

Effect of Present Application of Biomass Resources in Nigeria

At the beginning of last decade, Nigeria was unsustainably using its forest and natural vegetation, following the same pattern of consumption as witnessed over the previous century (Nigeria's woodland reduced by 84% between 1887-1986), as Fuel Wood and Charcoal (FWC) constituted in excess of one-third of total primary energy consumption, with 39 million tonnes estimated to be the national demand over the same period. Thus, significant total fuel consumption was related to domestic or related activities, causing significant deforestation (Sambo 2009; Dasappa 2010). Although the above was argued by some researchers to actually result from construction activities, farm land expansion due to population explosion, and other factors (Owen et. al. 2013; Akinbami et. al. 2003).

The implication of the unsustainable application of FWC is significant deforestation of approximately 350,000 hectares per annum as against reforestation rate between 4%-10% of that. This situation is associated to climate change effect. Considering the depleting woodland reserves, women and children have to travel in excess of 4km/day in search of energy wood for cooking. Also, use of FWC have caused lung related diseases to over 1 million women annually in rural developing countries particularly if used indoors (Sopian et. al. 201; Sambo 2009; Akinbami et. al.2003); there is the need for sustainable utilisation of biomass resources.

Way forward

Given the unsustainable application of biomass resources, especially FWC, it is feasible that natural resources will be depleted. The IEA (2010) projected that the number of Sub-Sahara Africa people dependent on biomass energy will increase by 60% in the next two decades. The above estimation is concurring with the ECN (1998) projection that traditional biomass application in Nigeria is expected to rise to 91 million tons by 2030 as against 39 million tons annually in 2000 if unchecked. The following strategies to combating this problem are as follows:

Firstly, there is need for government to counter the depleting of biomass resources through appropriate utilisation (adopting an improved wood stove with efficiency between 15-40% over traditional stoves), protection of forest and woodland through appropriate policy for forest management such as Certification Criteria, Council for Sustainable Biomass Production and Roundtable on Sustainable Palm Oil respectively for EU, USA and Asia respectively (Miyake et al. 2012), and finally through appropriate biomass conversion technologies such as pyrolysis, gasification and direct combustion utilisation for energy generation.

Secondly, while fertile land availability is the major weakness for biomass energy system as it affects food production, in Nigeria there is a vast amount of arable and semi-arid land areas that are yet to be cultivated. Dedicated short rotation (3-10 years) energy crops should be cultivated, such as willow, poplar, and eucalyptus (Evans et al. 2010). Already most forest developers in southern Nigeria have commenced growing these short rotation trees such as "Gmelina arborea, Gliricidia sepium and Leucaena leucophala" (Mohammed et al. 2013). Also, planting of Jatropha has commenced in Northern Nigeria in the form of pilot study particularly around Sokoto area. However, it is worth noting that unless there is significant rise in CO_2 taxes and stationary energy prices, energy crops may not be economically worthwhile for electricity generation (Clean Energy Council 2008).

Considering the biomass energy resources identified above, sustainable electricity is sufficiently possible from this source for distributed power generation and as a means of combating intermittency of other RET sources, for it to be considered for future electricity generation of the country.

2.3.5 Geothermal Energy in Nigeria

There are two locations of geothermal energy that exist in Nigeria: Ikogosi warm spring and Wikki warm spring in Ondo state and Bauchi state respectively. Similarly, high geothermal gradients have been identified in the Lagos sub-basin, Auchi-Agbede, Okitipupa ridge and also the Abakaliki anticlinorium (ECN 2005).

Obande et al. (2014) reported that there are signs of geothermal energy in the Upper Benue Trough of crustal thinning and inferred that abnormal hot material can be found under the trough at comparably shallow depths. The study concluded that "the Wikki Warm Spring area has a great energy potential with an estimated average Curie Point Depth (CPD) of 8km; an average geothermal gradient of 680 C/km and very high heat flow values (an average of 170mW/m2). It has been stressed that temperatures greater than 100^0 C can be reached at depths of less than 2 km thus making the Wikki Warm Spring a promising area for exploration of geothermal resources". Similarly, the study by Omanga et al. (2001) concluded that radioactivity (radioactive decay of various isotopes) is the source of the heat in Wikki region, following the revelation of a radiometric survey. The Wikki warm spring therefore has a high energy potential for utilization in a geothermal system.

The problems of this energy source include the lack of commercial proposition in the country and perhaps the lack of records. However, the situation may change if commercial quantities of energy from this source are established, thereby eventually allowing it to be enlisted to Nigeria's energy supply mix (ECN 2005).

2.3.6 Ocean Energy in Nigeria

Nigeria is bordered by the Atlantic Ocean in the southern part of the country, with the coastline extending from Bakassi to Badagry for a distance in excess of 850 km. This gives Nigeria the opportunity to produce electricity from ocean energy technologies (OTEC, wave and tidal energy) if the availability of the resources is confirmed.

The wave energy potential of the West African coast (including Nigeria) comprises the poorest resource in Africa, with an energy regime of 10 KW/m. According to ECN (2005), "Nigeria does not seem to have significant tidal energy resources". However, OPEC (2004) estimated that Nigeria has 150,000 TJ/annum of wave and tidal energy resources.

Furthermore, even if Nigeria has adequate resources from this energy source, the technology is still developing, along with high capital costs, long gestation periods and low load factors. Hence, it is not commercially viable at the moment even at the global level, let alone in a developing nation like Nigeria.

Currently, there is no existing ocean energy utilisation record in the country, also no known research and development (R & D) activity from this source or any record of potentials of this source as identified for other RETs in Nigeria; and this may not be unconnected to not enlisting this source in Nigeria's energy market.

2.4 International Utilisation of RETs

In spite of the fossil fuel prices falling and ever subsidies provision, RETs power generating capacity experienced the largest yearly addition ever in 2015, with an estimated 147 GW added. Cumulative world capacity was up by approximately 9% and 8.5% over 2014 and 2013 respectively (REN21 2015; REN21 2016), ending up the 2015 with an estimated 1,849 GW (REN21 2016). Over the last two years, RETs power source has added more capacity (net) annually than all the fossil fuel combined. In 2015 alone, renewables contributed over 60% of net additions to global power generating capacity, representing approximately 24% of global total electricity supply (including large hydro capacity of around 16.6%). The growth of non-hydro RETs was as a result of reduction in installation cost of the components and expansion into new market (REN21 2016).

Furthermore, from 2007 – 2013, approximately 6% growth was experienced annually from renewable power generation. However, in the same period global electricity utilisation increased by an average rate of 2.7% annually (REN21 2015). The percentage contribution of each RET by the end of 2015 from the total estimated 24% includes: hydropower (16.6), wind (3.7), bio-power (2.0), solar PV (1.2) and combination of geothermal, CSP and ocean (0.4) (REN21 2016).

Both wind and solar PV recorded significant additions in 2014 and 2015, and contributed over 90% and around 77% of non-hydro renewables respectively (REN21 2015; REN21 2016). However, large hydropower continued to experience decline over the last four years, with capacity addition of 3.6% in 2014, down to 2.7% in 2015 (Martinot 2013; REN21 2015; REN21 2016). Nevertheless, large hydropower maintain the lead among renewable power generation sources, accounting for approximately 1064 GW from the total capacity of 1849 GW by the end of 2015. Similarly, from 2012 – 2015, wind and solar PV each recorded global capacity additions surpassing hydropower source (Martinot 2013; REN21 2014; REN21 2015; REN21 2016).

According to REN21 (2016) “Bio-power capacity increased by an estimated 5% in 2015, to 106.4 GW, and generation rose by 8% to 464 TWh; the rise in generation was due in part to increased use of existing capacity”. The countries that led in bio-power generation by the end of 2015 were the United States, Germany, China, Brazil and Japan, respectively representing (69 TWh), (50TWh), (48 TWh), (40 TWh) and Japan (36 TWh). They were followed by the United Kingdom (UK) and India by order of importance. From the total bio-power generation in 2015, solid biomass contributed around 71%, followed by biogas (20%), MSW (8%) and 1% from biofuels (REN21 2016).

On the global scale, the leading RETs’ countries in 2015 were China, USA, Brazil, Germany and Canada; China alone accounted for over 25% of the total world RETs capacity. In Europe, Germany was the leader in RETs. Also, Scotland is the country that has met over 50% of its electricity demand from RETs, twelve months ahead of its set target (REN21 2016). Similarly, REN21 (2016) reported that in Africa “Morocco was the world’s largest CSP market, South Africa was the first country on the continent to achieve 1 GW of solar PV and helped push the continent’s wind power capacity above the 3 GW mark, and Kenya ranked fourth globally for new geothermal power capacity”.

Europe and Bio-power Generation

In Europe, Germany continued to dominate the bio-power in 2015 (just like in wind and solar PV), with capacity of around 7.1 GW from biomass power generation and around 70% of this capacity emanates from biogas fuel and remain the biggest power producer from biogas in Europe. UK is the second leading country in this respect, and has significantly improve in bio-power in recent years, with capacity and generation increased by 12% and 27% respectively over the same period. UK remains the sixth largest in the world in terms of bio-electricity as emphasized above. Just like in Germany, biogas market has experienced growth considerably in the UK, and represents the fastest growth in Europe over the same period (REN21 2016).

Regardless of the growth experienced in the area of biomass electricity generation in 2015, the leading countries have experienced setback in recent time. Typically, it is indicative that some existing bio- power in the United States are not financially competitive with low-cost generation from other renewables sources and natural gas. Similarly in china, the target plan of reaching 13GW by 2015 experienced impediments due to factors such as high feedstock prices, poor co-ordination among projects and technical operating difficulties; hence achieving only 10.3 GW. Also, in Brazil, bio-power experienced slow growth due to wind power domination of the RETs auctions from 2013 – 2015 (REN21 2016).

2.4.1 Social Impact of Communities RETs

RETs are increasingly becoming difficult to develop and has experienced slow growth particularly the UK's wind energy system due to localised public opposition (Aitken et al. 2008). People's attitudes towards wind farms comes from the perceived visual impact, landscape aesthetics, issues of participation and power inequalities, and fears about the impact on local traffic and roads (Strachan et al. 2010; Aitken et al. 2008).

Despite the above concerns, RETs has socially impacted in the area of low carbon energy provision in developed countries (Owen et al. 2013), especially the communities renewables in Germany, Denmark and Britain (Strachan et al. 2015); where the development of rural areas sustainable electricity has not only helped in reducing impact on the environment but also improving opportunities for waste to energy, generation of employment and social engagement among others (Evans et al. 2009; Moriarty & Honnery 2011). These positive impacts are similar to expected social benefits in Nigeria, except with additional context like selling of farms and animal residues (by both farmers and herdsmen; hence, reducing the endemic crisis between them), mitigate environmental degradation (example bush burning among farmers), helps in acquisition of emerging skills, partnership with larger corporation and capital acquisition (Strachan et al. 2015). Further, reduces pressure on the government in the provision of infrastructure in the cities as a result of endemic rural-urban migration phenomena experienced in Nigeria.

However, in the context of Nigeria's rural areas, the above mentioned negative impacts may not come to fore, due to the fact that sustainable and affordable electricity provision is currently their major requirements. Nevertheless, as the RETs reach maturity stage in the future, there may be social concerns, similar to what is happening in the UK right now. Already at the moment, there is chaotic youth restiveness in the Niger Delta region of Nigeria (as a result of oil exploration in the region).

2.5 ASSESSMENT of RETs

2.5.1 SWOT Analysis

Based on the secondary data collected from the systematic review as presented in the previous sections and the results of a pilot study, a SWOT analysis has been carried out to assess the potential of various RETs (see Table 2.8). RETs are largely emerging technologies trying to penetrate an energy market dominated by fossil fuel (FF) source. In order for these new energy technologies to get a significant share in Nigeria's energy mix and support the sustainability principle, there is a need to use an appropriate decision support tool such as SWOT analysis approach for identifying appropriate technologies for utilisation by the decision maker, investors and stakeholders.

Furthermore, the use of SWOT analysis involves generic summarising of all factors under a particular section (such as all the energy source's weakness or opportunities) rather than being specific, such as with the PESTLE analysis tool. For example, under strengths all the possible strengths of each competing technology are combined so as to enable decision makers to select from the technologies under evaluation. Table (2.8) details the assessment of six major RETs used globally using SWOT analysis principle to enable decision making.

2.5.2 Sustainability Indicators of RETs in Nigerian Rural Areas

Following the use of SWOT analysis in assessing RETs, this section has screened and ranked these RETs using various sustainability criteria (sustainable development objectives and resource criteria) with a view to identifying the best option for utilisation in rural areas. This is because a RET may not be sustainable if related resources (e.g., water, materials, land) are constrained (Manish et al. 2006). See table (2.9) for details.

In ranking each technology both quantitative and subjective assumptions have been used. Where it is impossible to decide quantitatively, subjective assumption takes place (typical case is social criteria, as effects of some of the technologies is relative to each person).

In ranking each technology, a scale of 1-3 is used to rate individual RETs in relation to each sustainability criterion used, with 3 and 1 being the highest and lowest marks respectively. For example, where the RET resource is continuously available, it scores 3, while partly available is 2 and intermittently available is 1. As shown in Table (2.9), the total score of each RET has been achieved by adding up these individual ratings (shown in brackets). These total scores are then used to rank the various RETs.

Biomass energy ranks first with the highest total score of 23, followed by hydropower, solar, and wind sources with total scores of 22, 21 and 20 respectively. The lowest-scoring technologies are geothermal and ocean energy with a total score of 18 each.

Biomass is already in used in the country but in a traditional form; this method of utilisation requires 'upgrading' to a modern form for sustainable electricity generation in rural areas but there is no record of the use of modern biomass energy in Nigeria, particularly for electricity generation. However, there have been around 30 pilot projects for the biogas energy source, with capacity between 10–30 m3, in the country for cooking purposes (ECN 2005). Also, demonstration farms for energy crop are available in southern Nigeria (Mohammed et al. 2013). This is followed by hydropower energy, especially small hydropower (SHP) source in term of sustainable electricity provision in Nigerian rural areas. Hydropower energy has been the largest RET both globally and Nigeria, contributing around 18% and 25% respectively. SHP been used in Nigeria since 1923 and its potential is evenly distributed across the country. Hence, its utilisation can be extended based on the resource potential.

Solar is the third energy source in term of sustainability in Nigeria, with potential energy generally available all over the country. This source is the most matured among modern RETs currently in use in the country. There is little utilisation experience but it is suitable for rural electrification provision. The fourth RET source is wind, but considering its sustainability indicators in the country it may not be feasible for rural electricity provision. However, it can support grid application, and commercial wind energy of 10MW capacity development is on-going in the country.

These findings are in agreement with previous research (e.g.; Oyedepo 2012; Shaaban & Petinrin 2014; Mohammed et. al. 2013; Sambo 2009) that RETs have the potential of providing sustainable electricity to Nigeria's rural areas. Biomass is the way forward for providing sustainable electricity for rural communities in Nigeria without supply chain problems. This research is the first to assess and optimise subsets of RETs only in Nigeria with a view to being economical and affordable to rural communities. Hence, based on the SWOT analysis assessment and sustainability indicators in the rural areas, biomass resources and technologies will be the adopted subsequently in the study for electricity generation in Nigeria's rural areas.

2.6 CHAPTER SUMMARY

In this chapter, an evaluation of renewable energy technologies (RETs) commonly utilised has been conducted using the principle of SWOT analysis. Similarly, sustainability indicators of these RETs vis-a-vis Nigeria's rural areas were also assessed using sustainable development principles and material resources availability. From these two assessment, Biomass energy system (BES) emerged as the most appropriate RET for providing sustainable electricity to Nigeria's rural areas. Nigerian RETs resources potential, and constraints hampering its growth has been assessed and way forward for sustainable utilisation have been proffered. Subsequently, BES has been adopted for utilisation in the study. The next chapter covers review of different biomass feedstock, conversion technologies, and their sustainability benefits.

Table 2.8: Summary of SWOT Analysis of RETs

	WIND ENERGY		
STRENGTHS	**WEAKNESSES**	**OPPORTUNITIES**	**THREATS**
Reduces GHG emission by ~98% when	-Experience intermittency and idleness	-High turnover-US$ 75 billion in 2012 as	-Landscape distortion
compared with coal	-Good resource location restriction	as against US$ 3.9 billion in 2000	-Bird deaths and displacement
Major source of RET after hydro source	Many experience high transmission line	-Uses of flown turbines (Kites) as wind	-Noise
Cost competitive with fossil fuel source	cost because good resources are located	speed at jet stream are high	-Growth decline in the last 3 years
Zero fuel utilisation	far from energy demand centres	-Use of Aluminium conducting secure	-Installation error
Generally available	-Low energy efficiency (24-54%)	anchored in space generating wind power	
Contributing over 3% of global power energy	-Low capacity factor (21%)	Installed capacity doubling every 3 years	
Use in about 100 countries	-Cannot produce base load		
	SOLAR ENERGY		
-Reduces GHG emission by ~95% when compared with coal	-Experience intermittency and idleness	-Experience unit cost priced reduction (between 20-30%) in 2012 alone	-Removal of incentives in 2008 in some European countries such as Spain
-Extremely modular	-Most expensive among RET sources	-Proposed advance application of	-General policies uncertainties
-Require little/no maintenance cost	-Low energy efficiency (<22%)	satellite and ground solar farm (such as	-Saturation of local grids particularly in Europe
-Zero fuel utilisation	-Low capacity factor (19%)	satellite power system, Desertec)	-Market saturation
-Contribute around 100GW of global electricity energy in 2012	-Cannot produce base load		-Fierce competition (over 100 organisations closed up between 2011-2013)
-Generally available	-Deployment is quite small considering global		-A lot of Companies went bankrupt
-Highest global energy potential capacity (170,000 TWh/year)	potential		
	HYDROPOWER ENERGY		
-Reduces GHG emission by ~96% when compared with coal	-Partially intermittent especially tropical and Amazonian reservoirs	-Can be started and stopped at any time and are modular in nature	-Declining hydro dam construction because of resistance from habitats and pressure
-Largest source of RET (contributing over 16% of global total electricity generated in 2012)	-May be responsible for earthquake	-More new electricity generation from BRICS and other developing countries as witness in 2012	-Effect on biodiversity
-Cheapest form of RET/unit of electricity	-Location specific		-Effect on water quality and hydrological regimes
-Zero fuel utilisation	-Displacement of populations		-Climate change effect
-Most available, reliable and flexible form of RET	-Declining fisheries		
-Can provide base load and peak load	-Partially Low capacity factor (20-70%)		
-Most energy efficiency among RET (>90%)			

	GEOTHERMAL ENERGY		
-Continuous available energy source	-Resource tapping is unsustainable	-Electricity generation is expected to rise	-Rivers and lake pollution
-Has the highest capacity factor (>90%)	-Lowest energy efficiency among RET (10-20%)	because of improved technology	-Cause land subsidence
-Cost competitive with fossil fuel sources	-Growing capacity is low	(Enhanced Geothermal System) by 2015	-Operation can induce micro seismic
-Can provide base load and peak load	-Lowest global potential among RET		
-Can provide 17% of global electricity needs	-Location specific		
	-Low potential for further expansion–using convention geothermal technology		
	-Highest source of GHG emission among RET		
	(6 times that of wind energy)		
	BIOMASS ENERGY		
-Generally available	-Deforestation (as result of land-used expansion)	-Arid land plantation can increase soil carbon	-Could worsen global climate change
- Carbon neutral (Reduces GHG emission by ~95% when compared with coal)	-Application causes food price increase	-Develop international policy mechanism for sustainable land use	-It is not naturally available (majority of the resources have to be sought)
-Good capacity factor (60-70%)	-Food usage for energy generation	-High priority to none/less land bioenergy	- Continuous expansion leads to displacement of
-Cost competitive with fossil fuel source	-Highest land utilization among RET	- Strengthen sustainability requirements and	communities
-Continuous source of energy		certification schemes	-Water scarcity
-Generate more employment than fossil fuel energy source/TJ energy	-Low return on investment when biomass is used for energy production		
-Good energy efficiency particularly if its gasification techniques (60-70%)	Huge water utilisation/kWh electricity (around 150-260kg/kWh)		
	OCEAN ENERGY		
-Generally available	- Location specific	-Enjoying policy support particularly in Europe	-Experiencing pressure from environmental campaigners
-Energy potential more than humans' needs	–Low capacity factor (23%)	-Has no significant impact on environment	-Ecological concern
-Highly dependable and predictable	-Lowest total installed capacity among RET		-Effect on ocean wild life
–Continuous energy source	(only 0.53 GW in 2012)		
-Reduces GHG emission by ~95% when compared with coal	-Most expensive after solar energy form of RET/unit of electricity		
-Good energy efficiency particularly if its gasification techniques (60-70%)	-Faces Engineering challenges		

Table 2.9: Sustainability Indicators of RETs in Nigeria's Rural Areas

CRITERIA	Wind	Solar	Hydro	Geothermal	Biomass	Ocean (Tidal)
ENVIRONMENT						
Green house emission (g/kwh)	25 (3)	90 (2)	41 (3)	170 (1)	70 (2)	41 (3)
ECONOMY						
Price -cost/kwh (US$)	0.07 (3)	0.24 (1)	0.05 (3)	0.07 (3)	0.06-0.08 (3)	0.12 (2)
Energy Efficiency (%)	24-54 (2)	4-22 (1)	>90 (3)	10-20 (1)	60-70 (2)	55-75 (2)
SOCIAL						
Visual, displacement, Noise, Pollution, Seismic etc	Visual, Noise & Bird strike (3)	Toxins & Visual (3)	Displacement health, Agric & Earthquake (1)	Seismic, Noise, pollution, odour (1)	Food shortage, biodiversity loss, more labour used (2)	Effect on marine life, visual (2)
RESOURCES						
Water consumption(Kg/KWh)	1 (3)	10 (3)	36 (2)	12-300 (1)	150-260 (1)	28-40 (2)
Land use/TWh	72Km^2 (2)	28-64Km^2 (3)	73-750Km^2 (1)	18-72Km^2 (3)	462Km^2 (1)	73-750Km^2(1)
Continuity of resources	Intermittent (1)	Intermittent (1)	Partly Intermittent (2)	Continuous (3)	Continuous (3)	Continuous (3)
Resources availability type	Location specific (1)	General (3)	Partly Location specific (2)	Location specific (1)	General (3)	Location specific (1)
OTHERS						
Nigeria potential (TWh/year)	1 (1)	17,702 (3)	58 (3)	NER (1)	225 (3)	41.7 (1)
Capacity factor (%)	21 (1)	19 (1)	20-70 (2)	>70 (3)	60-70 (3)	23 (1)
Total Score	**20**	**21**	**22**	**18**	**23**	**18**
Rank	**4**	**3**	**2**	**5**	**1**	**5**

Note: NER=No Existing Record; Numbers in the brackets represent (scores), other numbers/statements are raw data

CHAPTER THREE

BIOMASS ENERGY SYSTEMS

3.1 INTRODUCTION

This chapter discusses in detail various forms of biomass resources and biomass energy conversion technologies (thermo-chemical and biological). The discussion covers operating principles and stages of development of the technologies, together with their merits and demerits. Furthermore, sustainability indicators related to each conversion technology and biomass feedstock have been explained. This is to serve as a basis for selecting appropriate biomass feedstock and conversion systems for use in this study.

3.2 BIOMASS RESOURCES

Biomass resources are renewable in nature and represent the only organic petroleum products substitute (Zheng et al. 2010) being obtainable from animal materials (waste derived from human and animals) and plant materials (forestry and agricultural products like wood, waste derived from wood and agricultural processes) (Ramage & Scurlock 1996). Biomass is an energy source available almost everywhere in the world existing in different forms. It is organic comprising mostly plant derived materials, capable of being transformed to different forms of energy, and can quickly be regenerated in different environments (Evans et al. 2010).

A majority of the rural population in developing countries (over 50% of the total world population) depends on biomass resources. However, only 3% of the available biomass is consumed as primary energy in industrialised nations, whereas it represents 35% of primary energy consumption in developing nations (Demibras 2001).

Application of biomass for electricity generation has increased consistently by an average of 13TWh (tera-watt hour)/year between 2000 and 2008 (Evans et al. 2010). Breeze (2014) and Martinot (2013) reported that, by the end of 2012, the global total installed capacity of biomass energy systems (BES) was 83 Giga-watt (GW) representing 1.2% of electricity generated globally. BES is projected to reach 120 GW by the end of 2020. Breeze (2014) stressed that "Potentially, however, the industry could become much larger if biomass resources that have so far remained untapped were brought into use". This prediction has partially been achieved; by the end of 2014, bio-power global capacity had increased to around 93 GW, and in the same period, all the existing bio-power systems together produced around 1.8% of global electricity (REN21 2015). See sub-section 2.2.5 (biomass energy strengths) for details.

Ramage & Scurlock (1996) stated that "the earth's natural biomass replacement represents an energy supply of around 3000 EJ (3×10^{21}) a year, of which just 2% is currently used as fuel". This is further supported by the United Nations Conference on Environment and Development that biomass has a potential of supplying approximately half of the current world population with their primary energy needs by the year 2050 (Demirbas 2001).

3.3 BENEFITS OF BIOMASS ENERGY SYSTEM UTILISATION

The benefits of BES over other renewable systems include: is a continuous available energy source; it is combustible based technology, hence, existing fossil fuel (FF) plants find it easy to utilise biomass fuel with minor adjustment (Breeze 2014). Mahapatra and Dasappa (2012), argued that BES has significant advantages over solar PV system, in that it only requires additional fuel as operational hours increases, but "the increase in its load demand does not require increase in the gasifier rating, as the gasifier turndown ratio is quite high". In the case of solar PV "as the operational hours increase, the system size also increases and consequently, its capital cost". Burning waste for energy reduces 60-90% of the trash dumped in landfill sites, and also reduces landfill costs (Demibras 2001). According to Breeze (2014) and Shunmugam (2009) BES is considered to be a greenhouse gas (GHG) neutral energy source. See further details in sub-section 2.2.5 (biomass energy strengths).

Bocci et al. (2014) reported that the major drawbacks of the biomass application are its dispersion over a wide range of locations, inefficient small power generating plants with less than 7,000 operating hours annually, an overall efficiency of less than 25%, and has high environmental and local impacts through emission of pollutants. Also, biomass resources have low energy density, along with potential supply chain difficulties (often in competition with food and materials production) (Evans et al. 2010).

3.4 BIOMASS RESOURCE FORMS AND APPLICATION

Biomass has different forms of resources available for electricity generation, which are classified into three main sections as shown in table (3.1). For the purpose of this study, biomass resources have been classified as forest (plant) products, energy crops, and biomass residues (such as logging and urban wastes). Biomass resources are produced mainly from wood and wood waste, municipal solid waste, agricultural waste, and landfill gases, each representing 64%, 24%, 5% and 5% of the mix respectively (Demirbas 2001).

The choice of biomass resources for energy application is influenced by the following factors: conversion systems availability and efficiency, required energy type, significant availability of resources, appropriate physical properties (lower moisture content, high bulk density) and chemical properties (good calorific value, low ash-content, high carbon to nitrogen ratio and high volatile substance). See table 3.2 for details.

There are basically two types of biomass to energy sources including modern and traditional biomass. From the total installed capacity of 55 EJ contribution of biomass source by the end of 2012 to the global primary energy supply, around 18.5 EJ was from modern Biomass and the remaining 36.5 EJ was from the traditional Biomass. Also, as at 2011, it was estimated that renewable energy's contribution to the global total energy consumption pattern was 19%, around half of which was from traditional biomass (Martinot 2013). Previously (by the end of 2008), the capacity of modern and traditional forms of Biomass was around 4.6 EJ and 45 EJ respectively (Moriarty & Honnery 2011), indicating that the modern biomass system is aiming to replace the traditional system. The sustainable application of these (biomass) resources to modern systems will reduce end-losses of heat and also reduce GHG emissions.

Table 3.1: Biomass resources Forms (Adopted from: Demirbas 2001)

Forest Products	Energy Crops	Wastes
-Wood -Trees, shrubs and wood residues -Sawdust, bark etc from forest clearings	-Short rotation wood crops -Herbaceous woody crops -Grasses, Miscanthus -Starch crops (corn, wheat) -Starch crops (cane & beet) -Forage crops (grasses, clover) -oil seed	-Agricultural production wastes -Agricultural processing wastes - Logging residues -Mill wood wastes -Urban wood wastes (like construction) -Urban organic wastes (MSW)

3.4.1 Forest products

Plants are the commonest biomass materials used as 'fuel' for generating electricity (Evans et al. 2010; Demibras 2001) and are typified by trees, shrubs, herbs, grasses, and mosses. Hence, plants cut across the forms of biomass resource as shown in table (3.1) but the most form utilised for energy generation is the lower-moisture content wood and wood waste and dedicated energy crops (Mckendry 2002).

Wood

According to Demirbas (2001) wood fuels are obtained from forestry plantations and natural woodlands and include fuelwood, charcoal, sawdust and other wastes derived from wood processing and forestry activities. Wood's composition is a combination of cellulose (43%), lignin (36%) and oxygen (22%), with dry wood yield typically 52% carbon, 6.3% hydrogen, 40.5% oxygen and 0.4% nitrogen (Demirbas et al. 2009). This composition results in a calorific value (energy content or heat value) that, as with other biomass materials, is released when subjected to combustion, and is largely dependent on the carbon and hydrogen ratio, which are the major contributors to the biomass material heat energy value (Mckendry 2002; Demirbas 2001). A good wood fuel should have a density between 400 and 900 Kg/m3 and an energy content between 4200 and 5400

Kcal/kg, or a low heating value (LHV) of approximately 19 MJ/kg (see table 3.2 for re details). More so, wood has the lowest ash-content and is the most efficient fuel among the biomass forms utilised in thermo-chemical conversion systems (Bocci et al. 2014).

Gan & Smith (2006) opined that "Woody biomass energy is renewable and carbon neutral, namely its net carbon emissions are close to zero". From this, it implies wood fuel is a renewable source except that its utilisation has to be sustainably managed. Nigeria has a significant amount of this fuel source (see sub-section 2.3.5), hence its utilisation being considered for economic assessment using the whole life costing (WLC) analysis approach adopted in this study.

Table 3.2: Selected Biomass Resources: Chemical and Physical Properties (adopted from: Mckendry 2002; IRENA 2012; Bocci et al. 2014)

	Physical Properties		Chemical Properties			
Biomass Materials	Bulk Density kg/m3	Moisture Content (%)	LHV (MJ/kg)	Ash Content (%)	Volatile Matter (%)	Carbon Content (%)
Wood	400-900	<15	18-21	1	82	17
Cereal Straw	20-140	07-12	15-18	05-15	67-76	15-18
Shell	300-500	11-14	18-20	1-2	74-78	20-25
Rice Husk	35-50	12	16	<20	-	-
Guinea grasses	50-170	7	17	5	-	-
Bagasse	40-75	<50	16	3.5	-	-
Miscanthus	240	4	18	5	71	19
Poplar	320-550	45	18	2.1	-	-
Willow	320-550	60	18.5	1.6	-	-

3.4.2 Energy Crops

Energy crops "are crops grown specifically for the purpose of producing energy. These include short rotation plantations (SRP) such as eucalyptus, willows and poplars, herbaceous crops (like sorghum, sugarcane and artichokes), and vegetable oil bearing plants such as soya beans, sunflowers, cotton and rapeseed" (Demirbas 2001) and non-woody recurring grasses, such as miscanthus (Evans et al. 2010).

Energy crop production is an agricultural-based system related to recurring cropping systems utilised by modern farmers but with speciality requirements in terms of planting and harvesting equipment (Abrahamson et al. 2002).

Table 3.3: Energy Crops Nursery and SRP operations (Rafaschiri et al. 1999)

Operation	**Nursery**			**SRF**							
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Ploughing	1			1							
Field dressing	1			1		1		1		1	
Harrowing	1			1							
Cuttings planting	1			1							
Herbicides field distribution	1	1	1	1		1	1	1	1	1	1
Surface dressing	1	1	1	1	1	1	1	1	1	1	1
Herbicides local distribution	2	2	2	2	2	2	2	2	2	2	2
Cultivating	4	4	4	4	2	4	2	4	2	4	2
Antiparasitic agent application	2	2	2								
Surface Irrigation	2	2	2	2	2	2	2	2	2	2	2
Nursery tree harvesting	1	1	1								
Nursery tree transportation	1	1	1								
Cutting preparation	1	1	1								
Biomass harvesting					1		1		1		1
Tree levelling			1								1

Rotation periods for such crops are usually between 3-10 years (Goor et al. 2001). The production cycle typically starts with a three year period of nursery activities, although harvesting can start at the end of the second year particularly for poplar crops that can sustain a cycle of harvesting every 2 years (Rafaschieri et al. 1999). Heller et al. (2004) stress that willow selected for cultivation should be planted in a double row system of 15,300 trees/ha with a harvesting period of surface (above ground) stems biomass occurring every 3-4 years over the winter periods.

As wood plants are characterised by slow growth, high lignin and hard external surfaces, short rotation crops are normally recurrent, with a lower lignin proportion making their fibre more loosely bounded. Lignin and cellulose's relative proportions are among factors considered in determining the suitability of plant species for processing as energy crops (Mckendry 2002).

SRP can be in different forms and converted into various energy forms. Many species are multipurpose and can be utilised to produce more than one energy product form. Typically, hemp can be used as both solid biomass and oil. Similarly, cereal can be used to produce ethanol and their straws used as solid biomass (Sims et al. 2006). Majority of SRP such as willow and poplar have good ash-content and good LHV (energy content) similar to woody plants but generally of high moisture content; while the miscanthus plant has good low moisture content but reasonable ash-content compared to wood. See table (3.2) for further details.

Sim et al. (2006) estimated the technical potential for energy crops as 400 EJ/year by 2050. However, the economic potential estimates suggest energy crops will be between 2 and 22 EJ/year by 2025 and can eventually offset between 100-2070MtCO2-eq/year. Energy crops characteristics includes: high yield, low cost, low energy input to produce, low nutrient needs and waste with the least contaminants. The actual characteristics will be determined by the soil conditions, local climate and level of water consumption (Mckendry 2002).

The kind of energy crops adopted in various part of the world varies based on the energy policies and natural factors (such as soil and climatic conditions). For example, Europe is concentrating on short rotation crops such as willow, poplar and forestry residues. While USA and Brazil are concentrating on cereal plantation (wheat, oats, maize and rye) for ethanol production from the grains, and the straw 'wastes' are used as solid biomass. Tropical climates allow starch and sugar crops (potato, sugar beet, sugarcane) to be grown. In this case Brazil is the leading country producing large scale ethanol from starch and glucose through a fermentation process. This is used directly as fuel or blended with gasoline (Mckendry 2002; Sims et. al. 2006) but can be applied for electricity generation as well.

According to Breeze (2014) the energy crop yields of switch grass, poplar, willow and forest biomass range between 7.7–14.3, 8.1–12.8, 10.1–11 and 2.5 dry tonnes/ha/year respectively. While Rafaschieri et al. (1999) reported that realisable biomass yield is projected to be 20 Mg/ha/year (with wet content) and net quantity of dry biomass is 16 Mg/ha/year as a result of natural seasoning. Also table (3.4) presents the crop yield, energy yield and economic (global average cost) of some selected biomass resources for comparison.

Table 3.4: Energy yields and average cost from selected biomass (McKendry 2002; Walsh et al. 1999)

Biomass	Crop Yield (dmt/ha/a)	HHV (MJ/kg, dry)	Energy yield (GJ/ha)	Cost range US$ (per ton)
Wheat	7 grain/7 straw (14 total)	12.3 (straw)	123	50
Poplar	10-15	17.3	173-259	39-60
SRC Willow	10-15	18.7	187-280	39-60
Switchgrass	8	17.4	139	35-60
Miscanthus	12-30	18.5	222-555	50
Forest wastes	-	-	-	15-25
Corn stover	-	-	-	20-40

The area of land needed for energy crops should be carefully determined based on criteria such as technical, economic and social issues. The preferable sites for production are uncultivated land with low financial value (Rafaschieri et al. 1999), but also having good land drainage and only slight surface variations (as excessive variations make mechanisation of short rotation crops difficult) and slows land drainage, thereby reducing roots oxygen availability which compromises biomass yield.

Currently, Nigeria's climate allows production of starch and sugar crops and large cereal production all over the country particularly in the northern region. This is an opportunity for biomass resources production. Similarly, some of these crops are currently being planted in Nigeria for other applications (food and materials). Consequently, there are SRC demonstration projects in the country for energy purposes sponsored by both government and private organisations (Mohammed et al. 2013; Ajayi & Ajayi 2013). More so, biomass development policies, as obtained in USA, Europe and Asia, should be strictly adhered to, so as to achieve SRP sustainable production and utilisation particularly in developing countries (Miyake et al. 2012).

3.4.3 Biomass Wastes

Biomass wastes can be classified into four segments: wood waste, agricultural waste, animal waste and municipal solid waste (urban waste) (Demibras 2001; Breeze 2014). See table (3.1) for details.

Residues are waste that remains following processing of a higher value product from the original materials. Biomass wastes are cheaper materials per electricity unit produced since there is little or no cost for procurement, especially when minimal transportation requirements are involved (Evans et al. 2010). However, it is a misconception to believe that wastes are free energy fuel as procurement involves cost of handling and treatment (FAO 2015).

The benefit of using biomass waste is to redirect it from landfill sites or other means and can be obtained at little or no cost beyond any handling / treatment costs. Burning it efficiently can result in relatively little quantities of ash at the same time useful for electricity and heat generation (Demirbas 2001; Bridgwater et al. 2002).

Biomass wastes are generally available, but can only supply a limited global energy capacity (Breeze 2014). The above is supported by Mckendry (2002), that the projected global potential of agricultural and forestry waste resources could be around 30EJ/year as against total global annual energy demand of around 500EJ by the end of 2014 (Martinot 2015). However, Sims et al. (2006) stress that by the end of 2005 "residues from industrialised farming, plantation forests and food and fibre processing operations that are currently collected worldwide and used in modern bioenergy conversion plants contain approximately 9EJ/year of energy. Current combustion of over 130Mt of municipal waste annually provides a further 6 EJ/year (although this includes plastics, etc)".

Wood and Logging Residues

There are several sources for this residue type including forestry residues (logging and timber stand improvement operations), sawmilling, plywood and particle board production, construction activities residues, woody yard trimmings, and other wood wastes destined for landfill (Heller et al. 2004).

When contemplating whether or not the application of wood waste is economically viable for heat or power generation, the following factors have been suggested by FAO (2014) for consideration:

- "Present day and projected future costs of traditional energy sources and their availability";

- “Energy requirements of the plant (heat and electricity)”
- “Availability and reliability of residue supplies, their cost, type, size, moisture content and proportion of contraries”
- “The capital cost of equipment needed to collect, process and combust the wood residues”
- “Disposal cost of residues”
- “Resale value of the residues as a raw material for panel board or pulp manufactures”, among other factors.

Logging residues are one of the major resources of woody biomass and are obtained through conventional forests, with availability depending upon the ratio of timber harvested in relation to logging residues. The following factors influence timber harvests: market condition, forest inventory and environmental policies, among other factors (Gan & Smith 2006).

It is a common practice for around two-thirds of the trees to be left in the forest and some other species which are not of economic value to be slash, burn and/or felled and left unattended to rot (FAO 2005). This means logging residues resources are still adequately available, although FAO suggested that with adequate training and provision of appropriate tools, tree harvesting productivity can be improved. According to an estimate in USA, for every 1,000 cubic feet of harvested timber, 2.3 tons of logging residues are available (EPA Biomass CHP Catalog 2004).

Biomass procured from logging residues is cost effective compared to the cost of energy plantations (Gan & Smith 2006), see details in table (3.4). This may be connected with the high establishment and management costs of energy crops, which are higher than those of forest residues (Verdin et al. 2009). However, Fan et al. (2011) argued that the procurement of logging residues for biomass electricity generation is higher than energy crops considering production cost vis-à-vis transportation cost. Generally, logging residues are expensive to collect and transport to the power plant (Breeze 2014). All of these add up to the production cost; as such logging residue may only be used in situations where biomass fuel demand is high and transportation cost / distance travelled are less; perhaps mainly used on the site, such as sawmills where the residues are generated and utilised.

The constraints experienced in the application of logging residues for electricity generation among others include requiring a sustainable supply over a long period of time, high transport cost over long distance (considering low bulk density and energy content), unrecovered logging residues due to accessibility limitation, and unavoidable procurement processes loss (Gan & Smith 2006). Also, due to characteristics of the logging residue (relatively small and scattered pieces of wood) and the resulting requirement for special harvest equipment and intensive labour, it is not feasible to convert all the resources (Verdin et. al. 2009).

Agricultural Residues

Agricultural residues (AR) are wastes generated from agricultural harvesting and processing and are among most valuable biomass resources today as they are universally available. More so, as long as human beings exist, this form of waste will always be available. Hence, they are sustainable and renewable.

AR produced during harvesting and processing have good electricity fuel potential; rice produces straw during harvesting and husks during processing (as do maize and wheat), while other AR are mainly produced at the processing stage, for example sugarcane. Corn stover and wheat straw are the agricultural residues mainly used for energy production (EPA CHP Catalog 2004). Breeze (2014) asserts that "the shells and husks from coconuts can be used to generate electricity as can waste from oil palms, while the periodic recycling of oil palms and rubber trees (plantation trees have a life of 20–30 years) can provide wood waste for power generation". Other forms of AR include sugarcane bagasse, groundnut straw and shells among others (Evans et al. 2010; Demibras et al. 2001).

Biomass wastes have been used in so many places for electricity generation and other energy applications. For example, approximately 40% of electricity generated in Denmark is from waste wood, animal waste and straw through biogas process; also, 10% of electricity generated in Finland is from saw dust, forest residues and pulp liquors (Sims et al. 2003). Similarly there is increased straw waste utilisation in Sweden, and it has contributed approximately 17% of the national energy needs, and cost of the waste has dropped significantly (Demibras 2001).These best practices can be replicated in other places particularly in Nigerian rural areas where these types of fuel are largely available and there is a significant electricity deficiency. Further, considering these fuel types normally have disposal costs, waste conversion to electricity can be economical and have good market potential specifically in the rural areas where biomass is mostly located.

AR are generally of good low moisture content and good calorific value. However, AR contains more ash-content and has lower bulk density than other forms of biomass (Bocci et al. 2014) which slightly affects their energy content (see table 3.2). More so, these waste fuels are low value and low density while transportation cost can result in expensive electricity per unit produced (Evans et al. 2010). Hence, for sustainable and viable AR utilisation, the residues must be located close to the power plant or on-site application as obtained in rural areas and it must be in abundant in the area (Breeze et al. 2014). Furthermore, Thornley (2006) argued that AR have quantity limitations, are location specific and not good quality for generating power. Also, they have a seasonal problem in that they need storage if they will be used all year round for generating electricity (Breeze 2014). However, dispersion of biomass over wide areas makes it an excellent potential fuel for providing sustainable distributed electricity to rural areas (Sims et al. 2003).

Furthermore, use of organic wastes can mitigate concerns of the production of biomass resources displacing food production (the food versus fuel debate). Breeze et al. (2014) stressed that for sustainable practice in using AR as fuel for generating electricity, there is the need for some biomass materials to be returned to the soil after harvesting for it to retain its fertility. Total removal of biomass material will require artificial fertiliser; and this may result in unsustainable practice.

Animal Waste (Manure Biogas)

Animal wastes are used to generate biogas, which results from manure's decomposition anaerobically in a digester. Given the processes associated with animal husbandry, anaerobic digesters are used to reduce odour and pathogens (EPA Biomass CHP Catalog 2004), and the resulting biogas can be utilised for energy purpose. Animal wastes are largely located in rural areas, hence, it is suitable for electricity generation in these communities.

Given that Nigerian rural communities generally depend on farming (Rahman et al. 2013; ECN 2005) and largely live below US$ 1.25/day (UNICEF 2011) with a low energy consumption pattern (Sambo, 2009), the use of low-value biomass (animal, agricultural and forest residues) and wood are considered as fuels in this study, given the resources potential as explained in section (2.3.5). This is because energy crops are still considered emerging sources and are therefore somewhat more expensive than the biomass residues which are procured largely in rural areas at little or no cost.

3.5 APPROPRIATE FUELS FOR BIOMASS CONVERSION SYSTEMS

There are several conditions to be met in selecting appropriate biomass feedstock especially organic wastes. The first criteria used in the selection of feedstock to be used in biomass, particularly thermo-chemical systems, is the significant availability of low moisture content feedstock; then size and shape of the feedstocks are also important factors in order to ensure uniformity, consistency and efficiency of the gasifier (Bocci et. al. 2014), with efficiency being a key factor in the operating cost of the whole process.

For a gasification system (GAS), the most suitable biomass resources in Nigerian rural areas are wood, wood waste, and organic wastes (agricultural and forestry). This is because of their characteristics such as less chlorine and sulphur content, less ash content, high volatile elements and high caloric value. They are also readily available, with high density and low moisture content (see table 3.2).

Woody biomass is the most appropriate source (see section 3.4.1) and has a more stable chemical composition compared to other biomass resources such as municipal solid waste, hence why it is mostly required for utilisation. Also, over 80% of wood is volatile and the remainder 20% is charcoal. While coal has only 20% volatile material and the remainder is unreactive coke (Bocci et al. 2014). Wood base biomass have low ash content less than 2%, hence suitable for fixed bed gasifiers (Asadullah 2014).

Also, wood waste has similar features to wood, hence it is suitable for utilisation, but with the better advantage of being largely available in pieces or chip form, thereby reducing the cost of cutting to small (efficient) sizes. According to Asadullah (2014) a certain amount of agricultural residues such as maize cobs and coconut shells are the most recognised and unlikely to create problems when used in fixed bed gasifiers. Also, palm kernel shell is suitable for GAS. Conversely, some fibrous biomass materials such as coconut husk are reported to have associated problems in the feeder section though, they can be used in the gasifier after pre-treatment. Rice husk has the highest ash content representing over 20%, and perhaps the most difficult biomass to use with GAS. The utilisation of these feedstocks for generating a unit of electricity (kWh) in GAS will require between 1.1 – 1.5 kg (wood), 0.7 – 1.3 kg (charcoal) and 1.8 – 3.6 kg (rice husk) (Dimpl 2011; Mahapatra & Dasappa 2012).

In the case of pyrolysis, largely wood is the most suitable feedstock for bio-oil production, except for fluidised bed pyrolysis systems that use wood residues in this respect (Bridgwater et al. 1999). Refer to the paragraphs above for justification in selecting wood and wood waste.

Direct combustion (DC) systems accept all form of biomass fuels such as wood chip, pellets, bark and saw dust. Considering that developing nations rural areas' power energy requirement is low and usually evidences little growth, biomass materials such as agricultural residues of rice husk and nutshells can meet the fuel needs of DC systems (Demirbas 2001). For better DC system efficiency, low moisture content feeds such as wood and wood waste should be used. Thus, a pre-drying phase, as applied to other thermochemical conversion systems, of the feedstock is highly recommended prior to combustion (Gonzalez et al. 2015; Bridgwater et al. 2002). However, it is noteworthy that this has a financial implication through increasing the capital cost of the system along with different DC system capacities requiring varying fuel consumption patterns.

The following biomass resources are particularly suitable for biogas generation in Nigeria: animal dung (a kilogram of fresh animal waste around 0.03m3 of gas can be generated (Shaaban & Petinrin 2014)), cassava leaves, sewage, water lettuce, water hyacinth, agricultural residues and MSW (Akinbami et al. 1996), and it is noteworthy that better biogas resources are produced through the mixing of different forms of wastes (IRENA 2012).

Given some biomass feedstocks only exist on a seasonal basis (particularly the agricultural base residues in developing countries) and that short rotation crops are harvested every three years, the problem of regular supply can be resolved either through extensive storage facilities or utilising reactors that can accommodate diverse feedstocks (Bridgwater et al. 2002).

3.6 BIOMASS ENERGY CONVERSION TECHNOLOGIES

This section reviewed various technologies to convert biomass resources to electricity including thermo-chemical (direct combustion, gasification and pyrolysis) and biological (anaerobic digester) processes.

3.7 GASIFICATION TECHNOLOGY

Gasification is a thermo-chemical process that converts biomass through partial oxidation into a gaseous mixture of syngas consisting of hydrogen (H2), carbon monoxide (CO), methane (CH4) and carbon dioxide (CO2) (Wang et. al. 2008). In other words, it is basically a conversion of biomass fuels into a gas mixture ready for combustion (Dimpl 2011). The Product Gas (PG) is fed into Internal Combustion Engines (ICE) or Micro Gas Turbines/Fuel Cell to generate electricity (Bocci et al. 2014).

The major combustible elements of the PG are hydrogen, carbon monoxide and methane constituting approximately 40% of the gas (Breeze 2014; Mukhopadhyay 2004; Demirbas et al. 2009). The PG mixture has high calorific value (Bain et. al. 1998). However, Dimpl (2011), Breeze (2014), Bocci et al. (2014), and Manish et al. (2006) all agreed that PG is of low calorific value containing between 4-6 MJ/kg compared to other fuels such as natural gas (35-50 MJ/kg) due to high nitrogen presence in excess of 50% and other non-combustible elements. They further stressed that, through more reactions, additional hydrogen from carbon monoxide can be achieved if required. Typical chemical composition of PG by volume is: carbon monoxide (27%), hydrogen (14%), methane (3%), carbon dioxide (5%), oxygen (1%) and nitrogen (51%) (Breeze 2014).

Gasification technology is basically suitable for small power plants ranging from 10 kW to over 100 kW (Dimpl 2011) and has been fully commercialised. While for applications of over 1 MW, only a fluidised gasifier configuration is considered suitable (Bridgwater 2002). IRENA (2012) slightly differs from the above as shown in figure (3.1).

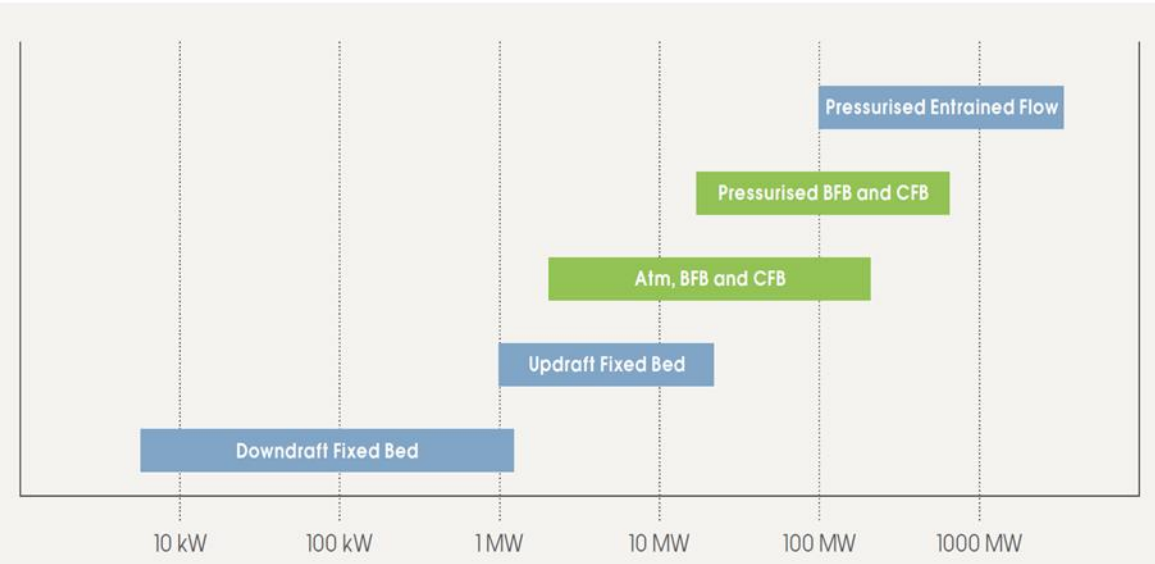


Figure 3.1: Gasifier reactor capacities by forms (IRENA 2012)

The gasification conversion process is mostly for plant biomass particularly wood (Evans et al. 2010). This is because it is the predominant resource utilised (other agricultural and forestry residues can undergo this process and are already used) representing approximately two-thirds of the total biomass resources (Demibras et al. 2009). Also, because of its properties such as low ash and low tar residues if burnt at a low moisture content, the gas cleaning process (GCP) is usually not necessary and sometimes not included in the processes (see figure 3.2). GCP main duty is to remove contaminants (like particulates and tars). See section (3.8.3) for detail. Mukhopadhyay (2004) opined that through the use of internal combustion Engine (ICE), solid biomass and their residues can be conveniently converted to high quality gaseous fuel.

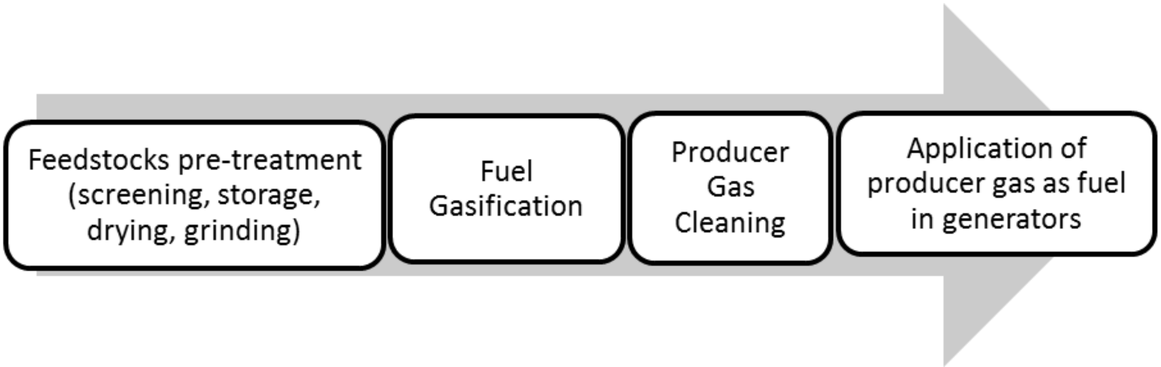


Figure 3.2: Gasification Processes for Electricity Generation (Adopted from: Demirbas 2009; Bocci et al. 2014; IRENA 2012)

Gasifiers using air as a gasifying agent (GA) are more economical (zero cost), generally available and produce PG but with a large nitrogen content resulting in a low energy content of between 5-6 MJ/m3. However, a steam/oxygen reactive agent based gasifier produces syngas with a high energy content of between 9-19 MJ/M3 as a result of the reasonably high concentration of carbon monoxide (CO) and hydrogen (H2), although at higher cost than the air based gasifiers (IRENA 2012; Bocci et. al. 2014). See table (3.5) for details

Table 3.5: Syngas Composition with Different GA (Bocci et. al. 2014)

GA	H_2	CO	CO_2	CH_4	N_2	LHV (MJ/Nm^3)
Air	9-10	12-15	14-17	2-4	56-59	3-6
Oxygen	30-34	30-37	25-29	4-6	-	10-15
Steam/CO_2	24-50	30-45	10-19	5-12	-	12-20

3.7.1 Gasification Reactors

The main gasification technologies are classified in to three forms: fixed bed, fluidised bed, and moving bed reactors (Demirbas et. al. 2009). This classification is similar to IRENA (2012) except that moving reactors are replaced with Entrained flow gasifiers. For the purpose of this research work both fluidised bed and entrained flow gasifiers will not be utilised because they are mainly for large scale application ranging from 10MW -100MW and 100MW and 1,000MW respectively (IRENA 2012). This study focuses mainly on rural areas electricity (low consumption pattern of mostly dozens of kW capacity).

Fixed Bed Gasifiers

IRENA (2012) describes fixed bed gasifiers (FBG) as gasifiers "that typically have a grate to support the gasifying biomass and maintain a stationary reaction bed. They are relatively easy to design and operate; generally experienced minimum erosion of the reactor body". FBG are designed in three patterns including updraft (countercurrent), downdraft (concurrent) and cross-draft configurations (Bocci et al. 2014; IRENA 2012; Asadullah 2014). See table (3.6) for further details.

3.7.2 Pre-treatment of Biomass in Gasification System

There is the usual requirement to match feedstock from harvest with feedstock for the gasification process given that a fixed bed system doesn't accept all forms of biomass resources like fluidised bed and direct combustion. These key requirements include reception and storage, screening, drying and grinding and densification (Bridgwater et. al. 2002). This sometimes can slightly increase the operational cost of this configuration.

3.7.3 Gas Cleaning Processes

According to IRENA (2012) the gasification process is mainly an endothermic process that needs large amounts of heat. The producer gas (PG) contains a number of contaminants, mostly detrimental to the power generating equipment. Hence, some PG will require clean-up. Typically, the impact of unclean PG is the possibility of blockage of the engine valves and accumulation on turbine blades by tar leading to higher maintenance costs and lower performance (IRENA 2012). Bocci et al. (2014) reported that "Fuel with high ash content requires greater attention because ash brings sintering, agglomeration, deposition, erosion and corrosion problems". Furthermore, the more the ash and tar content, the greater the PG cleaning process problem. In fact, tar shrinks at high temperature, resulting in blockage and damage of the equipment (Bocci et al. 2014), thereby increasing the operating cost.

Table 3.6: Types of Fixed bed Gasifiers (Adopted from: Bocci et al. 2014; IRENA 2012; Asadullah 2014)

Updraft Gasifier	**Downdraft Gasifier**	**Crossdraft Gasifier**
-Biomass enters from the top and gasifying agent from bottom of reactor	- Both fuel and gasifying agent move from the top to the bottom of the reactor	- Biomass moves downward and the gasifying agent is fed at the right angles (through the nozzle). -Usually used to gasify charcoal
- Biomass moving from the top is dried and pyrolysed, giving char which continues to move down to be gasified	- Both the fuel and the oxidant are forced to pass through a narrow (throat) where most of the gasification reactions occur	-Has small reaction zone with low thermal capacity; which gives a faster response time than any of the fixed moving bed. -Simple to construct.
-Producer gas together with tars exit from the top, while ashes and char fall through the grate at the bottom.	- The reaction products are intimately mixed in the unsettled high-temperature region around the throat (1100-1200 ^{0}C), which helps in cracking the tar.	
-The product gas exits from the low temperature pyrolysis and drying zone, and is assumed to be contaminated with substantial amount of tars	- Relatively clean gas and low tar (< 10 g/Nm^3) is reached in this arrangement; even though the particulates in the gas can be high	-Produce gas suitable for any applications.
-Gas contain huge tar content (up to 100g/Nm^3) but less ash, hence suitable for direct firing not for electricity generation	-Biomass residence time in this configuration is high leading to a high char conversion of approximately 95%	-Difficult to operate
-Gas intensive clean up can remove reasonable high levels of tar and other impurities, thus allowing for electricity generation	-Overall energy efficiency is low, because of the high heat content carried over by the hot gas following gas leaving the gasifier at temperature of ~900-1000^0 C	-Using tars and volatiles fuel, can leads to high present of tars and hydrocarbons in the producer gas.
-Suitable for up to 10MW	-Requires homogenous feedstock to achieve excellent output -Mostly utilised for small scale electricity generation with an Internal Combustion Engine -Unsuitable for scale (> 1 MW)	-Considering its low tar production (0.01-0.1 g/Nm^3), a simple gas-cleaning system is required

In the actual sense, the gasification process should only produce a non-condensable ash residue but reality suggests that "incomplete gasification of char and the pyrolysis tars will produce a gas containing varying levels of the contaminants such as particulate, tars, fuel-bound nitrogen compounds and an ash residue containing some char" (Bridgwater 2002).

The adoption of a gas cleaning (secondary) unit can sometimes increase the capital cost of gasification systems, and in some cases, its cost can exceed that of the gasifier unit, and sometimes unavoidable accessories in this kind of system (Bocci et al. 2014).

The PG used in generating electricity has a limitation on the level of impurities concentration that can be accepted by the power plant. While ICE can accept particle concentration < 50mg/Nm3, for gas turbines it is < 30 mg/Nm3. Hence the producer gas needs to be cleaned up for downstream application (Asadullah 2014).

Wet scrubbing is the preferred option for engine power generators such as ICE, because PG must be cool at the point of injection to the engine (gases must be cooled to under 150^0 C and then passed through a wet gas scrubber). This process removes tar, particulates, alkali metals and soluble nitrogen compounds and is an established gas cleaning method.

The hot gas filtration method is the best for turbine systems as the gases are partly cooled to approximately 500^0 C to reduce alkali metal vapours and particulates in the gas. Hot gas is filtered followed gas cooling to remove further particulates and the remaining alkali metals. Hence the gases are delivered to the gas turbine at around 450^0C, at which temperature some tar in the gas vapour can be tolerated (Bridgwater et al. 2002).

There are other means of cleaning up PG including hot methods (thermal crack, cyclone, and catalytic process) and cold methods (dry and wet) (Asadullah 2014; Bridgwater 2002; Bocci et al. 2014).

3.7.4 Gasification Power Production Systems

Electricity generation from small scale gasification plants is almost exclusively via Internal Combustion Engines (ICE), although a few Micro Gas Turbines (MGT) plants also exist. Currently at the development stage, alternatives such as Fuel

Cells (FC), or hybrid MGT/FC power plant, can only provide theoretical data (Bocci et al. 2014).

Internal Combustion Engine (ICE)

ICE has been the technology used for producing electricity from gasification PG because of its reliability and popularity. Considering the poor quality of PG as a fuel when compared with natural gas and gasoline, ICE requires certain design modifications for it to run on PG. Spark ignition and diesel engines are the most used ICE (Dasappa et al. 2011; Bocci et al. 2014), but diesel engines largely need co-fuelling with conventional diesel fuel, while the spark engines can only be operated on generator gas (Dimpl 2011). However, recent developments make it possible for PG to be the sole fuel (100%) on producer gas engine (Bocci et al. 2014). This is also confirmed by some manufacturers during data gathering stage, and indicates advancement in respect of gasification systems technology. ICE has matured and become fully commercialised, with extensive experience globally, but can only operate viably at a capacity less than 1 MW (Bridgwater et al. 2002).

Micro Gas Turbine (MGT)/Fuel Cell (FC)

Higher efficiencies can be reached using MGT, FC or a combination of the two technologies as electricity generation machines. However, MGT and FC systems are essentially still at a pilot stage of development (experimental or complex simulated systems (Bocci et al. 2014; Bridgwater et al. 2002).

In conclusion, the downdraft fixed bed gasifier technology has been selected for gasification system power generation in Nigerian rural areas given their low consumption pattern: basically suitable for small scale power generation ranging from 10 kW to over 100 kW and has been fully commercialised. ICE has also been selected because currently power generation from small scale gasification wholly uses this technology.

3.8 PYROLYSIS TECHNOLOGIES

Pyrolysis involves thermal destruction of biomass in an anaerobic environment, without the addition of oxidant to produce gases and condensable vapours (Evans et al. 2010). In other words, it is the conversion of biomass into liquids (pyrolysis oil), non-condensable gases and by-product char (Fan et al. 2011). The liquid part of the product is the main aim, and has a heat value of about half that of fossil fuel oil (Bridgwater and Peacocke 2000). The char and non-condensable gas can be used as process heat to dry biomass, so there is no waste in the streams (Bridgwater & Peacocke 2000; Fan et al. 2011). More so, considering pyrolysis oil (bio-oil) is a mixture of chemicals in liquid form of which certain chemicals are "soluble in water (aqueous), whereas others are not (organic), so depending on the processing conditions (fast or slow pyrolysis), the oil can be formed by a single phase or by several phases" (Pecha & Garcia-Perez 2015).

3.8.1. Pyrolysis Process Forms

There are basically two types of pyrolysis process including slow/traditional pyrolysis (TP) and fast pyrolysis (FP). The difference between traditional pyrolysis (TP) and fast pyrolysis (FP) is that TP is related to the processes of making charcoal, with operational variables such as slow heating under 10^0 C, large particle size (>2mm), and temperatures ranging between 400-6000 C (Pecha & Garcia-Perez 2015). While FP is the modern and advanced process carefully controlled to provide liquid at high yield. FP has the advantage of decoupling oil generation section from where it will be utilised, allowing it to be stored and/or transported. FP of biomass has reached a commercial level but there are aspects of the technology requiring further research as some processes are still at experimental / pilot stages (Bridgwater et. al. 1999; Ganesh & Banerjee 2001; Gonzalez et al. 2015). The major characteristic of FP is the fast heating-up of biomass feedstock in reactors, in excess of 100^0C with temperatures in the range of 400-650^0 C and with reactors designed to, within 2 seconds, extract and condense vapours (Pecha & Garcia-Perez 2015).

Similarly, Bridgwater et al. (1999) reported on the main characteristics of the FP process as follows:

- "Very high heating and heat transfer rates, which usually requires a finely ground biomass feed" (cutting/grinding them to <2mm size)
- "Assiduously controlled reactor temperature of 500^0C approximately in the vapour phase, with little residence times of the vapour normally less than 2 second"
- Fast cooling of the vapours constituent to provide the bio-oil product".

However, when comparing the properties of petroleum oil and bio-oil, they are actually not the same. This is because bio-oils contain water and an acid/aldehydes content which degrade its value (Pecha & Garcia-Perez 2015).

According to Pecha and Garcia-Perez (2015), the typical product outcomes of FP yields represent between 60-75 wt.% (liquid), 15-25 wt.% (char) and 10-15 wt.% (non-condensable gas). While TP yields represent between 30-35 wt% (liquid), 25-35 wt.% (char) are detected. The vapours do not escape rapidly, and tend to remain in the reactor for 5–30 min". More so, the main properties of pyrolysis oil are highlighted in Table (3.7).

Table 3.7: Properties of Pyrolysis oil (Pecha & Garcia-Perez 2015)

Property	Description
Appearance	Brown to black, depending on the feedstock
Structure	Multiphase structure at room temperature due to the presence of chair particles, waxy material, aquesous droplets, micelles, and water. Greater homogeneity is observed above 60 0C. In poor-quality oil, the oil separates into heavy (organic) and light (aqueous) layers.
Density	~ 1.2kg/L at 20 oC
Kinematic viscousity	Varies greatly: 50-672cst (20 0C), 35-300 cst (40 oC), 5-200 cst (50 0C)
Water content	15-30 wt% From biomass; up to 50 for moist biomass
High heating value (HHV)	20-24.3 MJ/kj (anhydrous), 15-18 (as produced)

3.8.2 Development and Benefits of Fast Pyrolysis

Pyrolysis is an emerging technology, following combustion and gasification technologies in terms of its application for renewable power generation (Demirbas 2001). However, the technology has been in existence since before the time of the Egyptians but in the form of slow pyrolysis (Pecha & Garcia-Perez 2015). Efficiency improvement and cost reduction have been the major reasons for moving away from the application of direct combustion and toward the development of fast pyrolysis and gasification technology (Ganesh & Banerjee 2001; Demirbas 2001).

Biomass decomposition in FP is determined by the rate and extent of the following: the process parameters of reactor temperature, biomass heating rate and pressure. The degree of secondary reaction of the gas/vapour products depends on the time-temperature history to which they are subjected before collection, and also the influence of the reactor configuration. Most woods give up to 80% (by weight) bio-oil yield as obtained on dry feed at 500-520^0 C with vapour presence times not more than 1 second (s) (Bridgwater & Peacocke 2000; Bridgwater et. al. 1999). Bio-oil can be produced with longer vapour residence times of up to approximately 5s and over a wider temperature range, but yields might be affected in two ways: at temperatures above 500^0 C secondary volatiles decomposition will occur, while at temperatures below 4000C condensation reactions in the gas/vapour product will occur (Bridgwater et al. 1999).

Fast Pyrolysis may be the most efficient biomass conversion process and the most suitable method capable of competing with and possibly replacing fossil fuel (FF) energy sources given its efficiency of approximately 70% if flash pyrolysis is used (Demirbas 2001). Pyrolysis is now considered a favourable means of producing renewable and sustainable oil and chemical products, and motivates agricultural economics (Pecha & Garcia-Perez 2015; Demirbas et al. 2009). Pyrolysis oil can be burned directly for electricity generation. Combustion of bio-oil occurs in a gas turbine and engine (Ganesh & Banerjee 2001; Fan et al. 2011; Demirbas 2001).

3.8.3 Pyrolysis Reactors Configuration

According to Bridgwater et al. (1999) basically, there are three technologies for achieving fast pyrolysis:

Ablative Pyrolysis

- Wood is pressed against a heated surface
- Quickly moved and allowed the wood melts at the heated surface and oil film is left behind which eventually evaporates
- Larger particles size of wood are used
- Constraint by the rate of heat supply to the reactor leading to compact and intensive reactors that require not carrier gas;
- Has drawbacks of a surface area controlled system and high temperature of the moving parts

Fluid bed/Circulating fluid bed Pyrolysis

- Heat transferred to biomass is through a combination of convection and conduction means
- High heat transfer rates but normally within the particles; hence, small particles of size not exceeding 3 mm is required in order to obtained good quality yields.
- Extensive carrier gas is required for transport or fluidisation.
- Also uses by-product gas and char to provide the process heat.
- Waste wood can be processed using this configuration
- Very good solids mixing
- Simple reactor configuration
- The most popular configurations due to their ease of operation and ready for modularity (Bridgwater & Peacocke 2000).

Vacuum Pyrolysis

- Slow heating rates but removes pyrolysis products as quickly as in other configurations.
- Bigger fuel particles are required; hence, the vacuum as the name implies leads to larger equipment and costs.
- Has merit of reduced char and ash contents in the oils over other reactors where fast heating rates are achieved particularly fluidising bed/circulating bed (Ganesh & Banerjee 2001)
- Has lower liquid yield at 60-65% compared with other technologies of 75-80 wt%.

3.8.4 Pyrolysis (Bio-oil) Product Upgrading

Considering bio-oil associated problems for utilisation such as high viscosity, solid content, alkali metal and water content, chemical stability and heating value of 15-18 MJ/kg (Chiaramonti et al. 2007), this oil product requires upgrading for wider application. According to Pecha and Garcia-Perez (2015), Ganesh and Banerjee (2001) and Demirbas (2001) bio-oil can potentially be upgraded to provide a more beneficial substitute for several petroleum products such as jet fuel, and asphalt equivalent. The following strategies can be used for upgrading and include:

- Dilution/solubilisation with alcohol for stabilisation
- Esterification or acetilisation to eliminate acids/carbonyls
- Hot gas filtration
- Catalytic hydro-deoxygenation of oil after pyrolysis
- Catalytic pyrolysis, and
- Aqueous phase fermentation

3.8.5 Pyrolysis Power Generation Plants

The most promising application of FP is in the area of power generation because of the ability to utilise the bio-oil as produced in a turbine or engine without requirement for extensive upgrading (Bridgwater et al. 1999). Power generation from bio-oil has the benefit of fuel production separated from power generation unit (Ganesh & Banerjee 2001; Bridgwater et al. 2002), with benefits of storage and transportation of the oil. This guarantees peak power provision, and suitability for dispersed power generation through smaller pyrolysis plants being served from a single bio-oil plant (Bridgwater et al. 1999; Bridgwater et al. 2002). However, small power generation from this technology is currently not available (still at pilot stage) (Gonzalez et al. 2015; Owen et al. 2013).

Bio-oil has been successfully combusted in boilers by DynaMotive. The steam generated was used for kiln heating (seasoning purpose of timber) of a flooring company (Bradley 2006). Also, it has been successfully demonstrated in slow and medium speed stationary diesel engines, substituting for diesel as a clean fuel. The demonstration exercises were carried out by "Ormrod Diesels (UK), Wartsilla Diesels (Finland), Pasquali/Lombardini (Italy) and Sener-Tac (Germany)" (Bradley 2006). Bridgwater et al. (1999) also reported that bio-oil has been successfully tested in diesel engines and can be applied for up to 15 MWe capacities. Pyrolysis oil has been tested on a small scale turbine by DynaMotive and Magellan aerospace in 2004. Subsequently, both commenced generating power with pyrolysis oil and delivered it to Ontario's power grid (Bradley 2006). Also, it has been successfully used in a 2.5 MWe gas turbine, though not for many hours of operation. There is limit of 10 MWe power generation plant available for exploitation (Bridgwater et al. 1999). However, application of bio-oil in gas turbines and diesel engines can cause problems due to differences in properties such as ash content, and low cetane (Pecha & Garcia-Perez 2015).

In line with the above assessment, diesel ICE engines and gas turbines are the most appropriate engines for power generation plants using bio-oil from fast pyrolysis. These power plants have been applied by both Fan et al. (2011) and Ganesh & Banerjee (2001) in their whole life cycle assessments and economic evaluation analyses reports respectively. More so, fluid bed reactor configuration is the most suitable for FP bio-oil liquid production considering its ease of operation, high popularity (little experience gain in term of maintenance) and use of by-product gas and char to provide process heat, which can cost a lot in some cases.

3.9 DIRECT COMBUSTION

Direct Combustion (DC) is a thermo-chemical process that converts biomass materials to heat and electricity through the production of steam in a furnace or boiler and uses it in a steam turbine for electricity generation (Demirbas 2001). In other words, it is a system that converts biomass in complete oxidation (in open air) process. In excess it generates water and carbon dioxide. The operating principle of this system is that as the boiler produces the steam it is transferred through the heat exchanger and the steam is fed, to drive the steam turbine/steam engines or stirling engines (Evans et al. 2010; Bain et al. 1998; Caputo et al. 2005). DC system application ranges from small scale domestic use to a high scale of 100 MWe (Demirbas 2001). However, the realisable scale of this technology is a capacity largely around 25MW because of materials limitations (Demirbas et al. 2009; Demirbas 2001). However, this bigger scale application is not appropriate for this research work.

By the end of 2012, DC conversion system accounted for around 75% of the total biomass electricity installed capacity globally (Martinot 2013). DC has an efficiency between 20% - 40% (Demirbas 2001; Caputo et al. 2005) which makes it the most inefficient among the thermochemical conversion technologies (Fan et al. 2011; Murphy & Mckeogh 2004). The key effect of this low efficiency is higher GHG emissions (Gonzalez et al. 2015). This low efficiency problem is worst with small scale applications which lose between 30%- 90% of the heat transfer. However, the efficiency of this system can be improved through co-firing/ cogeneration in coal power plants, or by increasing the capacity of the generation plant (Breeze 2014). For small scale size applications, it can be improved through use of a stove system (Demirbas 2001).

Miguez et al. (2012) reported that DC technology has been modernised with a view to reducing the GHG emission by adopting methods of operation (manual and automatic system) to ease and speed up its processes. This improvement in term of operation processes comes along with automation principles which cover the ignition system, ash removal, control techniques and feeding systems. Also, in terms of sustainability, most of the equipment (such as modern boilers) minimises the GHG emission impact through efficient combustion as result of the low volume of ash generated.

3.9.1 Direct Combustion Technologies Forms

There are numerous forms of DC technologies, ranging from conventional types (pile burners, fluidised beds and stokers grates) to non-conventional types (Whole Trees and suspension burners) (Gonzalez et al. 2015). Miguez et al. (2012) classified this technology based on their main system parts including: combustion chamber/burner/ ignition systems, feeding system and heat exchanger, whereas the majority of researchers classify DC systems based on the burners forms.

Figure (3.3) reveals that, as the system capacity increases, particularly for boiler size in excess of 40kW, the preferable technology is the moving grate. More so, the retort system is the preferable system for capacities more than 150kW. For the purposes of this study (rural application less than 150KW capacity), only fixed bed and moving bed grates will be considered.

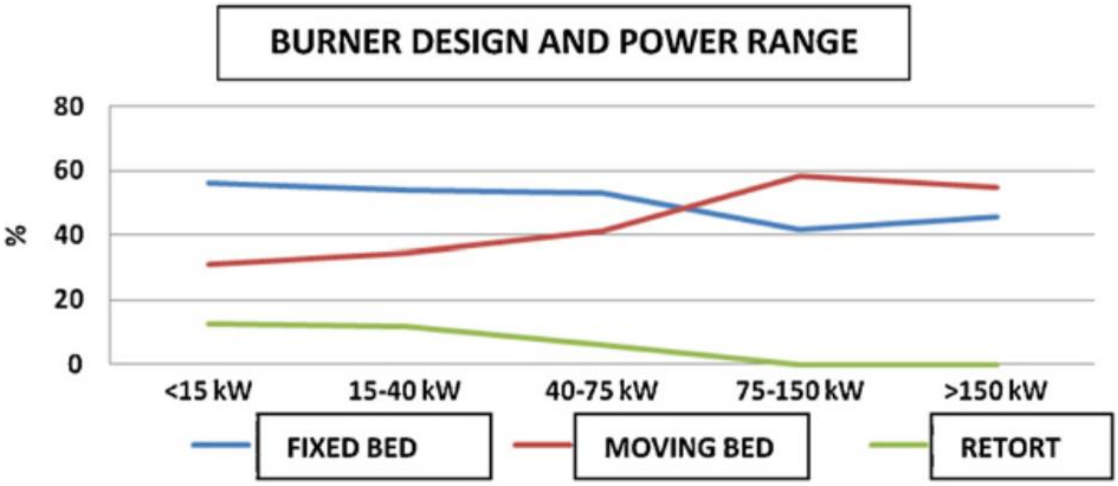


Figure 3.3: Types of DC burner technologies (Miguez et al. 2012)

Pile Burners

In this system, the feedstock enters the burner either from the top or bottom through a screw auger to form a pile on a grate at the bottom of the system, while the oxidation agent is fed inwardly from both sides and bottom. Hence, the feed is burned in the two-stage combusting chambers connected with a different boiler and furnace just above the secondary chamber (Bain et. al. 1998; Gonzalez et al. 2015).

The slowness of this system may not be unconnected with the design and characteristics, such as isolation of the burner from the furnace/boiler to allow the removal of ash residue manually from the grate after cooling. The system has to be stopped and restarted, as such, the operation is manually recurring, resulting in reduced productivity (Bain et al. 1998). However, the merits of this system are an ability to combust both dirty and wet feedstock and its simplicity of operation (Gonzalez et al. 2015). Hence, considering its mode of operation, it is fair to classify this system as a fixed bed grate system.

Miguez et al. (2012) stressed that fixed bed system is the most suitable for small scall utilisation, and moving grates use comes into effect if the boiler size/ capacities needs increases. Fixed bed grate is the most widely utilised in the industry, representing approximately 80% of the total capacity despite its low efficiency. See figure (3.4) for details. Also, 93% of the wood log and 99.3% of pellets boilers use fixed bed burners.

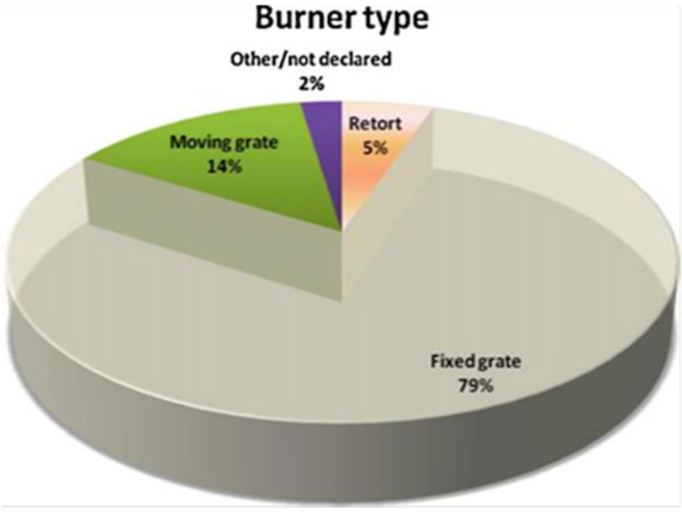


Figure 3.4: Burners types as applied in the Industry (Miguez et al. 2012)

Stoker Grate (Moving Grate)

This is an improvement over the pile burner (fixed bed grate) system. It replaces the fixed bed with a moving grate (stoker grate) with a view to remedying the pile burner's major disadvantages such as slowness, inefficiency and repeated operations of ash removal and collection. More so, in this system, the feed is evenly distributed in thinner layers with the help of a pneumatic system, giving the whole system improved and efficient burning in the combustion zone (Bain et al. 1998). Among different systems in this technology, the bascule form is the most efficient, as it allows both cinders and ash to be automatically transported to the ash holder just below the grate (Miguez et al. 2012).

This system accounts for only 14% of DC technologies used in the market as most "wood-log and small pellet stoves or boilers rarely use these types of burners" (Miguez et al. 2012). However, chip boilers and pellet and chip boilers usage of this system represent 41.3% and 22.9% respectively.

Burning Plate (Retort)

Retort grates are frequently suitable for capacity over 150kW, hence not suitable in this suitable (Miguez et al. 2012). See figure 3.4 for details.

3.9.2 Direct Combustion GHG Emission Factors

Despite biomass energy system being assumed by many researchers as carbon neutral through carbon sequestration via soil and plants through the cultivation of the next crop (Evans et al. 2010), there are unavoidably steps missing in the bioenergy processes that have not been captured in the calculation of the carbon neutrality of this energy system, such as: plantation fertiliser requirements, cultivation and collection, and transportation-related emissions (Fan et al. 2011). Furthermore, utilisation of biomass feedstock in generating electricity is another major source of GHG emission in a DC system's application (Shumnungam 2009). Among thermo-chemical conversion systems, gasification technology emits the lowest GHG emission, followed by pyrolysis, and DC has the highest GHG emission (Galbraith et al. 2006). However, with the recent developments in terms of automation and processes improvement in ash collection, there is a significant reduction in GHG emissions from DC systems (Miguez et al. 2012). Furthermore, emphasis should be given to plantations of crops with minimal maintenance in term of fertiliser used for energy generation with a view to reduce GHG emission (Evans et al. 2010); and encouragement of utilisation of biomass waste resources. Transporting of biomass resources should be minimised with a view to reducing GHG emissions through the adopting of densification of the biomass resources as most of them have low density but high volume.

3.9.3 DC Power Generation

The secondary conversion systems suitable for electricity generation in this context include steam turbine, steam engine, organic rankine cycle and the Stirling engine. However, the most utilised technology is the steam turbine (Gonzalez et al. 2015), which is commercially available, while other machines are either unavailable commercially or limited to small scale applications, and are mostly simple and inefficient (Bridgwater et al. 2002). The major benefit of steam turbines over other technologies is the long-time availability and high efficiency (Arena et al. 2010).

The most appropriate primary conversion systems in this respect are both fixed bed and moving bed grate, given the aim of this research work, utilisation experience, availability and efficiency. While in the case of secondary conversion (power generation), steam turbine is presently the most appropriate machine.

3.10 ANAEROBIC DIGESTER SYSTEM

Anaerobic digestion (AD) is a biological process of generating electricity via conversion of biomass resources with moderate moisture levels into biogas. Uninterrupted power energy generation and supply is achievable through AD systems but this requires a continuous supply of fuel (IRENA 2012). Also, IRENA (2012) opined that multiple feedstocks co-digestion is the best approach generally practiced in achieving good biogas. Biogas is a mixture of methane and carbon dioxide with other constituents. Pre-treatment of the feedstocks is also usually necessary for better biogas output and reducing the likelihood of 'killing' the natural digestion process. Its electricity generation capacity ranges between 10kW and several MW.

Biogas can be used for different energy purpose: electricity, heating and fuel provision. However, the majority of biomass resources have issues with energy balance. According to Poschl et al. (2010) who evaluated the energy balance of a biogas digester using Primary Energy Input to Output ratio (PEIO), the result shows that PEIO for single feedstock source digester match up approximately 34 -55% and co-digester feedstock has better energy balance (using PEIO) between 11 - 64%.

3.10.1 Anaerobic Digester Power Generation Systems

Appropriate AD technologies by residue or crops stream include lagoon/blanket, complete mix digester and plug flow digester (IRENA 2012). Power generation from biogas has been through ICE or gas turbine for electricity generation. See section (3.8.4) for details on ICE.

They are many applications of AD systems in many countries globally, such as in the European Union (EU) (Wiese et al. 2010) with approximately 15,000 biogas power plants in operation, with a total capacity representing around 7.9 GW by the end of 2014 (REN21 2015). China has around 5 million and 2,360 household digesters and biogas stations respectively (Zheng et al. 2010). India has approximately 3.8 million biogas plants and Nepal has installed 170,000 digesters (Maes & Verbist 2012; Ruane et al. 2010). Over 25,000 biogas plants exist in Bangladesh (Mondal et al. 2010). This is an indication of biogas system's adequate utilisation globally and the existence of operational experience.

3.11 CHAPTER SUMMARY

This chapter discussed details forms of biomass resources and identified most appropriate for utilisation in the rural areas based on their sustainability that include wood, wood waste, cereal straw, coconut shell and cattle manure among others. Biomass energy conversion technologies (thermo-chemical and biological) have been illustrated, together with their stages of development, and their merits and demerits. Then appropriate primary and secondary conversion systems for used in this study have been identified; that include downdraft fixed bed and ICE (for gasification); fixed bed and moving bed grate, and steam turbine (for direct combustion); fluid bed reactor configuration and diesel ICE engines (for pyrolysis) and finally complete mix digester and ICE are suitable for biogas system. The next chapter discusses energy policies in Nigeria and economic evaluation techniques of energy systems.

CHAPTER FOUR

ENERGY POLICIES AND ENERGY ECONOMIC EVALUATION TECHNIQUES

4.1 INTRODUCTION

This chapter covers assessment of various energy policies in Nigeria including renewable energy technology (RET), policy instruments applicable to RETs in the country and various energy economic evaluation techniques. This is for the purpose of determining if RETs can be economically affordable for rural communities.

4.2 NATIONAL ENERGY POLICIES

Until recently, Nigeria had no all-inclusive energy policy; instead every single energy sub-sector had its own energy policy such as oil and gas, electricity, solid minerals, transport etc. A National Energy Policy was produced by Energy Commission of Nigeria (ECN) and approved by the federal government in 2003, having passed through many reviews with a view to provide a comprehensive energy policy. The major aim of the policy is to promote increased participation of investors for the optimum usage of energy resources (conventional and renewable sources) of the country for appropriate energy generation (National Energy Policy (NEP) 2003).

Similarly, a Renewable Energy Master Plan (REMP) came into existence in 2005, through collaboration of a group of consultants commissioned by ECN and the United Nation Development Programme (UNDP). The mandate of the plan was to examine the country's existing energy situation and offer answers to improve the energy policy (ECN-UNDP 2005; Ajayi & Ajayi 2013) and form part of the greenhouse gas (GHG) emission reduction strategy in Africa through incorporating sustainable energy supply (Sambo 2009; Shaaban & Petinrin 2014).

Furthermore, the REMP group proposed strategies for the plan's implementation through executable projects and programmes with a view to increasing power generation capacity of the country (from an available capacity in 2005 of 5,000 mega-watt (MW)) through increased use of RETs to a projected capacity of

16,000 MW in 2015 (ECN-UNDP 2005). Other targets were also set out for RETs by REMP (2005). A decade after the formation of REMP 2005, despite all the targets set in respect of times, programmes and projects and resources committed, the country is yet to have modern RETs included in its energy mix beyond the small amount hydropower that has been in existence since 1923 (Garba et al. 2016a). The question still remains, what is causing this lack of progress regarding use of RETs to produce electricity in Nigeria?

4.3 ELECTRIC POWER SECTOR REFORM ACT 2005

Electricity generation and supply in Nigeria (rural areas inclusive) has an act of parliament related to it; the Energy Power Sector Reform (EPSR) Act, 2005. This Act was enacted in 2005 but before then, it passed through many reviews with the vision of providing a faultless Act (Ikeme & Ebohon 2005; Maduekwe 2010).

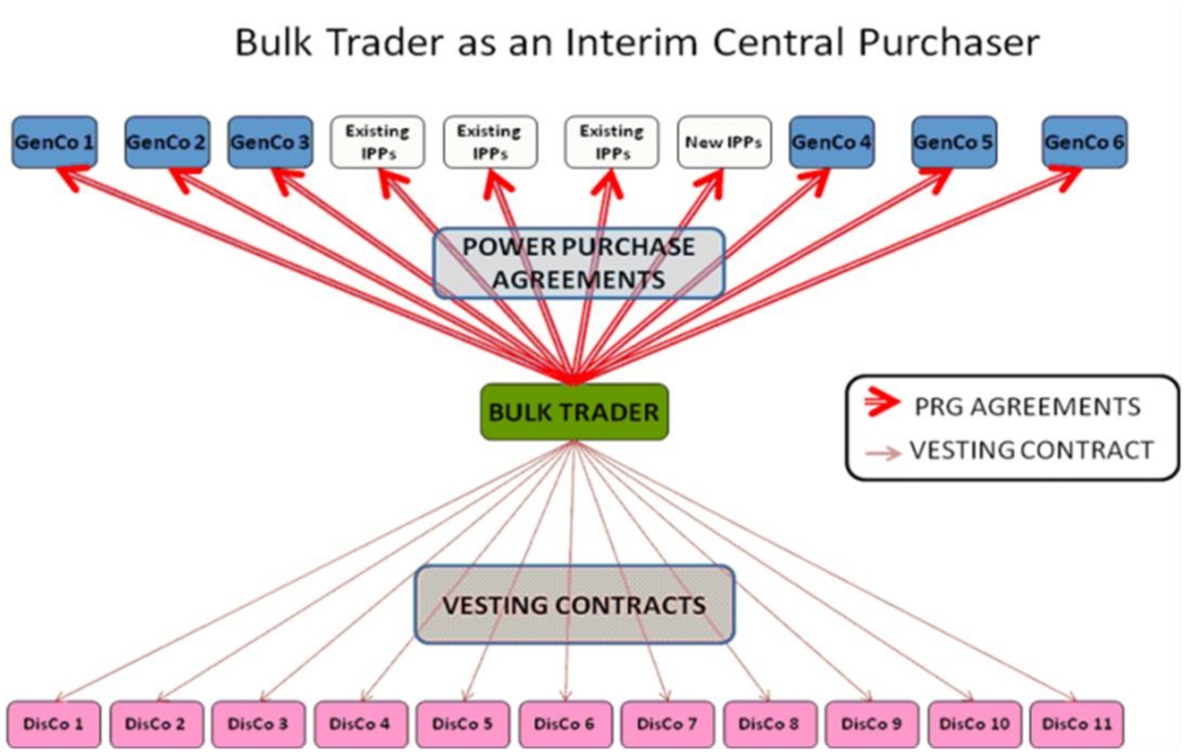


Figure 4.1: Reform structure between power producers and distribution companies (Nnaji 2011)

The overall aim of the "Act" is to break the monopoly of the country's utility company Power Holding Company of Nigeria (PHCN) by unbundling it to form three divisions with each comprising various numbers of companies (transmission, 11 distribution and 6 generation), and some private sector participation. In addition, there has been the introduction of strong regulatory agencies such as the Nigerian Electricity Regulatory Commission (NERC), the Rural Electrification Fund (REF) and the Consumer Assistance Fund (Nnaji 2011). See figure (4.1) for details.

In respect of EPSRA (REF in particular), it's expected to facilitate the growth of rural electricity access through a decentralised structure operating in a sustainable manner. Furthermore, this act provided a license-based incentive (electricity licence exemption) to organisations interested in participating in a decentralised power generation business not exceeding 1MW. Considering most of Nigeria rural communities' electricity demand is less than 1MW, such an incentive seems a good motivation for the adoption of RETs sources and also, a noble political will on the side of government. However, is it a sufficient for RETs to compete with the fossil fuel (FF) source in Nigerian rural areas? The incentive's effectiveness could be doubted given the high subsidies provided to FF sources in the country (around one quarter of the national budget).

4.4 NATIONAL RENEWABLE ENERGY AND ENERGY EFFICIENCY POLICY

Energy Policy (especially policy instruments) has been the major means of deploying RETs, based on the support of national governments and has become a game changer in energy generation and supply in many countries. Typically, by mid-2015, RET sources had contributed approximately 25% of total electricity generated in the United Kingdom, placing them ahead of coal for the first time (DECC 2015). Similarly, by the end of 2014, renewable sources took first position in Germany's energy generation industry with a 27.4% share (Energiewende 2015), largely as a result of government support through policy instruments, particularly those related to the implementation of a FIT incentive.

The implementation of National Renewable Energy and Energy Efficiency Policy (NREEEP) was approved by the Nigerian federal executive council in April, 2015, with the major aim of achieving the "optimal utilization of the nation's energy resources for sustainable development" (NREEEP 2015), primarily through a focus on technologies such as hydropower, wind, geothermal, solar, biomass and wave and tidal electricity systems, and co-generation plants, as well as energy efficiency improvement. NREEEP made reference to the ongoing co-ordination in the Economic Community of West African States (ECOWAS) region in respect of renewable energy and energy efficiency (REEP) policies. It is expected to be implemented through the national action plans of renewable energy and energy efficiency (REEE) of each country, for the purpose of guiding the development of future REEE associated sectoral policies in addition to achieving REEE targets.

By implication, NREEEP copied sections of each RETs (identified above), as contained in NEP (2003) pertaining the policies, objectives and strategies for achieving their goals. Hence, depending on what type of RETs you are interested in, you can make reference to this policy or NEP 2003. Given that this research focuses on biomass energy system application, its policies, objectives and strategies as contained in NREEEP are outlined in the next 3 sub-sections:

4.4.1 Policies

Key policies to drive the development of electricity generation from biomass are as follows:

- "The nation shall effectively harness biomass resources and integrate them with other energy resources for electricity generation".
- "The nation shall promote the use of efficient biomass conversion technologies".
- "The use of waste wood as a source of electricity shall be encouraged in the nation's energy mix".
- "The nation shall intensify efforts to increase the percentage of land mass covered by forests in the country".

4.4.2 Objectives

Key objectives include:

- "To promote non-wood fuel biomass as an alternative energy resource, especially in the rural areas, and promote its usage for remote and off-grid power generation".
- "To promote efficient use of agricultural residues, municipal wastes, animal and human wastes and energy crops as bioenergy sources".

4.4.3 Strategies

Key strategies include:

- "Developing extensive educational and outreach programmes to facilitate the general use of new biomass electricity technologies".
- "Promoting research and development in biomass technology and fuels".
- "Establishing pilot projects for the production of biomass energy conversion devices and systems".
- "Providing adequate incentives to local entrepreneurs for the production of biomass energy conversion systems".
- "Training of skilled manpower for the maintenance of biomass energy conversion systems".
- "Developing skilled manpower and providing basic engineering infrastructure for the local production of components and spare parts for biomass systems".
- "Cultivating fast growing tree species needed to accelerate the regeneration of forests".
- "Developing appropriate technologies for the utilization of alternative energy sources from fuel-wood".

4.5 FEED-IN-TARIFF INCENTIVE SYSTEM IN NIGERIA'S ENERGY SECTOR

Based on the power conferred on the national electricity regulatory commission (NERC) by the EPSR Act 2005, Feed-in-Tariff (FIT) regulation was formulated in 2013 for the purpose of procuring and pricing of renewable energy sourced electricity in Nigeria (NERC 2013). According to Otitoju (2010), FIT is a "policy instrument that obliges regional or national transmission system operators to feed the full production of green electricity into the grid at a politically fixed price". The focus of RETs focused FIT is the creation of a price that covers the cost of electricity generation plus a reasonable profit, with a view to encourage investors to invest.

A RETs FIT strategy assures a buying price for a certain period of time for various approved RETs, thereby providing a profit to investors, whilst also limiting electricity producers excess of electricity through a systematic yearly price reduction for new projects, based on a yearly cost reduction of RETs components and increased effectiveness flowing from the learning curve of its operation. The extra cost as a result of RETs FIT is offset by the consumers through a small amount of increase to their electricity tariff. Also, this additional power generation cost from the use of FIT may be sourced from the following: power consumer assistance fund, rural electrification fund, donor support and carbon finance (NERC 2013). In addition, NERC (2013) opined that the scope of RETs FIT is for a capacity not exceeding 2,000MW for all the identified RETs, with a minimum capacity of 1MW for each technology, and maximum capacities as follows: wind 10MW (this capacity is under construction in the country), small hydro 30MW, biomass 10MW and solar PV 5MW. Also, the current FIT is limited to grid connected electricity provision (rural non-grid electricity provision is not included).

The FIT system is expected to be reviewed every three years due to technology changes in terms of efficiency improvement and capital cost reduction, as witnessed with solar PV’s development over time (Renewable Energy Handbook 2010). However, it is noteworthy that this tariff system is still not operational in the country (as there is no report of its implementation) despite the laudable commendation, and even within a few months to the end of last year of the set target date. See table (4.1) for details. Hence, it is clearly indicative that investors, given what they are (profit-driven organisations), perhaps will wait for a new set of FITs, following the mandatory review every couples of years.

Table 4.1: RETs FIT Pricing Model in Nigeria (Prices N/kwh) (National Electricity Regulatory Commission 2013)

RETs	**2012**	**2013**	**2014**	**2015**	**2016**
SHP	23.56	25.43	27.46	29.64	32
Wind	24.54	26.61	28.64	30.94	33.43
Solar	67.92	73.3	79.12	85.4	92.19
Biomass	27.43	29.62	32	34.57	37.36

4.6 BARRIERS TO RETs POLICY IMPLEMENTATION IN NIGERIA

The following represents the constraints inhibiting the implementation of RETs policies in Nigeria:

4.6.1 Inadequate Policy Framework

Nigeria's energy policy is in place and it is assumed that the policy contains procedures, processes and ways to accomplish its objectives. The procedural parts of the policy detail how to implement the policy; while the process section is specific in terms of the technology to be adopted, capacity to be achieved and dates for achieving the required capacity. However, the policies lack implementation strategies, particularly market-oriented incentives (Mohammed et. al. 2013) and a selling point which is inhibiting the practice (Ajayi & Ajayi 2013). See figure (4.2) for details. Thus, the policies need to be reviewed in order for practice to be seen on the ground. Shaaban & Petinrin (2014) reported on Nigerian energy policy that "an implementation plan is yet to be developed and no explanation has been given for the lack of implementation of the laudable policy".

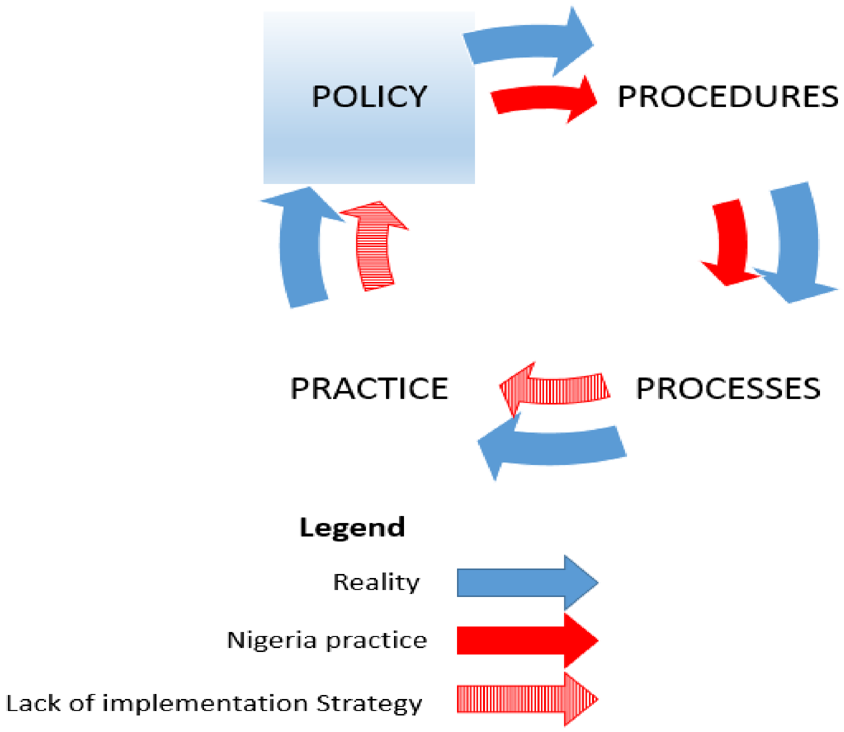


Figure 4.2: Stages of RET implementation Policies in Nigeria.

It is noteworthy that investors will only invest in business that is profitable. Given the huge subsidy for FF sources of energy generation (approximately one quarter of the national budget annually) (Garba & Kishk 2014), thus, there is the need for a policy review with a view to providing effective and efficient incentives for appropriate RETs so as to encourage investors' participation as seen in developed countries such as Renewable Obligation (RO), tax holiday, low/non-interest loans etc. Hence, RET practices can only succeed in Nigeria with an adequate incentives regime given RETs high initial capital cost (Alazaraque-cherni 2008). It should be clear as well, that RETs remain the one and only means of providing sustainable electricity to over 60% of the Nigerian total population who live in rural areas and are low-income earners, with a low energy consumption pattern (Sambo 2009; Shaaban & Petinrin 2014).

4.6.2 Inappropriate Budgetary Allocation

Despite a significant budgetary allocation to the energy sector in Nigeria, it was only recently that some of this budgetary allocation has been set for RETs source by the federal government. Typically, the total budget allocation of RETs for the years 2011, 2012, 2013 and 2014 amounts to US$ 22, 19.5, 35.2 and 17.3 million respectively (Ajayi & Ajayi 2013; Garba et al. 2016a). In the 2014 budget, small and medium sized hydropower projects were allocated US$ 14.38 million, while the remainder went to other RETs. In line with the total annual budgetary allocation to the energy sector, these sums are grossly inadequate for the development of RETs. For example, in 2014 approximately US$ 381 million was allocated to the power sector but less than 5% was set aside for RETs. Hence, there is the need for appropriate budgetary allocation in subsequent federal, state and local governments to support sustainable RETs development.

4.6.3 Apathy in Developing RETs in Nigeria

The emphasis on FF energy source in Nigeria continues despite the energy sector reform in EPSRA 2005 and NEP (2003). This is a situation where the proposed power generation projects were mainly from fossil fuel sources; of 28 licenses issued to Independent Power Providers (IPPs) for electricity generation as at February 2009, only 1 provider was expected to generate electricity from RETs source (Sambo et al. 2010). This is indicative that government is more interested in generating electricity from FF sources in Nigeria. Meanwhile, from the objectives of the NEP (2003), it was expected that the country's electricity needs would be met through both FF and RETs sources.

The interest in FF source in electricity generation may not be unconnected to the following reasons: lack of political will to develop RETs, no need for change (despite negative effects of FF utilisation) and perhaps due to oil and gas merchants' interest in sustaining FF source market. Conversely, the effect of FF energy source is now evident globally, considering climate change effects such as a high rate of precipitation in some regions leading to flooding, and excessive heat (Moriarty and Honnery 2011). Also, bearing in mind that Nigeria is the second largest FF gas flaring country globally (Oseni 2012) there is the need for sustainable energy generation and supply in the country.

4.6.4. RETs Discrimination in Nigeria's Energy Policy

The problem of favouritism impacts beyond the application of more FF sources; it occurs even among RETs sources. This is a situation where wind and solar are more favoured than biomass systems. Typically, National Energy Policies (NEPs) in Nigeria and other sub-Saharan African (SSA) countries consider solar, hydro and wind as renewables but biomass system is either relegated or excluded from this classification and termed as unsustainable (Owen et al. 2013). However, it has been found that biomass resources are generally available globally, and particularly in SSA countries. It is noteworthy that there is a significant excess of biomass generation over demand in SSA countries (Openshaw 2011).

Similarly, SSA countries governments deliberately refuse to take advantage of contemporary realities in respect of technological opportunities connected to biomass system. Instead, they continuously focus on FF energy sources to meet their energy demand (Owen et al. 2013). Given the economics of SSA countries, the majority of citizens perhaps could not afford the FF electricity provided, eventually forcing them to use traditional means of energy generation. For example, by the end of 2030, the number of SSA countries' citizens depending on biomass consumption will increase by 60% (IEA 2010), but the NEPs in these countries contradict this reality. This is because the NEPs have been based on an erroneous assumption that biomass utilisation can be substituted with petroleum products and electricity. Meanwhile, there is a significant shift across developed countries back to low carbon renewable energy, particularly biomass based, with a view to achieving a sustainable and low-carbon energy strategy (Owen et al. 2013).

4.7 ENERGY POLICIES WAY FORWARD

There is the need for an energy policies review with a view to providing effective incentives to potential RETs investors. Policy instruments should not be limited to only the FIT system proposed in the country, but should include incentive strategies like Renewable Obligation (RO), tax holiday for investors, low/non-interest loans as witnessed in developed countries, along with identification of optimal technology for each location, that is not using generic system (RET), particularly given the problem of RETs resources intermittency. Appropriate budgetary allocations should be provided to support RETs by the governments at all levels, and legislative backing to all the policies in the country, considering the high capital cost of RETs. Similarly, the FIT incentive strategy should be extended to rural areas, as currently it is limited to only grid systems of more than 1MW.

4.8 RENEWABLE ENERGY SYSTEMS ECONOMIC EVALUATION TECHNIQUES

According to Short et al. (2005) there are many available techniques for economic evaluation and investment appraisal of energy systems, including net present value (NPV), levelised cost of energy (LCOE), total life cycle cost (synonymous to whole life costing (WLC)), revenue requirements (RR), internal rate of return (IRR), modified internal rate of return (MIRR), simple payback period (SPB), discounted payback period (DPB), benefit-to-cost ratio (B/C) and savings-to-investment ratio (SIR). However, based on table (4.2) the most widely utilized techniques for economic evaluation in the energy sector, particularly for decentralised supply systems are LCOE, LCC (WLC- annualized and present value), NPV and lastly the review method.

Following the explanation above, this study will not use NPV because it is not required to consider economic appraisal from a social perspective (where all costs incurred by society are considered). Also, even though NPV is suitable for determining the optimal option among mutually exclusive projects, it fails to determines the worth of larger profit that can be made by investing in larger projects, which is not the case in this study (only used for small-scale projects in rural areas) (Short et al. 2005).

Table 4.2: Decentralised RETs Economic Evaluation Techniques and Technologies

	Author(s)/ year of publication	Technolog(ies)	System Capacity (kW)	Method(s)	Location	Publisher
1	Sadhan et al. (2009)	PV, biomass, biogas, solar lantern	up to 37	Annualised LCC	India	Elsevier
2	Oparaku (2003)	PV, diesel & GE	up to 280	Present Worth LCC	Nigeria	Elsevier
3	Diyoke et al. (2014)	Biomass	80	NPV/LCOE	Nigeria	IJRETR
4	Deichmann et al. (2011)	PV, wind, biodiesel	up to 100	Review	SSA	Elsevier
5	Rezk & Dousky (2016)	PV, wind & fuel cell	up to 52	LCC	Egypt	Elsevier
6	Ohunakin et al. (2012)	Wind	300-1000	Present value cost	Nigeria	Elsevier
7	Banerjee (2006)	wind, PV, biomass & non-renewables	_	Annualised LCC	India	Elsevier
8	Evans et al. (2009)	PV, wind, hydro, geothemal, ocen	_	Review	_	Elsevier
9	Mahapatra & Dasappa (2012)	PV, biomass & GE	up to 120	LCC	India	Elsevier
10	Gilau et al. (2007)	PV/wind/diesel & diesel only	_	NPV	_	Elsevier
11	Bryne et al. (1998)	PV/wind hybrid	5.5	LCOE	China	Elsevier
12	Chaurey & Kandpal (2010)	PV	_	Review	_	Elsevier
13	Evans et al. (2010)	Biomass	_	Review	_	Elsevier
14	Nouni et al. (2009)	biomass, small hydro, PV, wind	up to 100	LCOE	India	Elsevier
15	Roy & Kabir (2012)	PV	up to 100	NPV	Bangladesh	Elsevier
16	Garba & Kishk (2015)	Biomass	up to 125	WLC	Nigeria	SEEDS Conf
17	Nouni et al. (2007)	Biomass, diesel	up to 40	LCOE	India	Elsevier
18	Baurzhan &Jenkins (2016)	PV	up to 5	LCOE	SSA	Elsevier
19	Ohunakin et al. (2011)	Small hydro	_	Review	Nigeria	Elsevier
20	Nouni et al. (2008)	biomass, wind, PV, coal	small-medium	LCOE	India	Elsevier

Although LCOE and WLC are very similar in their operation and application, when selecting the best investment option from mutually exclusive projects, LCOE is not suitable in this study because its fails to recognise the difference in sizes of investment options; large investment size gives opportunity to the investors to make more profit considering economies of scale, etc. Thus, WLC is suitable for both selections between mutually exclusive options and in ranking among the same set of investment alternatives. However, the WLC approach has been criticised for not taking into account returns and benefits of investment (Short et al. 2005), but this problem can be resolved by taking the total expenditure throughout the lifespan of an asset into consideration. Hence, it is the responsibility of the investor to decide afterward on an acceptable profit suitable for its firm, bearing in mind the communities (rural areas) energy is being provided, and any incentive strategies in place.

4.8.1 Renewable Energy Systems Economic Evaluation (Empirical Studies)

Over the last two decades, several studies have been conducted in respect of the economics of RETs with a view to providing sustainable electricity for developing countries’ communities without access to electricity, representing around 1.6 billion people (World Energy Outlook 2004).

Table 4.2 reveals the trend of technologies, system capacities and techniques utilised in evaluating rural areas electricity in developing countries. The most utilised in this context is solar PV with 14 research projects; followed by biomass, wind and small hydropower representing 10, 9 and 3 projects respectively. Also, given the low energy consumption pattern in these communities across geographical locations, they are typically low and the maximum capacity is just few hundreds kW.

Some of the research findings in table (4.2) are discussed in detail to bring forth their contributions in terms of the economics of decentralised RETs and research techniques used, so as to identify the most appropriate technology and technique(s) for evaluation in this study (research gap). Typically, Mahapatra and Dasappa (2012) reported on the whole life costing (WLC) of biomass, solar PV and grid extension systems. The study concluded that biomass is more cost-competitive than solar PV and grid extension (GE) systems. This is because the biomass system only requires additional fuel when there is an increase in operational hours, while in the case of solar PV, there is a need to increase the system capacity, which adds capital cost. Also, WLC provides an overall cost of the operation in the study for facilitating an appropriate decision by investors. Also, a study by Gilau et al. (2007) reported on the economic evaluation of hybrid (wind-diesel, solar PV-diesel) and stand-alone (diesel only) systems, and revealed that economy of scale has significant impact on reducing electricity cost, and the higher capacity systems represent the lowest net present value. In a life cycle cost analysis comparison of solar PV, diesel generator and grid extension systems in Nigeria by Oparaku (2003), the report suggests that solar PV represents an alternative option in terms of cost competitiveness.

Similarly, Nouni et al. (2007) reported on the LCOE of 100% fuelled producer gas engines and dual fuelled (both biomass gasifiers) engines against diesel generators in a decentralised setting; at 40 kW capacity, biomass gasifier and 100% gas engine is cost competitive to dual fuel engine and diesel generator, given the cost of diesel at that time. In a study by Baurzhan and Jenkins (2016) on the investment of home system solar PV (using the LCOE approach) in sub-Saharan African (SSA) countries, it was found that solar PV is still very expensive per/kW electricity, and it will take up to the year 2030 before it becomes affordable and cost-competitive with diesel generator in the region. Further, in a study by Garba & Kishk (2015) using WLC approach to evaluate economics of decentralised biomass gasification technologies (BGTs) in Nigerian rural areas, it was shown that BGTs are cost-competitive with a centralised grid system using fossil fuel (FF) sources. However, Evans et al. (2010), using the systematic review method, argued that biomass energy technologies (BETs) are cheaper than solar PV but more expensive than a grid extension system. Hence, this study builds upon all these findings, and will be assessing all the available BETs (gasification, combustion and biogas) as highlighted in chapter 3. This is the first time the economics of BETs will be evaluated in the context of providing sustainable electricity in rural areas. Also, it is fair to conclude that the WLC approach is appropriate for conducting an economic evaluation of decentralised small capacity BETs.

4.8.2 Whole Life Costing (WLC) Approach

WLC has been defined by authors in different forms, ranging from the generic to customised definitions, with the simplest definition being by Kishk et al. (2003) "systematic consideration of all costs and revenues associated with the acquisition, use and maintenance and disposal of an asset". Similarly, WLC is defined as the sum of all expenditure related to a physical asset from the commencement stage through the operation to the end of the asset's life (Woodward 1997). The purpose of WLC is to optimize the cost of owning and running a physical asset, as stressed by Woodward & Demirag (1989) "optimise the cost of acquiring, owning and operating physical assets over their useful lives by attempting to identify and quantify all the significant costs involved in that life, using the present value technique". WLC aims to assess various alternatives with a view to ensuring the adoption of the optimum asset configuration. Also, during the life phases of the assets, it allows trade-offs between cost elements to be studied so as to ensure optimum selection and enable the total cost to be realised (Woodward & Demirag 1989).

WLC Application

The WLC concept is applicable in many industries, ranging from construction, to transport, and has been used by management as a tool for assisting in effective selection among competing options. It also has a value in determining the exact maintenance and operating costs of an asset before procurement occurs (Ferry & Flanagan 1991; Kishk et al. 2003). Furthermore, WLC helps in making the right decisions at the beginning of an asset's life or during its operation (Woodward 1997).

WLC and RETs Evaluation

One of the objectives of this research work is to evaluate and optimise the economic viability of the identified subsets of RETs in the provision of sustainable electricity in Nigeria. This evaluation is a form of strategy for business success and/or community development benefit, particularly considering the privatisation of Nigeria's energy sector, where investors need to practice informed decision making before embarking on any investment (due to cost benefit analysis) focused on providing electricity, especially to rural areas. One of the tools used for this evaluation is WLC. WLC is majorly used in the selection of optimal technology among various competing options, bearing in mind important cost (Woodward 1997) and can assess the consequence of a decision already made (Kirk & Dell'isola 1995).

Barriers of WLC

Despite the numerous benefits of the WLC concept, there are barriers associated with it. Flanagan & Jewell (2005) identified challenges and concurred with Kishk et al. (2003), see summary below of generic barriers:

- Lack of reliable and effective cost data and relevant performance that can be tested
- Uncertainty associated with events projection in to the future over the life of a physical asset

- High cost of data collection
- Insufficient time for data collection and analysis exercise affect decision making process.
- The complex problem of the time value of money
- Clients/Industrial Managers lack of understanding of the benefits of WLC

However, new procurement routes, information technology advancement, and awareness of the clients/captains of the industry concerning the relevance of the technique are combining to help in solving the above barriers. Furthermore, the WLC frameworks for calculating BETs and gridline extension (GE) systems costs have been identified.

WLC Framework Identification and Application

This section has identified WLC framework as suitable for evaluating RETs and GE systems. Given the various WLC frameworks assessment, Mahapatra & Dasappa (2012) WLC frameworks have been identified, modified and adopted for this study. This is because their framework is appropriate for calculating the costs of different energy systems, with different capacities, and can accommodate both energy systems that require continuous fuel utilisation such as biomass resources, and energy systems with little or no operating and maintenance requirements like solar and wind. The framework's formulae are presented in section (5.6.3) in chapter five.

Key Elements of WLC

Kirk & Dell'isola (1995) identified six key elements that form WLC analysis:

- Which analysis approach to apply
- What is the realistic discount rate for use in the analysis?
- How are the effects of inflation and increases in individual cost to be taken into account?
- Over what specific period of time are the total costs of ownership be determined?
- When does that time period begin?
- What types of costs are to be included in the analysis, and what costs may be ignored?

4.9 CHAPTER SUMMARY

This chapter has critically assessed energy policies in Nigeria. It identified that Nigeria's energy policies lack implementation strategies. The FIT incentive strategy has been discussed. The study identified that the incentive strategy is limited to centralised grid system only with minimum of 1 MW capacity. Barriers inhibiting RETs policies implementation in Nigeria have been identified that include: inadequate policy framework, apathy in developing RETs, and discriminating among RETs in the country; way forward for the energy policies has been emphasised (that include effective incentives to potential RETs investors, policy instruments should not be limited to grid system only and use of FIT incentive system alone). Further, various energy economic evaluation techniques have been identified and illustrated. The WLC approach has been identified as the most suitable technique for economic evaluation in this study. The next chapter present research methodology for answering the research questions.

CHAPTER FIVE

RESEARCH METHODOLOGY

5.1 INTRODUCTION

The methodology utilised in answering the research questions in this thesis is outlined in this chapter. Firstly, the difference between research methodology and method are illustrated. This is followed by a discussion on the research methodology categorisation on the three dimensions (research philosophy, reasoning and data), and the philosophical standpoint underpinning the study. The research design and processes undertaken in this study are then presented, highlighting the methodological framework. Then followed by the methods (data collection and data analysis) for the study including sampling methods and sample of the participant. A case study approach to strengthening the outcomes of both interview method and WLC approach is illustrated. Validity, reliability and ethical considerations of the research methodology are highlighted. The concluding part discusses the methodological limitations of the research work.

5.2 RESEARCH METHODOLOGY

Both terms, method and methodology are occasionally used interchangeably; however, they differ. According to O'Gorman & MacIntosh (2015), methodology is the study and application of methods and the overall track for answering research questions; while Hussey (1997) refers to the methodology as the overall approach taken, alongside a researcher's theoretical basis, with a view of solving a research question. Methodology encompasses all the step-by-step procedures of executing the research, such as strategy and approaches including methods. Whereas research methods are understood as those tools/techniques used for conducting research (Kothari 2004), or any means for collecting data and analysing them (Hussey 1997). O'Gorman & MacIntosh (2015) offer a structural approach for ensuring identification of an appropriate choice of research methodology as shown in figure (5.1). This ranges from interaction between a research paradigm, approaches, strategies, techniques and procedures.

Sutrisna (2009) categorises research methodology into three main dimensions that may be considered in chronological order, where the preceding dimension informs its relation with the succeeding dimension. This classification includes research philosophy, research reasoning and data dimension. Sutrisna (2009) was of the view that "The philosophical stance of the researcher will strongly influence the reasoning of the research and both will influence the data required by the research and analysis of the data". Although Sutrisna's (2009) classification has been adopted for convenience in this study, the arrangement is not far from O'Gorman & MacIntosh's (2015) approach.

5.2.1 Research Philosophy

In line with philosophical views in explaining methodology, there are two main parts: epistemology and ontology. Epistemology can be described as the process of knowing things and indicates that we have knowledge about something happening. Also, it answers the questions of what and how, while ontology can be described as what things are and/or the study of existence (Renaud 2015). In other words, epistemology has to do with how world knowledge is discovered, or how we obtain valid knowledge, while ontology is the study of being or reality and assumptions about how the world is made (O'Gorman & MacIntosh 2015).

The most acknowledged ontological positions are objectivism and subjectivism/constructivism. Objectivism is a viewpoint that stresses the independence of existence between phenomena and their meanings and the actors. While constructivism is a position that affirms that phenomena and their meanings are continually being accomplished by the actors (Sutrisna 2009). O'Gorman & MacIntosh (2015) further explained that an objectivist position looks at reality as a solid object that can be measured and tested, and exists even when actors don't have a relationship with it. A subjectivist position looks at existence as a collection of views and relationship of existing subjects. Orchestrating the research methodology will require the need to articulate the researcher's perspective - whether you see the world in an objective or subjective way (O'Gorman & Macintosh 2015).

In the context of epistemology, two positions are considered in this research; positivism and interpretivism, with both underpinning the quantitative and qualitative strategies respectively. Although there are other philosophical stands; see figure (5.1) for details. A positivist stand is a deductive/theory-testing approach creating suitable hypotheses, searching for objective knowledge, usually using statistical logic, measurement, correlation and verification to answer how and why things happen. It uses natural science methods such as survey, questionnaire and random sampling (mostly taking big samples). In addition, a positivist stand explains principle and focuses on fact; the research is based on generalisation and abstraction (Raddon 2010; O'Gorman & MacIntosh 2015; Carson et al. 2001).

In the case of interpretivist research, the researcher is more or less a detective searching for subjective knowledge and uses an inductive/theory-building approach. Interpretivism focuses on people and the understanding of relationships. Typical methods used include interviews, analytical techniques, ethnography and focus groups (mostly with small samples but in-depth investigation) and the research is based on the specific and concrete (Raddon 2010; O'Gorman & MacIntosh 2015; Carson et al. 2001).

According to Lee (1989) looking for distinctions among research approaches is irrelevant, as a single philosophical viewpoint may not necessarily accommodate various methods. In fact, it is also debatable to say one philosophical stand is better than the other in an absolute sense; instead the research problem and researcher goals should influence the strategy to be selected (Benbasat et al. 1987). More so, McGrath (1982) makes it clear that "there are no ideal solutions, only a series of compromises". So the objective is to "balance" the compromises.

In line with the above explanation, the link between the two main philosophical stands is unavoidable, this is because positivism usually adopts objectivism as a means of explaining realism, while interpretivism takes subjectivism as a means of understanding the reality that was built independently by each person, and also interpreted differently.

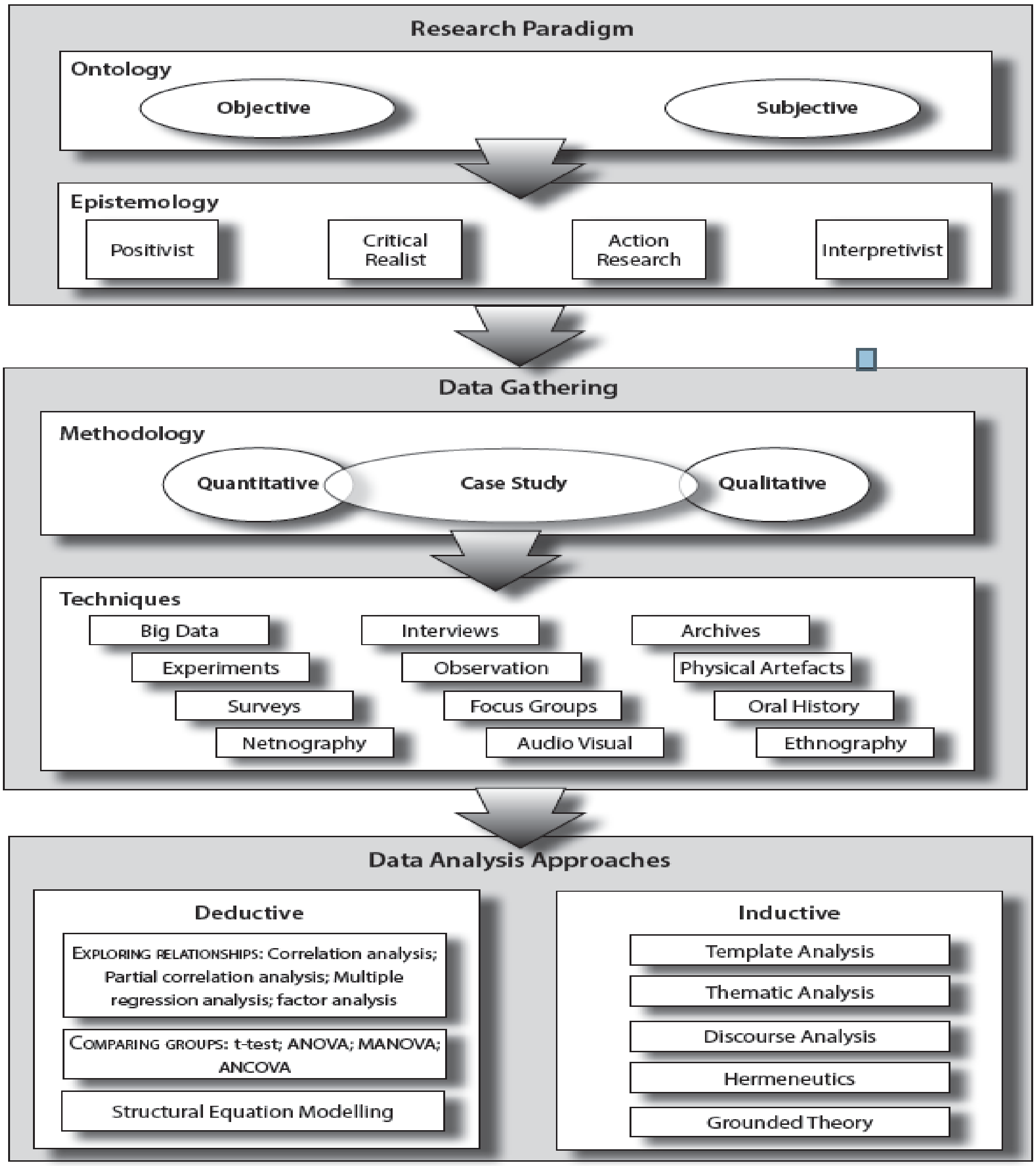


Figure 5.1: Methods Maps (O'Gorman & MacIntosh 2015)

5.2.2 Research Reasoning

Research reasoning refers to the logic of the research; meaning "the role of an existing body of knowledge gathered in the literature study, the way researchers utilise the data collection and subsequent data analysis" (Sutrisna 2009). In this dimension, there are two main approaches: the deductive approach which works to analyse quantitative data, and inductive approach, which analyses qualitative data (Gorman & Macintosh 2015). The two approaches work in alternate direction but it is not impossible to utilise both in a study at the same time or at different levels. The major difference between the two approaches lies in the application of a hypothesis at the beginning, or emerging towards the end of the research work, in arriving at the research outcome (Sutrisna 2009).

5.2.3 Research Data

Traditionally, data collected or analysed are either quantitative or qualitative. Quantitative data require quantitative methods for their generation in terms of collection and analysis. This method is associated with positivism, and a deductive and scientific approach used to collect factual data and at the same time study the relationship between them (Sutrisna 2009; Kothari 2004). Scientific methods utilised in obtaining these factual data include measurements, statistics and quantified data analysis; the conclusions are usually drawn from results evaluation vis-à-vis existing theory and literature (Fellows and Liu 2008).

In contrast, qualitative data emphasise those phenomena qualities being investigated rather than figures (quantities). According to Miles and Huberman (1994) qualitative data are collected through an intense and prolonged encounter in the field or life situations. In other words, they investigated peoples' beliefs, views and understandings and captured them in descriptive form not reliant on figures (Fellows & Liu 2008). Qualitative data are usually obtained mostly through interviews, focus groups, observations, and documents analysing techniques among other methods (Meurer et al. 2007; Kothari 2004). They are normally obtained from a small group of people, unlike questionnaires that use large numbers of respondents to help its data outcome to be generalised. The outcomes of qualitative data are perhaps difficult to replicate, are subjective in nature and data collecting techniques are less structured and mostly use open-ended questions (Meurer et al. 2007; Naoum 2007). Qualitative data outcomes may yield surprises based on the obtained evidence (Sutrisna 2009).

5.3 THE PHILOSOPHICAL STAND

This research adopted a mixed methods approach. This is because the research work aims to proffer a solution to the current lack of commercial electricity in Nigerian rural areas (with only 10% accessibility) using RETs (biomass energy system). Although the study focuses principally on a quantitative approach, electricity provision deficiency to these communities is also a social problem, therefore the perspective of the power-deficient people (stakeholders) requires to be captured. Hence, an interpretive viewpoint has been utilised, with a view to probe this complex problem and seek understanding of the issue.

It is noteworthy that over three decades of establishing energy research centres (RETs inclusive) in the country, little or none of these energy systems have been utilised in Nigerian rural areas. Also, RETs are yet to be enlisted in the energy mix in the country despite reasonable resources being committed to them. According to the revised report of Clean Technology Fund Investment Plan (CTFIP) for Nigeria (2014), less than 1MW of electricity has been generated and utilised from modern RETs (excluding small hydropower that has been in existence since 1923) system in the country. This is not reciprocating the value of the resources allocated therein. More so, from the literature so far reviewed, and the pilot study conducted, using an interpretivist study (interview) technique, it is indicative that the high cost of these RETs is the major barrier preventing their wider utilisation within rural communities, along with a lack of effective competition in the Nigerian energy market (Mohammed et al. 2013; Alazraque-Cherni 2008). Hence, there is the need for a positivist approach (quantitative) in this research; this is with a view to evaluate the economic viability of biomass energy technologies (BETs) regarding being the most suitable technology for rural areas using a whole life costing (WLC) approach. (See table 2.8 and 2.9 for details). Hence, the research work is based on mixed philosophical stands involving both interpretivist and positivist viewpoints.

5.4 RESEARCH DESIGN

According to Yin (2009) research design is a "logical plan for getting from here to there, where "here" may be defined as the initial set of questions to be answered, and "there" is some set of conclusions (answers) about these questions". Getting from here to there is achieved by completing activities such as pertinent data collection and analysis that enables research questions to be answered.

Authors have classified research design differently, including those who classified it from the experimental point of view; true, quasi and non-experiment (Trochim and Donnelly 2008). Whilst Fellows and Liu (2008) classified it into case study, field study, experiment, ethnography, quasi-experiment. Also, Yin (2009) added to the above: survey, archival analysis, history, to which can be added ethnography and grounded theory (Saunders et al. 2003; Creswell 1998). Selecting the research design approach to follow, depends on the research type and aim, information availability (Naoum 2007), time and resources availability, and whom is going to use the findings (Patton 1990).

In line with the aims and objectives of this research, an experimental design will not be suitable, because the researcher is not going to be involved either directly or systematically in manipulating of behaviours, or evaluating any intervention on an object. The study is not going to use ethnography because the researcher is not going to engage in the field extensively with a view to study a group through observation and learned customs and ways of life. Also, the research is not trying to generate theory, as is the case in grounded theory. Instead, survey and case study designs will be utilised.

Survey design is a systematic way of gathering data from a reasonably large number of respondents within a specific time frame through the use of interview, questionnaire or observation techniques (Gary 2004; Naoum 2007). For the purpose of this study, an interview method has been selected and reasons for the selection were because it assisted in knowing facts and views of respondent about the phenomenon through meeting them directly, not through questionnaires (which its questions, factors and variables not yet been empirically tested before particularly in this case (Naoum 2007)). More so, as a WLC approach has been adopted for economic evaluation purposes in many industries, it has also been adopted in this study for the same reason. Hence, WLC approach has been selected for evaluation of economic viability of biomass energy technologies (BETs) in provision of sustainable electricity in Nigerian rural areas.

This study is also using a case study design. This is with a view to strengthening the WLC approach result outcomes from the economic evaluation exercise. Yin (2009) described case study as an "empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". The case study approach can investigate single or multiple units of study through application of familiar research methods. Hence, multiple isolated rural communities have been utilised as case studies in this research.

5.5 RESEARCH PROCESS

This section presents the research process within the context of this study. The research process is divided into four stages: planning, data collection, data analysis, and RETs implementation framework development and evaluation. See figure (5.2) for details.

- The planning stage consists of the identification of a topic, research problem formulation (gap identification) through pertinent literature reviewing and a pilot study (exploratory interview) and development of appropriate research questions and hypothesis.

- This study used mixed method approach. Literature review has been utilised to collect secondary data, which has been used to inform how primary data can be collected and analysed by the study. Primary data have been collected using both interview method and WLC approach.
  Interview method has been used in this study with a view to seeking to know from RETs stakeholders (practitioners, regulators, academia and energy researchers) what is inhibiting progress in Nigerian energy sectors, despite the abundance of energy resources. WLC approach has been utilised to evaluate and optimise the economic viability of biomass energy technologies (BETs) in provision of sustainable electricity in Nigerian rural areas. This is with a view to examine its affordability to rural communities.

- The data collected from the two research methods have been respectively been analysed using content analysis method (see chapter 7) and WLC approach (see chapter 6).

- Finally, a RETs (BETs specifically) implementation framework has been developed, evaluated, tested and reported. The case study approach has been used in evaluating, testing and validating the framework based on the WLC outcomes, using some isolated rural communities for this purpose.

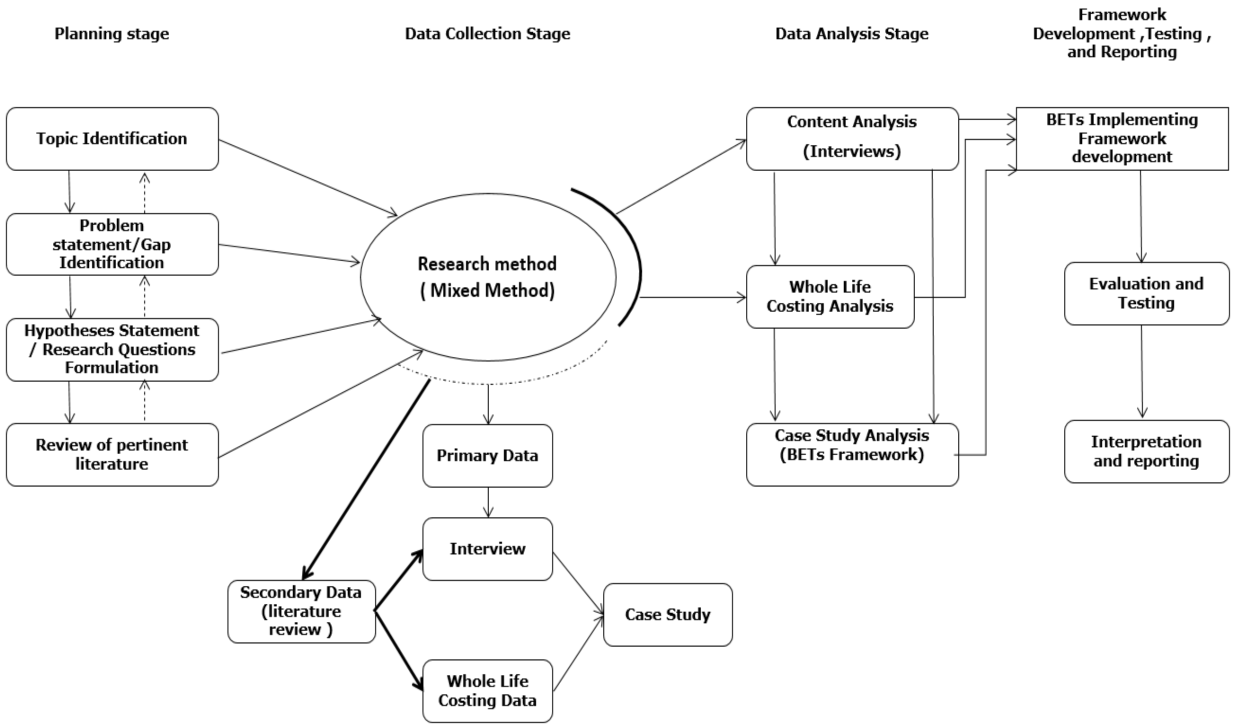


Figure 5.2: Research process

5.6 METHODS OF DATA COLLECTION

A mixed method of data collection has been used in this study. This is with a view to eliminate/reduce the demerits of a particular approach, and at the same time gaining the benefits of each, both, or a combination of all. Also, research may have different research questions, requiring different methods to find an answer (Fellows & Liu 2008; Gary 2004).

The interview method and WLC approach have been used for collecting primary data, and secondary data has been collected mainly through a literature review. Also, a case study method has been utilised to evaluate the outcomes of the WLC approach (by collecting and analysing a new set of data from the six villages). Hence, cross-sectional data have been collected (see figure 5.2 for details).
According to Knight and Ruddock (2009) the mixed method can benefit research through assisting a deeper understanding and the proffering of a better solution in answering research questions. It is also a valuable strategy to positivists who always relegate the qualitative approach to the background. Hence, this will make researchers in the energy industry (economics side), which largely

depends on the quantitative approach, gain better understanding about how people's perspective can influence their research.

The utilisation of a mixed methods approach is not without problems. Knight and Ruddock (2009) stated that the combination of methods is by no means a direct strategy of conducting research. This is because it involves a range of philosophical, techniques, methods, cultural and psychological problems that confront the researcher. However, the strongest strategy is collecting data via many sources and the comparison of the resultant outcomes (James 2007).

Data Requirements

In spite of the expected data to be collected being mainly quantitative; qualitative data will also be collected with a view to answering some research questions. For successful WLC economic evaluation and optimisation, the following primary data for the biomass energy systems utilisation in provision of sustainable electricity in Nigerian rural areas have been collected: initial capital/acquisition costs of the systems, asset life, the discount rate, subsidy and incentives rate, inflation rate, maintenance and operating costs (biomass fuels, operators), end time cost, taxes and levies, downtime cost and time (Woodward 1997). Also, data for a centralised grid extension energy system have been collected for the purpose of comparison. While on the qualitative data requirements, the collected data should be able to answer questions such as, "What are the constraints inhibiting implementation of RETs in Nigeria?", "What are the appropriate strategies for moving RETs forward?", and the suitability of biomass energy system utilisation for provision of sustainable electricity in Nigerian rural areas, among others.

5.6.1 Literature Review

Reviewing literature is not only about reading and appraising what others have done in a study area, it can equally be analytical and descriptive in nature (Naoum 2007). When it critically analyses the work of others (by revealing differences, contradictions and similarities) it is analytical, while if it describes people's work it is descriptive. Literature review is also a recognised technique that underpins the entire research process through the methodology, data collections and findings. Similarly, it assisted in identifying suitable research strategies and methods utilised for this kind of research as indicated in figures (5.1) and (5.2).

A literature review has been used in this study to generate research questions, aims and hypotheses (Creswell 1994), helping to arrive at a research design and helps in identifying the research gap of the research (where only approximately 10% of Nigerians rural communities have access to commercial electricity). Then, it systematically helps in dismembering the information obtained into meaningful components with a view to identify relevant pertinent literature. This has been achieved through exploring, refining and processing to specified outcomes (Gary 2004) using journals, conference papers, textbooks, Nigerian energy policies, newspaper publication etc. Similarly, it helps in determining the characteristics of the six major RETs using the concept of SWOT analysis (table 2.8), assessment of sustainability indicators of the RETs in the context of Nigerian rural areas (table 2.9), identification of existing energy policies and policies problems in the country, and many other variables. Also, it has been used in identifying the most appropriate sustainable energy source for Nigerian rural communities. Further, it helps in avoiding duplication of research.

Finally, this method has been used in discussing the outcomes of interview and WLC approaches in answering the research questions. The literature review can also come after the emergence of a research pattern to support it (Gary 2004). This further supports the assertion of Creswell (1994) in respect of the positioning of a literature review; that it can be in the "Introduction, as a separate section and as a final section in the study". Hence, its position largely depends on the research strategy adopted.

5.6.2 Interview Method

According to Naoum (2007), an interview is a technique for collecting information and opinions directly from respondents by the interviewer with a view to obtaining clear answers related to a research hypothesis. In other words, it is a "managed verbal exchange" (Newton 2010). An interview method is usually used with a view to detecting a problem, selecting solutions and to establish new ideas (Zikmund 1997), and is normally used where importance is attached to personal language as data, to generate rich data, and the understanding of perception (Newton 2010).

According to Cohen and Manion (1997) cited by Gray (2004, p. 214):

"Interview can serve a number of distinct purposes. First, it can be used as the means of gathering information about a person's knowledge, values, preferences and attitudes. Secondly, it can be used to test out a hypothesis or to identify variables and their relationships. Thirdly, it can be used in conjunction with other research techniques, such as surveys, to follow up issues"

In order to improve understanding of the study area, a pilot study was first conducted at the beginning of the research using exploratory interviews, and later on a detailed study was conducted using semi-structured interviews. The reasons for the interview method used in this research are that the problem under study needed detailed investigation concerning what, how and why things happened regarding the energy crisis in Nigeria, particularly in its rural areas, with only 10% accessibility despite significant energy resource (Nigeria being a member of OPEC). Also, it assisted in knowing facts and views of respondents (practitioners) about the phenomenon through meeting them directly with a view of understanding the complexity of the problem, and provide a rich solution(s) for the case under study (Miles and Huberman 1994), rather than through questionnaires reliant on questions, factors, variables and themes that sometimes have not yet been empirically tested, particularly in this case (Naoum 2007).

More so, the questionnaire approach uses mostly closed-ended questions without the researcher's supervision, which may eventually lead to nuances of the respondent's voice. Also, an interview is more desirable than questionnaires where questions are complex, and there is the opportunity for probing where necessary (Gray 2004).

Questionnaires are however, good for generalising, are more economical in terms of data collection and analysis, and good for testing hypotheses (Gray 2004; Kothari 2004); but also require a large sample for effective generalisation. This is impossible in this context, as a large sample cannot be drawn following the outcomes of two exploratory studies conducted at the beginning of the research work (see section 7.4.3-human capacity deficiency constraints). These provided evidence that the industry is full of quack practitioners. Hence, care was exercised in selecting an appropriate sample (see section 5.7 and 5.71 and table 5.3 for details).

The major demerits of this method are a likelihood of bias, unapproachable top management staff or executive, and being uneconomical compared to a postal questionnaire technique (Kothari 2004). More so, the expected outcome might not be achieved given the fact that the respondents may not be willing, or are uncomfortable, to provide the data the interviewer is hoping to explore. Also, the interviewer may not have asked the questions appropriately considering the fact that s/he is inexperienced or not familiar with the local language (Gray 2004).

Basically there are three kinds of interview: unstructured, semi-structured, and structured (Naoum 2007; Kothari 2004). Newton (2010), states that "The 'unstructured' pole is closer to observation, while the 'structured' use of 'closed' questions is similar to types of questionnaire". Other researchers categorise interviews into formal and informal, controlled and uncontrolled, and flexible and inflexible (Gray 2004). See details of interview methods in table (5.1).

It is a recognised strategy that the interview analysis framework should be established before data gathering, and the questions to be asked are discussed and reviewed before going to the field. See appendix A for both questions asked during exploratory and semi-structured interview sessions respectively.

Table 5.1: Interview Methods (Adopted from: Kothari 2004; Naoum 2007; Knight & Ruddock 2009)

Unstructured	Semi-structured	Structured
Open-ended questions are asked	Uses both open and closed ended questions	Mostly closed-ended questions are asked
Usually for exploratory studies	More formal than "unstructured" interview	Usually for descriptive studies (generalisation)
Flexible in asking questions	Start by asking indirect question	Pre-determined set of questions
Interviewer has significant degree of freedom in questioning	Interviewer has great deal of freedom to probe	Interviewer has great deal of freedom to probe
No standard means of recording	Taking note/tape recording	Highly standardised techniques of recording (tape recording)
Similar outcomes are not expected	It "depends"	Mostly of similar findings and more accurate
Difficulty in analysing	Less difficult compared to unstructured	Relatively straight forward analysis and interpretation
	Focus attention on the experience of the respondents	Interviewer requires lesser skill
	Demerit - Order of questioning may change (can diver interview)	Demerit - Interviewer responding with a single word or phrase

In the introductory letter sent to interviewees, they were assured of anonymity and the researcher getting back to them after transcribing the interview content, with a view to confirming, rejecting or reviewing what they said. This was again mentioned to everyone in the opening statement during their interview sessions. This improved the level of co-operation from them. More so, Patton's (1990) suggested strategies for conducting interviews were followed, whereby exact wording and the sequence of questions are determined in advance, all the interviewees were asked the same basic questions and questions are worded in a completely open-ended format. All the interview sessions were conducted face-to-face and in the interviewees' office premises. Both exploratory and semi-structured interview sessions lasted between 21-28 and 30-46 minutes respectively. Also, all the interview sessions were tape recorded. Details of the sample, sampling methods and sample size chosen with their characteristic can be found in section 5.7 and 5.71.

5.6.3 Whole Life Costing (WLC) Approach

WLC has been recognised as a tool or an approach for decision making in various industries and suitable for testing hypothesis (Short et al. 2005). The reason for choosing WLC in this research is to evaluate and optimise the economic viability of the biomass energy technologies (BETs) and grid extension (GE) systems in the provision of sustainable electricity in Nigerian rural areas. WLC approach utilisation was informed based on the findings of the literature review, pilot (exploratory) and semi-structured interview methods, which identified that high cost has been the major barrier in the development of RETs in rural areas (Alazraque-Cherni 2008).

The application of WLC can be found in many sectors such as construction, transport, and energy. Usually, it is used as a management tool to enable appropriate selection among various mutually exclusive competing alternatives, and in ranking among the same set of investment alternatives bearing in mind important cost relevant to investment ownership, operating and disposal (Kishk et. al. 2003; Ferry & Flanagan 1991; Woodward 1997; Short et al. 2005). In this research, the WLC approach enables the capital cost and unit cost of electricity of various energy systems under consideration (BETs and GE) to be determined. See further details of WLC in section 4.8.2.

In this study, the WLC framework proposed by Mahapatra and Dasappa (2012) has been adopted with some modifications specifically for this application. The reason for selecting the WLC framework is because it is suitable for evaluating energy technologies such as BETs and GE systems, given that the framework can accommodate energy systems requiring the continuous utilisation of fuels such as biomass and fossil fuel resources. The carbon trading incentive incorporated in the framework is not applicable in the Nigerian power sector currently, and is therefore replaced with the Feed-in-Tariff (FIT) incentive strategy in the country. See details of FIT incentive strategy in sub-section (4.5) and table (4.1). Salvage value and inflation are not considered in this study for ease in decision making. See the expressions (formulas) of the WLC framework for both BETs and GE systems calculations in sections (6.4 and 6.6) and Table (6.5) for their nomenclatures (all in chapter 6).

The biomass conversion technologies considered for economic viability evaluation in this study include gasification, combustion and anaerobic digestion (biogas) systems, while pyrolysis technology, despite relevant literature having been reviewed, was not included. This is because "there are no commercial plants for electricity production based on this process" (Gonzalez et al. 2015), let alone for small (typical rural requirements) capacities not exceeding 150kW identified in this study. While there is increasing market attention to the studying of pyrolysis operations for co-generation purposes, all of the pyrolysis components being utilised are still at the pilot stage (Owen et al. 2013).

The costs of all the biomass primary and secondary conversion components have been sourced directly from the manufacturers. While the costs for grid line components have been obtained directly from the Nigeria's open market. For biomass equipment's prices in particular, the existing literature reported widely varying figures; these did not change within the context of this research as such variations are as a result of, size, location factor, and technology maturity. This problem may be connected to the fact that some BETs are emerging systems. Typically, gasification (GAS) being classed as an emerging technology, along with the impact of location factors (more expensive in Europe and America but cheaper in India), are emphasised by Breeze (2014) and O'Connor (2011). In addition, Ganesh and Banerjee (2001) confirmed that 'gasifiers' cost in India is much lower than those elsewhere". In comparison, direct combustion (DC) components' prices are the most stable because the system has been utilised for a long period and by the end of 2012 around 75% of the biomass electricity generation is produced from this system (Martinot 2013).

Biogas system components' prices were only obtained through a turnkey procurement process as manufacturers are reluctant to participate under the traditional contractual approach and small capacities. See table (6.1 and 6.2) for details of the prices of the BETs components. Furthermore, all the conversion systems' cost have been presented in US$ for universal understanding, despite the costs having been obtained in India Rupee (INR) for GAS and AD systems, Chinese Yuan for the DC system, and Nigerian Naira for the gridline extension system. It is noteworthy that approximately Nigerian Naira 200 is exchange for US$1 (from 2015 to date–official rate).

The current prices of the biomass fuels were sought directly from the market (field survey of vendors) as it is impossible to obtain the required details from the stock market. Fuel wood weights are measured and subsequently converted to unit cost/tonne. A typical case is where fuel wood costs were obtained through step-by-step details being sought from the vendors. A Mitsubishi Canter truck with a loading size capacity of: length (4.2m), width (1.8m) and depth (1.5m) is typically utilised for transportation. The total price of the supply chain including transportation is US$112.50 representing 45 units as classified in the Nigerian open market and each unit is approximately 105kg/unit and sold at around US$3.00. Hence, the unit cost of the wooden fuel is US$28.57/ton. This principle has been adopted for other biomass fuel types utilised. See section 6.3 and table 6.3 for further details. Furthermore, the discounted rate used is 13%, this figure has been obtained from the Central Bank of Nigeria. The annual maintenance cost for the various biomass energy technologies differs, hence, the figures utilised have been obtained from the studies by Mahapatrra and Dasappa (2012), IRENA (2012), Ganesh and Banerjee (2001) and Banerjee (2006).

5.6.4 Case Study

Yin (2009) describe a case study as an "empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". Case study research helps in gaining specific understandings and knowledge of contemporary phenomenon under investigation. The technique can investigate a single unit or multiple units of study through application of familiar research methods. More so, case study research and its outcomes are not only limited to qualitative evidence but also covers quantitative research (Farquhar 2012; Yin 2009).

Schramm (1971) opined that the benefit of a case study lies in its ability in illuminating decision(s), based on why, how and with what set of results. Also, the technique is good for triangulation purposes where data are converged with a view to provide constructive validity to the overall data collected. Finally, a case study helps in gaining better confidence when testing a concept or theory (Yin 2003), which is the reason for its application in this research.

The common demerits of case study research include: a lack of rigor when compared to surveys or experiments; may not be suitable for exploratory study for other form of research techniques; generalisation concerns of the research outcomes possibly coming from a single case study, and even the result size (huge and long) and problems associated with a non-repetitive process of data collection (Yin 2009; Yin 2003).

In this research, a case study approach is used for validating the outcomes of WLC analysis and testing of the developed RETs implementation framework in respect of the economic evaluation of BETs and GE systems for sustainable electricity provision in Nigerian rural areas. To do this, new sets of data have been collected. According to Fellows and Liu (2008) "in any testing, it is essential that data are used which have not been employed in building the model". In this respect, six isolated rural communities have been selected, which include four villages from Funtua local government and two from Dandume local government; all the communities have distance of approximately 5km from the nearest power energy transformer. Both Funtua and Dandume local government area councils are located in Katsina state, northwest Nigeria. Although, not that the total population of the community was not of interest to the researcher and the study, but instead the study focuses on the total number of the houses (usable rooms in particular), with a view to determining the total power energy required by the communities. This was achieved by liaising with the communities' heads who instructed every household's head to grant access to their various houses. See section 8.11 and table 8.1 for details of the villages' energy requirements, numbers of households among other data obtained.

The application of a case study approach does not mean the result cannot be generalised, but rather it provides an in-depth understanding of a specific problem. According to Naoum (2007; p45) "case studies are used when the researcher intends to support his/her argument by an in-depth analysis of a person, a group of persons, an organisation or a particular project".

5.7 SAMPLING

A sample is part of a whole which is obtained with a view to reveal what the remainder is like (Naoum 2007). Sampling is necessary because it is usually difficult (if not impossible) to examine an entire population. For instance, it will be possible to survey a technique (such as uses of prefabricated components by a firm) among construction firms in Nigeria because the population is small, but it will be difficult to use a population survey to discover how many Nigerian construction workers like to take coffee or tea every morning (Fellows & Liu 2008). Hence, the characteristic of a sample should ensure similarity (be representative) to the population and act as its true representative when examined statistically by the researcher (Naoum 2007; Fellows & Liu 2008). Drawing up a sample from a sample frame is possible randomly or non-randomly (purposefully); details of other sampling styles under these two main sampling techniques can be found in Patton (1990), Gray (2004), Kothari 2004 and Naoum (2007).

Random sampling is mainly used when particulars about the characteristics of the sample are unnecessary such as size of the organisation, respondents' background and work type, among others (Naoum 2007), also where every person in the total population can be chosen (Knight & Ruddock 2009). However, care needs to be exercised here in respect of the purpose of the study. While purposeful (non-randomly) sampling is usually selected based on the interview technique (Naoum 2007), other criteria may be used such as knowing the respondents, access gained, or meeting an expert in the field of the study (Knight & Ruddock 2009).

A combination of critical case and snowball purposeful sampling methods have been used in this study; critical case sampling allows logical generation and full utilisation of information to access other cases, where if it's true of that person, it is the same for his/her colleagues or persons. A snowball sampling style has been adopted because it determines cases of interest, such that people who know a set of people know them based on the case information (Patton 1990). Both purposeful sampling techniques have been used based on the problem of quack practitioners identified during the data collection at the exploratory stage of the research as explained previously. This situation arises because of limited real (not quack) RETs practitioners in Nigeria. Hence, during the final stage of the interview sessions (semi-structured), extra care has been taken with a view to select suitable participants (interviewees). This exercise was undertaken via conducting background checks on interviewees, by asking their details from their colleagues, consulting their human resources department were an opportunity presents itself, and based on their contribution to RETs. The criteria utilised in the selection include work type (for example, energy research centres, RET practitioners), and qualifications related to RETs. Also, through the literature reviewing exercise, some of the participants were identified. Their addresses and names were identified and later contacted via emails and telephones.

5.7.1 Sample Size

Given that sample size must be determined with caution, so as not to be overly large or small, because of economic and unattainable objective reasons respectively. Hence, as a general principle, sample size must be an appropriate size and should be selected through some logical process from the population (Kothari 2004). Kothari (2004) suggested the following factors for consideration when determining sample size: nature of universe, nature of study, sampling types, number of groups, standard of accuracy, acceptable confidence level, resource availability, questions and population size; then time availability and what will be beneficial (Patton 1990). Patton (1990) depicts that a qualitative approach is full of uncertainty, and the uncertainty becomes clearer when determining sample size. Patton added that in qualitative research "there are no rules for sample size" rather "it depends". Hence, determining sample size in purposeful sampling should be based on informational considerations (when no new information is forthcoming) (Patton 1990).

There are basically two methods of determining sample size, which include the mathematical approach (precision rate and confidence level base) and theoretical method. According to Kothari (2004), the mathematical model works by specifying the desire of the estimation precision; while the theoretical approach works through the use of Bayesian statistics to measure the cost of obtainment as against the expected value of additional information required.

The Patton's statement above has been reflected in this study. This is situation where the number of interviewees was informed based on the fact that no new data emerged. Hence, this is indicative the data collection has reached saturation stage. Also, in particular, this problem of inadequate respondents (interviewees) may be connected with the limited numbers of real RETs practitioners in the country (Garba et al. 2016a).

Table 5.2: Details of Interviewees

Interviewees	Establishment	Qualification	Year of Experience
1	Academic	PhD	18
2	Research Centre	PhD	28
3	Academic	PhD	16
4	Regulator	Msc	14
5	Research Centre	PhD	31
6	Research Centre	PhD	27
7	Research Centre	PhD	20
8	Research Centre	PhD	23
9	Research Centre	Msc	8
10	Practitioner	PhD	35
11	Regulator	Msc	28
12	Research Centre	Msc	11
13	Regulator	PhD	27

In the light of the RETs quack practitioners problem identified during the exploratory study and RETs being emerging technologies, this study initially contacted 20 participants. 13 persons participated and were considered suitable for this study, because it is a technical survey and the method is used for triangulation purpose. According to Kothari (2004) a small sample is considered appropriate in a technical survey. More so, 4 persons declined because of their schedules in their various places of work; while the remaining 3 persons did not respond to the emails and calls made to them. See table (5.2) for details of the participants' qualifications, years of experience, practice types and affiliation. During the interview sessions, varying questioning styles as described by Ritchie and Lewis (2003), were utilised. Despite the challenges, sampling combination theories were used, where the interviewees' selection covered all the areas of RETs expertise in Nigeria, so as to ensure rich outcomes.

5.8 DATA ANALYSIS

Following the successful completion of data gathering, the researcher will become aware that a considerable quantity of data will need to be reduced to form identical groups or classes so as to make meaning out of them. The purpose is to highlight differences, trends or similarity with the original body of knowledge in an appropriate pattern and then draw conclusions accordingly. If this is not achievable, there will be a need for the development of a new hypothesis that has to be tested statistically or qualitatively (Kothari 2004; Naoum 2007). More so, there is the need for understanding analysis techniques by researchers making use of both qualitative and quantitative approaches for the purpose of testing a hypothesis or answering research questions.

Some researchers were of the view that there is no difference between data processing and data analysis, and some have a contrary view. The difference depends largely on the type of analysis being undertaken. In technical terms, data processing are the initial arrangements before data analysis which involves editing, coding, classification and tabulation of data collected such that they are congruent with analysis requirements. Data analysis also means the "computation of certain measures along with searching for patterns of relationship that exist among data-groups" (Kothari 2004).

Given that a mixed methods approach has been used for the data collection, the same approach has been used for analysis. The data collected has been analysed using both qualitative and quantitative approaches. There are many methods of analysing qualitative research including content analysis, semiotics analysis, discourse analysis, content analysis, thematic analysis, grounded theory, and conversional analysis (Fellows and Liu 2008; Vaismoradi et al. 2013; Gray 2004). Despite considerable overlap between qualitative data analysis methods in terms of techniques and procedures "as they are term family approach", there are still differences between them (Vaismoradi et al. 2013). For the purpose of this study, these differences are as follows:

- This study is not using grounded theory analysis because the study is not interested in developing a theory; the study has research questions and hypothesis which need to be answered and/or tested respectively, which is contrary to the principle of grounded theory (Gray 2004; Creswell 1998);

- The study does not use conversational analysis because it is not analysing everyday conversations outcomes like telephone calls or courtrooms sessions;
- The study is not concerned with analysing the linguistic expression of the participants, as in the case of discourse analysis (Gray 2004; Flick 1998; Creswell 1998; Tong et al. 2007);
- The study does not make use of thematic analysis because it is not interested only in identifying, analysing and reporting themes within the data (Vaismoradi et al. 2013). However, the study does make use of the content analysis method.

5.8.1 Content Analysis

As this study is interested in generalisation of result outcomes through the application of a qualitative approach, and given the fact that the research subject under study has no significant factors and variables that have been reported in the literature, or tested empirically using questionnaire or other method. Hence, content analysis is suitable to conduct this form of analysis. According to Gray (2004) content analysis is more of a deductive approach which can lead to generalisation of the result outcomes. The analysis form can help with logical organising of data so as to form a recognisable pattern (Tong et al. 2007).

According to Dey (1993) (cited by Gray 2004; p327) content analysis is the "process of breaking data down into smaller units to reveal their characteristic elements and structure". Content analysis objectively and systematically identifies distinctive features among the data with a view of making inferences (Gray (2004). Vaismoradi et al. (2013) added that the goal of content analysis is the description of content characteristics with a view of investigating what was said, to whom and for what purpose. Content analysis measures evidence in a positivistic way (Fellows & Liu 2008), and can also be utilised in testing a hypothesis (Berg 1995). Also, it is more suitable for situations that require low-level interpretation (Vaismoradi et al. 2013). In the process of achieving objective measurement in content analysis, there is the need for establishment of the rule called "criteria of selection" long before the data are analysed (Gray 2004).

As regards the qualitative approach in this study, it has been used for the purpose of triangulation, where data in respect of constraints inhibiting RETs development in Nigeria, and strategies for moving RETs forward in rural areas needs to be identified from stakeholders directly. While the use of content analysis in this study relates to the measurement of various codes, concepts, categories and themes frequency in the data collected, with a view to determining patterns and trends of words used (Vaismoradi et al. 2013). All the qualitative data collected from stakeholders with a view to understanding their perceptions about the phenomenon under study, and subsequently analysed, have helped quantitatively in identifying the most significant barriers and best strategies for moving RETs forward in the country. The results have been partly analysed using percentage and numbers (nominal analysis) of the interviewees, and presented in tables and charts; but the analysis has been largely qualitative. Naoum (2007) opined that some of the qualitative data may be quantified subsequently but the analysis is mainly qualitative, which is the case in this research.

The following sections present the processes involved in analysing qualitative data using a content analysis approach comprising of preparation (transcribing), organising (coding, concept, themes/categories development and data display), and reporting (Vaismoradi et al. 2013). See figure (5.3) for details.

Interviews transcribing

13 interviews were conducted and transcribed. All the interviews were transcribed using the full writing-out method, which placed pressure on the researcher’s available time resource. As the transcribing process progressed, the researcher highlighted key issues and factors forming part of the many codes identified subsequently. Having finished each interview transcription, the researcher reads through the text many times with a view to make meaning out of it. This has helped significantly during the coding and reporting stages.

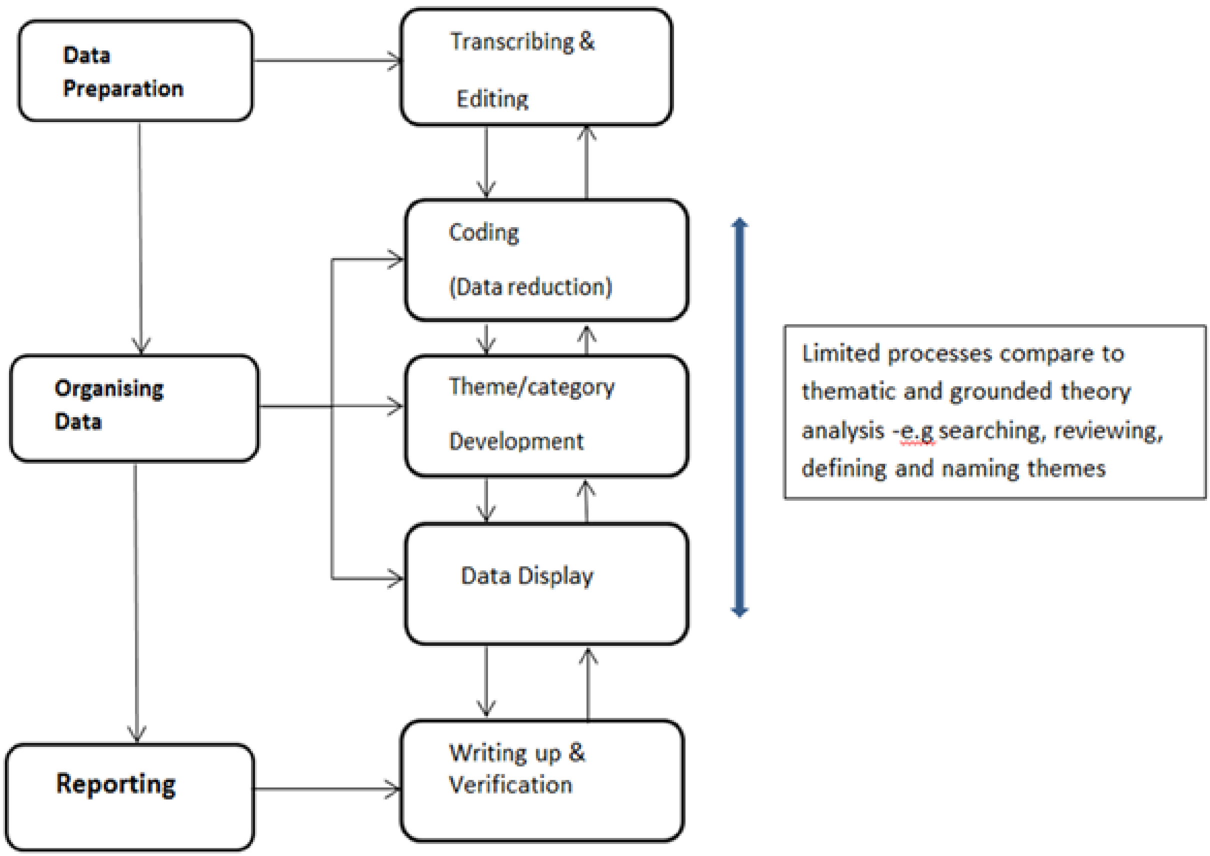


Figure 5.3: Content Analysis Processes (Adopted from: Vaismoradi et al. 2013)

Coding to Concept

In order to summarise the responses and identified answers from the interviewees, and then extract meaning out of them, it is necessary to codify them. Naoum (2007) describe coding as the means of "identifying and classifying each answer with a numerical score or other character symbol". Open coding approach has been used to disaggregate transcribed data into units (Gray 2004); clusters of codes with identical features are grouped together to form concept. Typically, similar related codes from different interviewees under constraints of RETs question were counted and presented in tables. See table (5.3) for instance. In this context, the total numbers of interviewees that mentioned data/information that could be placed as a codes are grouped together and expressed in percentages which then forms part of the analysis. See table (7.1) for details. This analysis resulted into identifying major and minor constraints of RETs in Nigeria. Similarly, it helps in identifying new themes which serve as findings from the qualitative analysis. See table (5.3) for typical example of codes in respect of constraints of RETs in Nigeria that were developed to concepts and then themes.

Table 5.3: Codes to Concept Development

S/no	Codes	Concept	Category/Theme
1	"High investment cost has been one of the greatest problems for fuel wood alternatives" (I-5)	High investment cost Barrier	Economic Constraint
2	"Because of high investment of solar PV, people could could not pay for upfront money to procure it" (I-7)		
3	"While people are willing to buy, initial cost to do so is very difficult to come by" (I-8)		

Note: I=Interviewee

Categories/Themes Development

Following on from concepts generation based around groups of codes, clusters of concepts with identical features were grouped together to form categories/themes. This iteration process comprises constant comparison and contrasting of the sentences and paragraphs from the transcribed interviews being carried out until new codes, concepts and themes could no longer emerge; hence, data saturation is achieved. The themes/categories in this context are the main findings of the qualitative analysis that have been reported in chapter seven (7). Codifying information into themes and ideas is considered the best way to analyse qualitative questions (Naoum 2007). During this exercise, many concepts, sub-categories and categories were collapsed, and new ones appeared (kind of iteration process). The identified codes were intended to support the themes during the reporting stage in terms of who say this, and to whom, and for what reason.

Data Display

Data display is a systematic compressed assembly of information that allows conclusion drawing (Miles & Huberman 1994). In this context, some of the themes/categories generated have been displayed in tables, charts and in words. These presentations helped to simplify and reduce the whole processes into a compact form for the reader’s consumption, considering that humans are not good at processing large amounts of information (Miles & Huberman 1994).

Reporting

Given the tabulation and presentation of figures of the identified categories/themes under different sets of questions of the interview; percentages and numbers of the interviewees who support this or that have been used to analysed the data. Typically, the percentage value has been used to identify the most and the least significant constraints based on the numbers of the interviewees that mentioned them. This has been repeated when identifying strategies for moving RETs forward in Nigerian rural areas and so on. More so, there are instances where numbers of the interviewees have been used to conduct the analysis. At this stage of analysis, a lot of interviewees' quotes and some levels of description were utilised in answering research questions (Flick 1998).

During the analysis, differences and similarity, supporting or disagreeing with various variables from the interviewees were identified; these lead to description of their views in answering research questions or confirming or rejecting the hypothesis. Then, conclusions were drawn accordingly. It should be noted that the qualitative approach has only been used in this research for the purpose of triangulation (this has helped in identifying high cost and policy constraints as the most significant barriers of RETs development in the country, and subsequently led to the application of a WLC approach). During the reporting processes the suggested checklist by Tong et al. (2007) has been adopted, and this significantly helped in including the omitted items in both the organising and reporting stages. More so, Microsoft "Excel" and "Word" software have been used in processing, analysing and managing the study.

5.8.2 WLC Analysis

Understanding a statistical analysis technique is essential for researchers using a deductive approach to test a research hypothesis. Inferential statistics are the most widely used in this context, as they help in confirming or rejecting the assumption(s) made (Fellows & Liu 2008; Field 2009). However, in this study, a WLC approach has been utilised to do similar work as would inferential statistics, as it uses quantitative means (figures and measurement) in confirming or rejecting hypothesis; it is part of an energy systems' economic and investment evaluating techniques. In this study, WLC has been used to evaluate and optimise the economic viability of biomass energy technologies (BETs) (combustion, gasification and biogas systems) vis-à-vis centralised grid extension (GE) energy system in supplying sustainable electricity to Nigerian rural communities. The main benefits of WLC analysis lay in the selection of optimal technology among competing alternatives, and the ability to assess the consequence of a decision previously made (Kirk & Dell'isola 1995; Woodward 1997). Hence, it is appropriate to use it to accept or reject an investment proposal or hypothesis that BETs is suitable for providing sustainable electricity in rural areas.

WLC analysis in this study has been used to determine the following:

- The capital cost of different BETs based on their various capacities per kW (capacities from 150kW – 10kW). Similarly, investment cost of GE energy system has been evaluated.
- Unit cost/kWh of electricity from BETs and GE energy systems, taking into account presence of incentive or without incentive strategy (Feed-in-Tariff).
- The various system capacities, and fuel consumption pattern vis-à-vis operational hours (given these communities might not need 24 hours electricity at the moment).
- The single present worth formula has been used (to determine replacement cost for internal combustion engine under gasification for example, because it only need to be replace once during the lifespan of the asset).
- All the relevant costs over the life period of the assets being discounted to the base year using the present worth analyses methods.
- Enabling periodic payments of operations and maintenance (minor and major) based on the discounted rate. For example daily biomass fuel, services of the equipment (quarterly) etc. Also, the incentive (FIT) system has been discounted throughout the whole life of the equipment. However, some sections of the analyses include scenarios where a FIT system is not applied for comparison purpose. The findings of the WLC analyses are presented in chapter 6.

5.9 VALIDATION AND RELIABILITY

The objective of the methodology chapter is to provide rich information indicating that appropriate methods have been utilised in data collection and analysis in research design, and subsequently lead to the answering of research questions. This has been achieved in this research through application of a mixed method (triangulation) approach, which enables many methods to be used. More so, the logical way of data collection and analysis, such as a literature review informing a pilot study with a view to exploring what is out there in practice. The outcomes of the two methods led to the semi-structured interview method. Then the convergence of the three approaches led to the WLC approach. The outcome of WLC analysis informed the use of a case study technique, and this is with a view to validate the suitability of the BETs sustainable electricity implementation framework developed. Hence, this is a kind of internal validity. According to Yin (2003), constructive validity uses many sources of data collection, internal validity is in the systematic process of data analysis, and external validity lays in the application of systematic iteration in many case studies. All of these validation approaches have been utilised in this study.

Further, all the methods used in this research were appropriate, and all the data collected and analysed were based on the requirement to answer the research questions. As mentioned above, the sample utilised under interview was informed by a pilot study; the required data have been collected from experts in the field of RETs in Nigeria. Thus, during the second phase of the interview for confirmation or rejection of the transcribed contents from the interviewees, they were asked similar questions as in the first phase, and there were no new answers emerging from them. Hence, this is a strong indication of validity. More so, considering interviewees were people from different backgrounds, origins and working in different forms of organisations (private, public, research centres, academic, and professional practice), that they were asked similar questions, and responded with similar answers is an indication of reliability (Yin 2004). Hence, this signifies reliability of the interview method.

The case study approach, applied with a view to validating the RETs (BETs) implementation framework developed, and also strengthen the findings of WLC approach, allowed a new set of biomass fuel costs and labour cost data to be collected from the villages visited (see table 8.1). However, despite sourcing these data from different locations at different times during the research processes as suggested by Fellow and Liu (2008), similar results (unit cost/kWh of electricity) were obtained from these communities. This is also guaranteeing the WLC method and indicating it is reliable.

5.10 ETHICAL CONSIDERATIONS

The major area that required ethical consideration in this study, was the use of an interview method. Semi-Structured interview was used and that required tape recording of the interview sessions. The interviewees were informed of the purpose of the interview and their anonymity and confidentiality were assured in the introductory and consent form (see appendix A). Also, all other ethical consideration were observed. In the opening statement of interview sessions, these ethical issues were also mentioned, and their consents were sought before commencement of the interview, and all of them gave approval for this. More so, after transcribing, the content of the interview sessions were returned to them, with only one interviewee raising concern in respect of a single quote, which was subsequently corrected as he wished. More so, their personal details have remained anonymous as presented in Table (5.3)

5.11 METHODOLOGY LIMITATIONS

WLC analysis did not take into account some variables that include: salvage value, interest on capital cost outlay, and land cost. This is because at the moment land for RETs projects is free and RETs are enjoying fiscal incentives like low import duty. Also, on the interview method, the proliferation of quack practitioners in the Nigerian RETs industry is the major drawback experienced in this study, as it was difficult to identify real RETs practitioners. In fact three appointments were cancelled with would-be interviewees due to information received in respect of this problem particularly at the exploratory study stage. Hence, this problem limited the numbers of persons to be interviewed. It is also noteworthy that, some of the interviewees still see BETs as biogas system only, which eventually leads to a limited value of their responses. They did not look at the bigger picture which includes thermo-chemical conversion systems (gasification and combustion, with around 90% of current biomass electricity generated globally).

5.12 CHAPTER SUMMARY

The overall methodology of the research has been illustrated and discussed in details. The chapter addresses the differences between methodology and methods. The research paradigm (Philosophical stand of the researcher) underpinning the study has been illustrated, which involve both positivist and interpretivist stand given the nature of the study. Mixed method approach has been used for both data collection (WLC and interview methods) and data analysis (content analysis and WLC analysis). Research design chosen and research process (that elucidates steps-by-steps research process) have been presented. The combination of critical case and snowball purposeful sampling methods have been adopted, because of the limitation of real RETs practitioners in the country. This leads to limitation of the sample size utilised. The validity and reliability of the research design and research method utilised have been outlined. Finally, the limitations of the research methodology have been illustrated.

CHAPTER SIX

WHOLE LIFE COSTING ANALYSIS INTERPRETATION

6.1 INTRODUCTION

Economic evaluation of Biomass Energy Technologies (BETs) and Grid Extension (GE) energy systems for electricity provision in Nigeria's rural areas is the focus of this chapter. Although interview analysis was initially planned to be the first part of the data analysis (due to its leading to the economic evaluation of the BETs and GE systems), it was decided that the largely quantitative nature of the economic evaluation could be beneficially checked against the interview analysis (which is presented in the following chapter).

A whole life costing (WLC) approach has been utilised for economic assessment of the various energy systems considered in the study based on the fact that it is suitable for both selecting between mutually exclusive options, and ranking among the same set of investment alternatives. While the approach has been criticised for not taking into account returns and benefits of investment (Short et al. 2005) these aspects are not of significant concern. The system's capacity boundary of this study is sustainable electricity provision for small scale (not exceeding 150 kW) application in Nigerian rural areas for each of the energy systems considered. Also, the analyses cover the investment cost of all the BETs and GE systems, cost of biomass feedstock in relation to the identified BETs, unit cost of generating electricity from all the energy systems and various system capacities considered, and finally the sensitivity analysis regarding the effect of inflation on the biomass fuel cost. All the findings of the analyses are presented in the subsequent sections. In addition, this chapter informed the development of journal paper (Garba and Kishk, 2015), and conference papers (Garba & Kishk 2016; Garba et al. 2016b). See appendix B for further publications.

6.2 BETS INVESTMENT COST IN NIGERIAN RURAL AREAS

The investment cost and efficiency of a technology can have a significant effect on an electricity tariff. Also, the investment cost/kW of energy technologies can differ depending on the size of the system (economies of scale), location of the manufacturers, level of maturity, nature of feedstock, and the feedstock consumption and process patterns. (See details in section 5.6.3- research methodology chapter).

In this study, the cost of each of the biomass conversion systems was sourced directly from manufacturers, rather than adopting the approach of other studies that used business journals, literature, tender price and auctions among other sources of data. Also, the literature reports wide-varying figures on investment cost, such variation was also a factor encountered within this research work despite sourcing the cost from manufacturers. However, it has been noted that a wide range of cost in respect of a given energy technology is indicative of the availability of many different system capacities (Prognos 2014) along with the level of maturity of the technology, as evidenced in the case of gasification systems' with wide cost range and direct combustion systems' narrow cost range, where differing equipment costs/kW have been reported based on the fact that they are respectively emerging and matured technologies. Also, the location factor that is cheaper in emerging countries than developed countries (refer to section 5.6.3 under methodology chapter and table 6.1 and 6.2 for details).

As highlighted in the methodology section, the pyrolysis system will not be used in this context as "there are no commercial plants for electricity production based on this process" (Gonzalez et al. 2015).

The cost of BETs thermo-chemical (direct combustion and gasification) and biological (anaerobic digestion) systems' components, accessories and fittings and installation figures are presented in tables 6.1 and 6.2. The cost obtained for the gasification system (GAS) has been classified under high, medium and low rates, due to the fact that the technology is still an emerging one and different manufacturers are still progressing along the learning curve. In comparison, other systems' cost have no varying classification due to their maturity level; direct combustion (DC) system costs, for example, were closed and consistent. However, it is worthy of note that the capital cost obtained for the anaerobic digestion (biogas) system has been based on a turnkey procurement route (refer to section 5.6.3 in methodology chapter for details).

This study has considered various capacities for GAS technology ranging between 10kW to 125kW. The cost/kW in order of classification in table 6.1 are as follows:

- ✓ High rate = US$2,252 - 3,604
- ✓ Medium rate = US$1,289 - 2,470 and
- ✓ Low rate = US$594 - 1,594.

The difference in the cost ranges is connected with the fact that GAS is an emerging system, and also of the many system capacities as considered in table 6.1. The findings are in agreement with studies by IRENA (2012), Nouni et al. (2007) and O'Connor (2011). This is also in agreement with the study by Prognos (2014) that where various cost ranges of a given product are detected, this is an indication of the impact of many different system capacities.

Table 6.1: The Cost ('000)/kW of Gasification Technology in Nigeria's Rural Areas

Manufacturer of Gasifier	**Manufacturer (High)**			**Manufacturer (Medium)**						**Manufacturer (Low)**			
Gasifier/Engine type	DD + PGE			DD + PGE						DD + PGE			
Capacity (KW)	**120**	**70**	**25**	**125**	**100**	**50**	**32**	**24**	**10**	**125**	**100**	**24**	**12**
Gasifier and accessories	110	80	45	95.1	79.3	41	27.66	20.6	14.3	43.8	34.4	23.5	9.37
Chiller (Optional)	20	20	-	-	-	-	-	-	-				-
Wood cutter	10	10	6	-	-	-	-	-	-				-
Dryer	5	5	3	-	-	-							-
Total cost of gasifier	**145.0**	**115**	**54**	**95.1**	**79.3**	**41.0**	**27.7**	**20.6**	**14.3**	**43.8**	**34**	**23.5**	**9.4**
Gas Engine & accessories	100	60	25	53.4	44.2	22	14.4	11.9	6.6	23.45	19.6	8.9	6.3
Civil works	2	1.5	1.5	2	2	1.5	1.5	1.5	1.5	2	2	1.5	1.5
Earthing work	0.4	0.4	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.3
Total cost of genset	**102**	**62**	**27**	**56**	**47**	**23.8**	**16.2**	**13.7**	**8.4**	**25.9**	**22**	**10.7**	**8.1**
Total Cost of Gasifier+Engine	**247**	**177**	**81**	**151**	**126**	**65**	**44**	**34**	**22.7**	**69.7**	**56.4**	**34.2**	**17.5**
Installation + commissioning	10	10	5	1.5	1.5	1	1	1	1	1	1	0.81	0.78
Price & Design Risk (5%)	12.9	9.4	4.3	7.6	6.4	3.3	2.2	1.8	1.1	3.5	2.9	1.7	0.9
Total Cost of the system	**270.3**	**196.4**	**90.3**	**160**	**133.8**	**69**	**47**	**37**	**24.70**	**74.2**	**60.3**	**36.7**	**19.2**
Cost/KW (US$)	**2.25**	**2.81**	**3.61**	**1.28**	**1.34**	**1.38**	**1.47**	**1.54**	**2.47**	**0.59**	**0.60**	**1.5**	**1.6**

'Note: DD=Downdraft; PGE= Producer Gas Engine

The economy of scale detected in the exercise is indicative that the higher the GAS capacity, the lower the cost/kW and vice versa. This also agrees with Siewert et al. (2004) that higher capacity plants are more economic than smaller plants, thereby eliminating the need for incentives. The average cost reduction between the highest capacity and lowest capacity under the three rates - high, medium and low represent 38%, 49% and 63% respectively. These differences are indicative that the technology is still developing; and as the technology matures, the investment cost may be stable or even reduce.

Table 6.2: The Cost/kW of Combustion and Biogas systems in Nigeria's Rural Areas

Direct Combustion				**Biogas Plant**				
Boiler				**Digester**				
Capacities (kW)	**50**	**100**	**150**	Capacity (kW)	**10**	**20**	**50**	**100**
Boiler Plant	32,525	32,937	57,115	Biogas Plant and accessories (pumps, tanks & heaters)	51000	83000	171000	290000
Accessories and Fitting	12,500	13,200	13,200					
Total cost of Boiler	**45,025**	**46,137**	**70,315**	**Total Cost of digester**	**51000**	**83000**	**171000**	**290000**
Steam turbine				**Biogas Generators**				
Steam turbine and accessories	57,377	81,967	127,868	Biogas engine	7300	10600	24500	46700
				H2S and moisture	1300	1600	2200	3000
				Parking charges	900	1100	1400	1700
Total cost of steam turbine	**57,377**	**81,967**	**127,868**	**Total Cost of Generators**	**9500**	**13300**	**28100**	**51400**
Total cost of boiler & turbine	**102,402**	**128,104**	**198,183**	**Total Cost of digester & Generator**	**60500**	**96300**	**199100**	**341400**
Others				**Others**				
Installation + commissioning	2,500	2,500	3,000	Installation + commissioning	2500	2500	3000	3000
Civil works	2,000	2,000	2500	Civil works	0	0	0	0
Earthing work	350	400	400	Earthing work	0	0	0	0
Price & Design Risk (5%)	5,120	6,405	9,909	Price & Design Risk (2.5%)	1512.5	2407.5	4977.5	8535
Total cost of the system	**112,372**	**139,409**	**213,992**	**Total Cost of the system**	**64513**	**101208**	**207078**	**352935**
Cost/kW (US$)	**2,247**	**1,394**	**1,427**	**Cost/KW (US$)**	**6451**	**5060**	**4142**	**3529**

Table 6.2 reveals that the cost/kW for DC and anaerobic digester (biogas) technologies ranges between US$ 1,427 - 2,247 and US$3,529 –6,451 respectively. Also, it depicts that AD is the most expensive technology among the BETs in this study. This is a situation where cost/kW of the biogas system capacities is double the rates of the remaining BETs (GAS and DC) system capacities. The high cost identified under all of the AD system capacities has been connected with the turnkey procurement route followed; it was difficult to obtain costs for the components (digesters and generators) separately for the capacities under this kind of study as previously explained.

A further factor is that, under the DC system, (see table 6.2) the cost of a boiler for a 50kW capacity system is virtually the same amount as that for 100KW capacity. The electricity consumption under all of DC systems in this case is fixed (36KW), as highlighted in table 6.4, and has significantly impacted on these scenarios, particularly 50 kW. For instance, if you deduct 36kW from 50kW, the owner/investor is left with only 14kW capacity electricity. However, as the capacity increases, so also the efficiency increases. Also, cost/kW of 50 Kw capacity is higher than that of 100kW and 150kW capacities by 61% and 58% respectively. Hence, it is inefficient to adopt a 50 kW system capacity.

Furthermore, economies of scale are clearly reflected within gasification and AD systems, but not within direct combustion systems. This is because the cost/kW revealed under 150kW capacity should have been lower than US$ 1,394 (100 kW) under normal circumstances. Furthermore, if the study only used investment cost as the basis for selection of optimal option under DC technology, 100kW capacity is the most suitable alternative. However, based on figure 6.1, the efficiency gain for a 150kW capacity is much higher than that for 100kW (considering fixed 36kW is required for operation of each system capacity under DC system in this study). See section (6.4) for details.

Both table 6.1 and 6.2 reveal the cost structure associated with BETs. In all the three technologies and various system capacities considered in this study, the primary (gasifiers, boilers and digesters) and secondary (generators) conversion systems, together with their associated fittings and accessories, account for between 90% and 96% of the total investment cost. Other cost factors such as civil and electrical works make up the balance. Furthermore, the primary conversion systems represent an approximately 58% average of the total investment cost across the board, while generators have an average cost of around 34%. The reason why both primary conversion systems and generators costs are higher in this context, is because all the adopted systems are automated and movable, with limited permanent civil structure and electrical interconnectivities, resulting in less labour utilisation during operation, particularly given the location of their application (rural areas).

More so, the technology that has the highest cost of conversion system is the AD, while the lowest is GAS. The reason for this is because the AD procurement route is a turnkey system under which the supplier provided limited information; the opposite was the case for the GAS (significant information was provided by the manufacturers). The above finding is in agreement with IRENA (2012) "The converter system usually accounts for the largest share of capital costs". However, it disagrees with Macdonald (2011) in that the percentage contribution of the generators to the overall investment cost ranges between 5% and 15% as against 34% in this study. The difference between this study and the 2011 study by Macdonald is connected with small scale capacities in this study, as economies of scale have significant impact in reducing the unit cost of a system.

It is noteworthy that any application of BETs is yet to commence in Nigeria, let alone thinking of cost saving. However, the cost savings can only be achieved through a learning curve when many units have been developed, particularly for the emerging technologies such as GAS and AD systems. This is in agreement with Bridgwater et al. (2002) "it is widely accepted that the cost of a process reduces as more units are built and experience accumulates". The findings in respect of BETs investment cost, especially for gasification system of 100 kW and above (under medium manufacturer's cost classification), amazingly depicts that they are cost competitive with the majority of recently built fossil fuel (FF) thermal plants in Nigeria of over US$1,000/kW (Eberhard & Gratwick 2012), despite the fact that they are large scale (many MW) capacities compared with this study's capacities not exceeding 150kW for largely emerging technologies. More so, the BETs systems are sustainable and will create some form of economic benefit for the rural communities where they either plant crops for energy or use their farm waste for energy production.

6.3 BIOMASS FEEDSTOCK COST AND CHARACTERISTICS

Avoidance/limiting of pre-treatment of biomass feedstock and minimising the maintenance of biomass conversion systems during/post operation as a result of utilisation of some certain fuels types is a source of concern. These problems can significantly increase operational cost and reduce efficiency of the equipment. Also, Biomass fuel's cost has been acknowledged as the most important factor for the sustainability of BETs in providing sustainable electricity. Biomass fuel accounts for over 55% of total cost over the life cycle of the assets operation (Mahapatra & Dasappa 2012; IRENA 2012). Hence, the understanding of physical and chemical characteristics of biomass feedstock should be fully considered before selection of any BETs if an optimum result (competitive electricity tariff) is to be achieved.

Table 6.3: Biomass fuel prices and characteristics in the Nigerian Rural Areas

Biomass Energy Technologies	Biomass Resources (suitable fuel)	Price US$/ton	LHV MJ/kg	Moisture Content	Recommended size & shape	Ash content	Market Status	Availability
Thermo-chemical								
Direct Combustion	Wood (chip)	28.57	18 -21	< 15%	6-50mm	1-2%	established	universal
(stoker grate boiler)	wood waste	28.57	18 -21	< 15%	6-50mm	1-2%	established	universal
	cereal straw	29.76	14- 16	7-12%	6-50mm	4.30%	SE	seasonal
	Sugarcane Bagasse	Gate fee	15 -17.9	50-70%	6-50mm	3.50%	NE	SR
	rice husks	62.5	15.2	7-12%	NA	< 20%	SE	universal
	Guinea grasses	75	16.9-17.3	6%	6-50mm	5%	established	universal
Gasification	Wood (chip)	28.57	18 -21	< 15%	< 50mm	1-2%	established	universal
(Downdraft)	wood waste	28.57	18 -21	< 15%	< 50mm	1-2%	established	universal
	maize cobs/straws	33.65	16.8 -18.1	7-12%	< 50mm	4.30%	S-estabd	seasonal
	shells (coconut, palm kernel, peanuts)	42.86	18 -20	11 -14%	< 50mm	2%	NE	SR
	cereal straw	29.76	15-18	7-12%	< 50mm	4.30%	SE	seasonal
Biological								
Anaerobic Digestion (biogas)	Animal waste-dung, drop	14.71	13.4	20-70%	NA	24%	SE	universal

Note: SE= semi-established, NE = not established, SR = seasonal & regional.

Size, shape and density of the feedstock are major factors considered for physical characteristics, while moisture and ash contents are criteria considered for chemical characteristics (Bocci et al. 2014). The chemical characteristics determine the energy density of biomass, while the suitability of fuel utilisation is considered in the context of physical characteristics. High moisture content reduces a system's energy value (LHV), and high ash content increases the gas cleaning process, thereby leading to high operational cost. Also, low density feedstock increases transportation cost, and a uniform size of fuel allows homogeneity and consistency (Bocci et al. 2014, Asadullah 2014; IRENA 2012; Evans et al. 2010).

6.3.1 Biomass Feedstock Economic Assessment

Table 6.3 reveals the cost, level of availability and market status of biomass feedstock in a Nigerian field survey. The biomass resource vendors were interviewed; prices of feedstock obtained, and weight of feedstocks were taken and subsequently converted to unit cost/kg. Other factors have been obtained from literature/reports such as in IRENA (2012), Bocci et al. (2014), Asadullah (2014) and MCkendry (2002).

In line with thermo-chemical conversion systems, the cheapest biomass fuel in Nigeria is wood and wood waste costing US$28.57/tonne, closely followed by cereal straw (higher by 5% cost). Under the DC system, fuels such as rice husk and guinea grasses are more expensive than wood and wood waste (cost/tonne is approximately 119% and 163% respectively higher than wood/wood waste cost). This makes both the most expensive biomass fuels in the country. However, sugarcane bagasse seems to be the cheapest fuel under DC as it only requires gate fee (handling and collection cost) for its procurement, but it is the most widely dispersed and disestablished fuel in the Nigerian biomass market. It therefore cannot be considered for application, particularly in the rural areas. For gasification systems (GAS), the third and fourth most expensive fuels are maize cobs/straw and shells respectively (more expensive than wood by around 18% and 50%). The cheapest among all the biomass feedstock considered in this study is animal dung and drops, costing approximately US$14.71, which is 100% lower than the cheapest fuel under thermo-chemical conversion systems (wood).

6.3.2 Biomass Feedstock Market Status and Availability in Nigeria

The most established and universally available biomass feedstock in the Nigerian market are wood, wood waste and guinea grasses. They can be procured at any time of the year without a seasonal break (particularly wood fuel). However, guinea grasses are limited to some extent in the northern region during the winter season (Nov-March) but are widely established in the country's market (see table 6.3).

The next set of biomass fuels available are rice husk and animal dung; both are readily and largely available everywhere in the country, but their market status is only partly established. This is because of seasonal unavailability, particularly for rice husk, which is only available just after the harvesting period from the commercial local rice mills (although harvesting period varied in the country; the harvesting period in Abakaliki is earlier and longer than other parts of the country).

The third set of biomass fuels in the country are cereal straw and maize cobs/straw; these are generally available but highly seasonal in nature (mostly found during and immediately after the rainy season), therefore their market status is limited availability, as they cannot be found every time of the year. The least available set of biomass feedstock in the country are shells and bagasse. They are not universally available due to the fact they are found on a seasonal basis and specific to only some regions in the country. There is no reliable market for these resources. The major concern for most of the biomass fuels in Nigeria is the fact that they have been traditionally used as animal feeds, stabilisation for local blocks for mud buildings (largely used in rural areas), thatch houses, organic fertiliser and inefficient energy production for cooking and water heating. This finding agrees with Karampinis and Grammelis (2012) that a majority of the biomass fuels such as straw "do find application as materials for animal feeding and bedding, mushroom cultivation".

6.3.3 Biomass Feedstock Ash and Moisture Contents

It is widely agreed among BETs experts such as (Bocci et al 2014) that the higher the ash content, the more uneconomical is the unit of electricity generated; high moisture content reduces the energy value of biomass feedstock. In line with table 6.3, the feedstock with the lowest ash content includes wood, wood waste and shells, with less than 2% ash content residues after combustion. They are closely followed by bagasse and cereal straw with 3.5% and 4.35% ash content respectively. The least efficient fuels in this context are animal waste and rice husk with ash content representing 24% and 25%. Hence, the first set of biomass fuel such as wood, wood waste and shell should be utilised given their low ash content to avoid much gas cleaning. This is in agreement with IRENA (2012) "ash can form deposits inside the combustion chamber and gasifier, called slagging and fouling, which can impair performance and increase maintenance costs".

The selected biomass fuels in this study have a water content ranging between 6 - 70%. The fuels with the lowest moisture content, and therefore acceptable for gasification (<15%) and stoke grate boiler (<50%) systems usage, by order of priority are: guinea grasses, cereal straw, rice husks, wood and wood waste (see table 6.3). The fuel with the highest water content is bagasse (minimum of 50%), followed by cattle dung with an average 35% moisture content. It is noteworthy that any biomass fuel with over two-thirds water content renders the energy content a minus value (uses more energy than it generates) (Ogi 2002).

Similarly, table 6.3 evidences that wood and wood wastes are the most suitable and sustainable biomass fuels for thermo-chemical systems in the context of this study, as they are the most economical vis-a-vis market status, universal availability, highest LHV (high energy content), lowest ash content, acceptable moisture content and are appropriate for both downdraft gasification and stoke grate boiler DC technologies. This finding agrees with Bocci et al. (2014) that wood has the lowest ash-content and is the most efficient biomass used in thermo-chemical conversion systems. They are followed by cereal straw, based on economic competitiveness, low moisture content, reasonable LHV and general availability. However, cereal straw produces a high ash content after combustion and is only available during the rainy season, particularly in the north. This agrees with Deliyannus (2012) "despite the favourable conditions of the low moisture and high volatile content, it is the chlorine and ash content which poses the most significant issues in thermal processes involving herbaceous biomass". The findings also agree with Galbraith et al. (2006) that combustion of straw for energy generation produces the most GHG emission, and forest residues wood chip gasification produces the least GHG emission.

Further, straw fuel is utilised in Europe and America for energy generation (Martinot 2013) even though, as Deliyannus (2012) notes, despite straw's shortcomings for energy production, there are many successful examples of its utilization, among them "is the utilisation of straw in Denmark for power production or district heating. ----- increasing the share of bioenergy produced from herbaceous biomass resources------is an important target for EU". Also, just as the waste from biogas systems has been used as an organic fertilizer, the ash content remainder in the thermo-chemical systems can as well be utilised for the same purpose (organic fertilizer). Deliyannus (2012) agrees with the above "The re-cycling of biomass ashes as a fertiliser is a major option". Hence, this will also be attractive to rural communities in Nigeria, as they struggle to procure chemical fertiliser.

Rice husks and guinea grasses are not very suitable at the moment for electricity generation in Nigeria, as are both overly expensive based on cost/ton of feedstock despite their universal availability. The prices of biomass fuels in Nigeria, particularly rice husk, disagrees with IRENA (2012) in that the price of rice husks in India of approximately US$ 22/ton is lower than the price of US$62.75/ton in Nigeria. Moreover, rice husks have the highest ash content (and a low LHV) among all the biomass fuels suitable for a thermo-chemical system, but have a good low moisture content (see table 6.3). This finding agrees with IRENA (2012) "Some types of biomass have problems with the ash generated. This is the case for rice husks that need special combustion systems due to the silica content of the husks". However, the cost of rice husks may likely reduce following the Nigerian government's policy in recent times of discouraging importation of rice into the country. This policy may likely increase the quantities of rice locally produced and subsequently lead to more husk generation.

While guinea grasses have good LHV, a low moisture content, acceptable ash content, and are generally available within an established market, their key disadvantage is a high cost after drying. Bagasse is the least recommended fuel suitable for a DC system; it has a high moisture content, low LHV, and is more highly geographically dispersed than any of the feedstock considered in this study (procuring suitable and sufficient quantities of the fuel is a big task). Considering a stoker boiler in a DC system can tolerate more moisture content (up to 60% wet) feedstock than that of a gasifier, bagasse may be suitable for a stoker DC system. The above disagrees with Deliyannus (2012) that "bagasse has much higher moisture content (40 – 60%) and can be problematic in combustion applications". Alternatively, it can be used in a biogas system, given that such a system can accommodate a high moisture content, and always does better with combination of feedstock and can be fed into classes of high solid – dry and high solid-wet feedstock patterns (IRENA 2012).

Hence, the most sustainable and economical feedstocks suitable for a DC system by order of priority are: wood and wood wastes, cereal straw, rice husk, and guinea grasses. Bagasse should only be used where necessary, despite only a gate fee currently being required for its procurement.

In the case of a gasification system (GAS), both wood and wood wastes, followed by cereal straw are the most suitable biomass fuels. The third fuel in the ranking is maize cobs/straw, having close characteristics with cereal straw but being more expensive. This may not be unconnected with its higher LHV than other straws, particularly because of the cobs with long combustion characteristic (slow burning). Also, it is in high demand in the country as a fuel for traditional forms of energy production. The least recommended fuel under a gasification system is shells; the most expensive, location specific (mainly found in only a few regions), and seasonal in nature. However, it has a low ash content and a high LHV similar to wood.

Despite all the short comings of shells as a fuel at present in Nigeria, by 'creating' organised supply chains for energy firms, the waste can be effectively procured. A relevant example of what can be achieved is the case of steel waste gathered for recycling in Nigeria. This has generated employment for numerous people and resulted in many small and medium sized firms being established. The same business case can be replicated for biomass resources (wastes). Also, rice husk can be used for a gasification system but requires a greater amount of pre-treatment before use, which eventually increases its operational cost compared with other feedstock. While it can be used in combination with other fuels like wood, it has a demerit of consuming more fuel per kWh of electricity generated (Garba & Kishk 2015).

Following on from the GAS preference for feedstocks of low moisture, low ash content, large availability of resources, an already established market and economic availability of the fuel, the most recommended feedstocks in order of priority are wood, wood waste, cereal straw, maize cobs/straw and shells. This finding agrees with Bocci et al. (2014) "the most suitable biomass for gasification must have availability on a significant scale (ton/year), good physical and chemical characteristics".

As with biogas system feedstocks, the combination of feedstocks, particularly animal wastes and other fuels, is the most suitable approach. Animal wastes are the most suitable for a biogas system, based on the economy of the fuel as identified in this study, universal availability and coupled with reasonable utilisation experience in the country (not for electricity) as highlighted in table 6.3. However, it has a high ash content, the lowest LHV and a high moisture content. Fortunately, a high moisture content is not a serious issue in this system since there are other pathways for energy generation. This agrees with IRENA (2012) "the key problem with high moisture content, even when it is destined for anaerobic digestion, is that it reduces the energy value of the feedstock". However, the biogas system is widely utilised for power energy production and represents the second largest technology that biomass electricity is generated from by the end of 2014, accounting for almost 17% of total 93 GW (REN21 2015).

6.4 UNIT COST OF BETS IN NIGERIAN RURAL AREAS

The major concern of biomass energy system is in the procurement and transportation of its resources. Mahapatra and Dasappa (2012) and IRENA (2012) opined that the sustainability of biomass energy technologies (BETs) depends on the economic viability of its feedstocks.

The recent 45% (from an average of N16 – N26/kWh) increase in electricity tariff in Nigeria (approximately the same as the current electricity price for average residential apartment in UK £0.09/kWh) which became effective from February 1, 2016 raises hopes that service delivery and customers' satisfaction will be enhanced as claimed by the National Electricity Regulatory Commission (NERC). Perhaps this will also encourage participation of utilities companies in the provision of sustainable electricity to Nigeria's rural communities to address the high energy poverty in these areas. In addition to an increase in the electricity tariff, there is also an incentive (feed-in-tariff) in place for those generating electricity through renewable means (see section 4.5 and table 4.1). Although, the incentive strategy in the country does not extend to decentralised system, there are a few incentives available for rural areas, such as license fee exemption, free land and other import duty exemptions.

Table 6.4: The parameters utilised

Factors	**Combustion**	**Gasification**	**Anaerobic Digestion**
Biomass Technology Cost (US$/KW)	1,427 -2,247	1,280 - 2,470	3,529 - 6,451
Fuel Consumption/Kw (kg/hr)	50kw -8.6 100kw-5.4, 150kw -4.30	Wood - 1.4 Cereal Straw 2.9	Cattle Manure -2
Fuel Cost (US$/kg)	Wood - 0.029	Wood - 0.029 cereal straw - 0.03	Manure - 0.015
Life span of Primary Conversion system	Boiler -25 yrs	Gasifier - 15 years	Digester - 25 years
Life span of secondary conversion system	ST -25 years	ICE - 7.5 years	Engine -13 years
Energy Consumption	Fixed -36kW	20% -syst cap	20% -syst cap
Engine replacement	NA	1	1
Discount Rate	13%	13%	13%
Annual Maintenance cost (US$/ kW)	0.024	0.024	0.027

Based on manufacturers' manuals, the suggested biomass fuel types to be utilised for the conversion systems have been largely the same with what is reported in the literature. See table (6.3) for details. For the purpose of this study, and based on the feedstock study for the country's rural areas above, the following biomass fuel types have been considered for the BETs systems for electricity generation: gasification (wood and cereal), DC (wood and associated waste), and cattle manure for a biogas system. The parameters and feed-in-tariff (FIT) incentive strategy considered for this section of the analysis are presented in table 6.4 above and table 4.1 (chapter four). The WLC framework for calculating unit of electricity cost from BETs is given below using the following relation:

WLC Expression for Calculating Biomass Energy System

$$WLC_{BG} = \frac{C_G + C_E + (C_F + C_M) \times P(d,n) + C_R \times P(d,n_1) - FIT \times P(d,n)}{L \times h \times n} \tag{1}$$

Where: $CF = (SC \times f_{con} \times h \times fc)$; $CM = (SC \times h \times MC)$; $FIT = (L \times h \times n \times C)$

Table 6.5: Nomenclature

Nomenclature	
Biomass Energy System	**Grid Extension System**
C_G capital cost of gasifier C_E capital cost of engine C_F annual fuel cost C_M annual maintenance cost S_C gasifier rating (kg) f_{con} fuel consumption (kg/h) f_C unit fuel cost M_C maintenance cost of the system P present worth factor d discount rate n life of the project n_1 life of each component C_R component replacement cost FIT annual feed-in-tariff benefit C carbon emission benefit h annual operation hours L load (kW)	X distance of the village to existing grid point L Load demand h annual operation hours d discount rate n life of the project t_{gen} electricity generation cost $\delta_{t\&d}$ transmission and distribution losses C_{grid} grid line cost C_t distribution transformer cost S_C gasifier rating (kg) β fraction of capital cost (for operation and maintenance of the grid)

6.4.1. Direct Combustion System

In line with figure 6.1, three different system capacities and three operational hours have been considered for a direct combustion (DC) system. The findings reveal that both 100kW and 150kW scenarios have WLC/kWh ranging from US$0.068 - US$0.11 without incentive; while with the FIT incentive the prices reduce significantly to US$0.041 - US$0.08. Both scenarios are cost-competitive with the current electricity tariff in the country using grid (fossil fuel) system (approximately US$ 0.13). (See figure 6.1 for details). However, the WLC/kWh for a 50kW capacity system running for three different operational hours per day, with and without incentive, varies from US$0.30 – US$0.37. This is significantly higher (over 100%) than the existing electricity tariff in the country and for other system capacities considered in this study (see figures 6.1 to 6.4 for details). Also, even the usage of incentive in this case (50KW) does not influence any of the operational hours cost. The problem of a system (boiler and other factors) meeting the electricity consumption pattern has significantly impacted on this scenario, as DC systems capacities considered in this context have a fixed energy consumption of 36kW for all of the scenarios considered (see section 6.2 for details). This finding agrees with Demirbas (2001) that "higher efficiencies are obtained with a system of many MW". More so, the fuel consumption of the 50 kW scenario is the highest among all the technologies and various system capacities considered in this study, with over 8kg/hr/KW (see details in table 6.4).

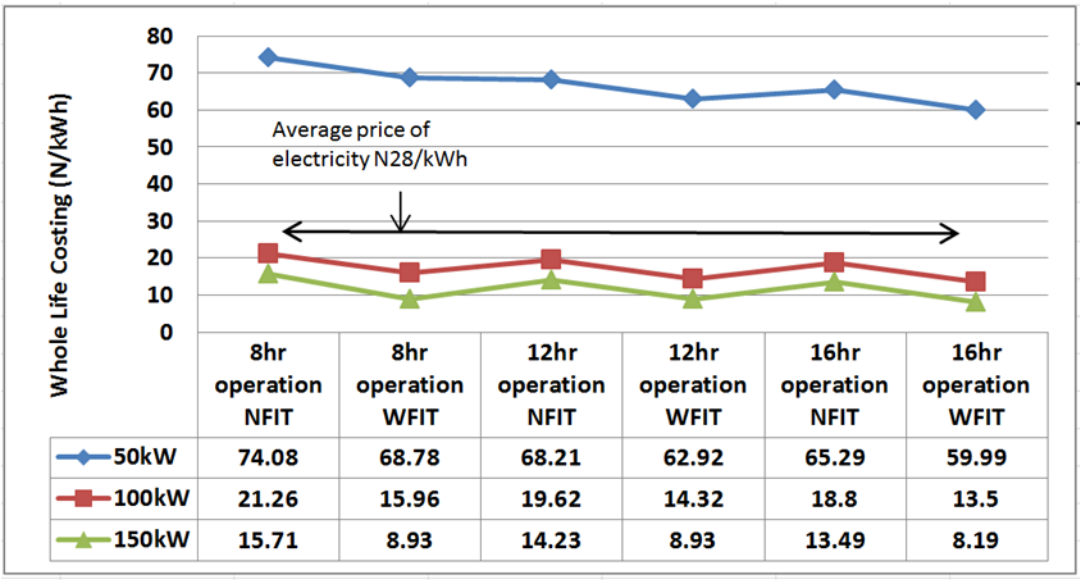


Figure 6.1: WLC/kWh of Electricity from Direct Combustion (wood fuel)

Hence, only 100kW and 150kW scenarios are suitable for providing sustainable electricity in rural areas using DC system. Furthermore, the high cost of DC generators (steam turbine) also contributes to the high cost of electricity tariffs but has been offset by no replacement for the steam turbine during the life cycle of the system being considered. This is not the case for GAS and AD systems where the generator needs replacement at least once during the system's life cycle. The steam turbine generator is a well proven technology globally and can meet the expected requirements during the life cycle of the system. This is in agreement with Gonzalez et al. (2015) that steam turbine "is a well-proven and mature technology with a high level of deployment, and the main advantage of STs is its high time availability".

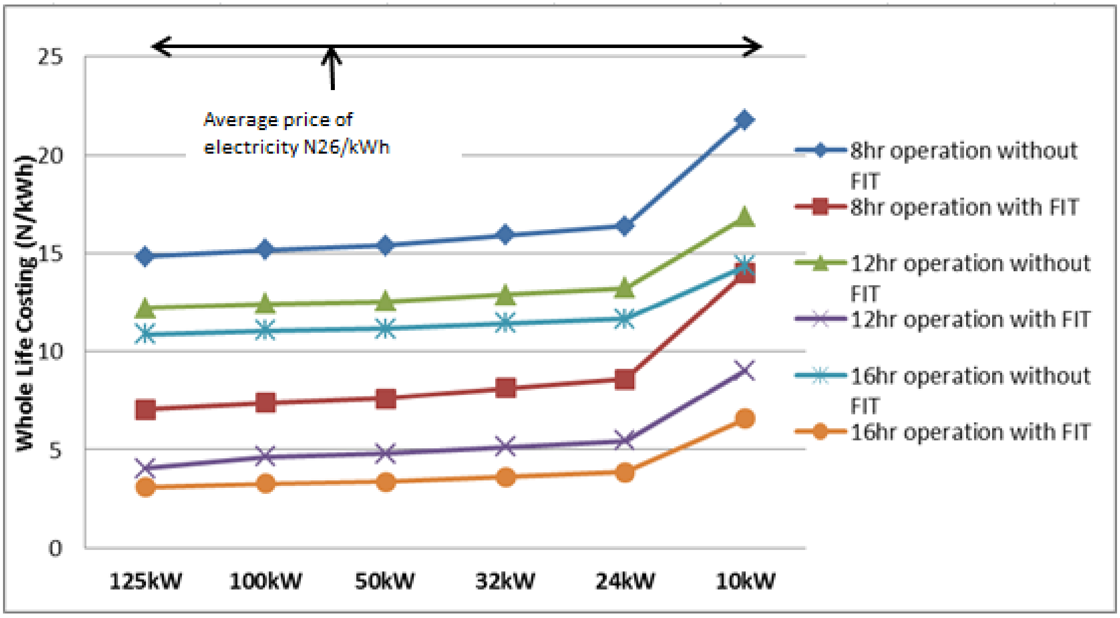


Figure 6.2: WLC of Electricity from Gasification system (wood fuel)

6.4.2 Gasification system

On the basis that GAS is an emerging technology and has better efficiency than other BETs, two alternative fuels have been considered for evaluation: these include wood and cereal straw. GAS (wood fuel), using six different system capacities and three different operational hours patterns, was considered first. Figure 6.2 reveals that the WLC/kWh for generating electricity with and without FIT incentive ranges from US$0.015 – US$0.07 and US$0.054 – US$0.11 respectively for system capacities between 125KW – 10kW. In this context none of the scenarios exceed the current electricity tariff in the country using grid system (US$0.13). Using the same variables above, but with the fuel changed from wood to cereal straw, the WLC/kWh for electricity generation with and without a FIT incentive will respectively range from US$0.04 - US$0.095 and US$0.079– US$0.13. The only scenario that exceeds the current price of electricity generation using a grid system in the country is the 10kW capacity operating at 8 hours without a FIT incentive (see figure 6.3 for details).

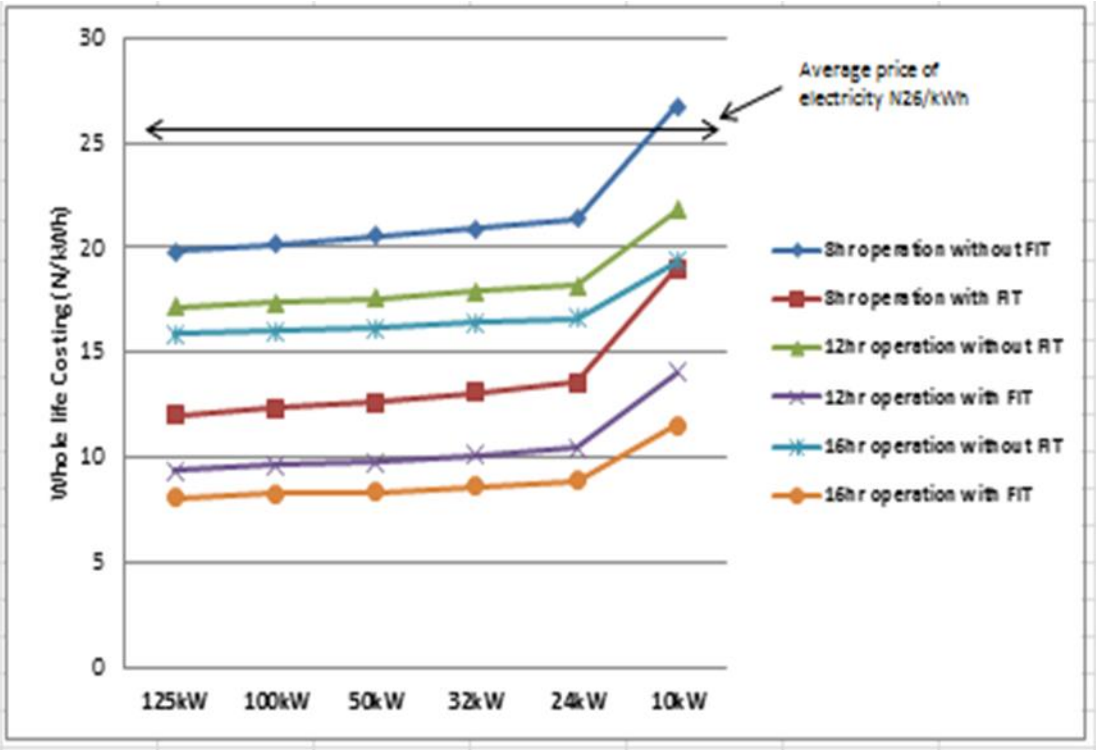


Figure 6.3: WLC of Electricity from Gasification system (Cereal Straw)

The effect of the fuel change (from wood to cereal straw) has reasonably increased the unit price of electricity (by over a third without FIT and up to 150% with FIT). This agrees with IRENA (2012) "the economics of biomass power generation are critically dependent upon the -----biomass feedstock at a competitive cost". The lowest and highest WLC/kWh in this context are the 125 kW capacity (16 hour operation with incentive) and 10 kW capacity (8 hour operation without incentive) respectively in both wood and cereal straw fuels. The economies of scale have also been revealed in this context.

6.4.3 Anaerobic Digestion (Biogas) system

Four different system capacities and three operational hours have been considered in this section (see figure 6.4). Generally, all of the scenarios (by order of priority, 100kW-10kW) considered are below the current price of grid system electricity in Nigeria. It is feasible for investors to make a reasonable profit based on the WLC/kWh of electricity from this system, with and without FIT incentives ranging from US$0.02 – 0.10 and US$0.046 – 0.13 respectively, despite its high investment cost/kW. More so, the price/kWh of electricity can be further reduced if the system can generate up to 16 hours as suggested under thermo-chemical systems. However, the study keeps to the limit suggested by the manufacturer for these kind of capacities, even though this source is suitable for continuous available electricity (IRENA 2012).

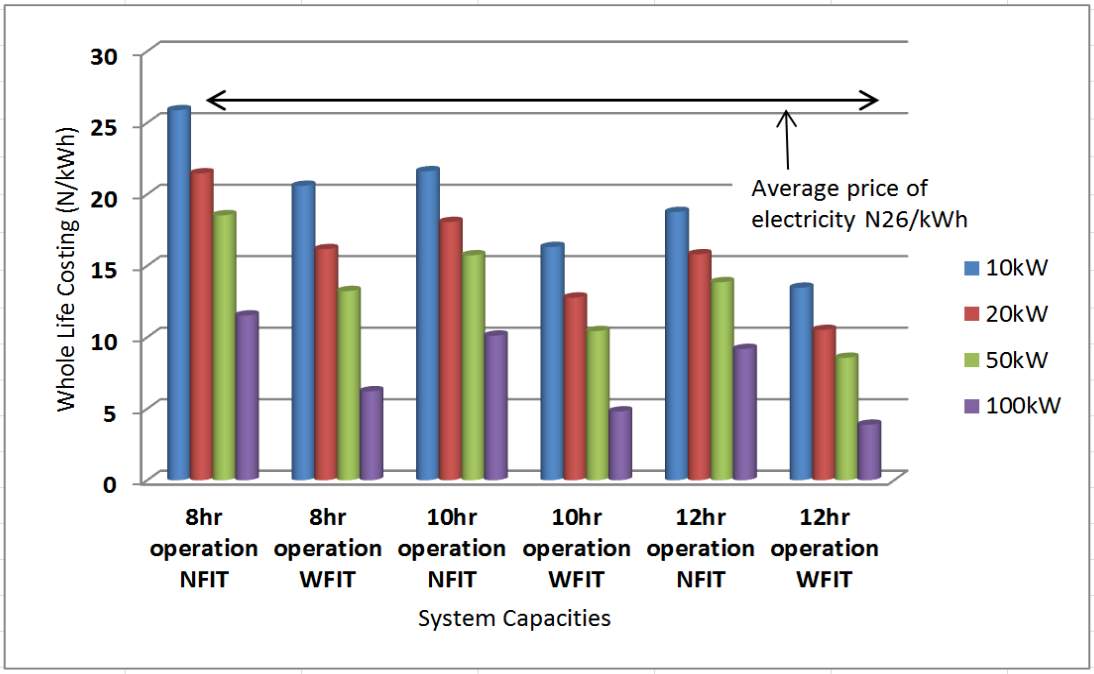


Figure 6.4: WLC of Electricity from Anaerobic Digestion (cattle manure)

It is also noteworthy that the annual operational cost of this system has been reviewed upward by 10% during the evaluation, given the logistic nature of its fuel types (mainly from animal sources) in this context. However, its feedstock price as shown in table 6.4 had partly offset the increase in the annual operational fee.

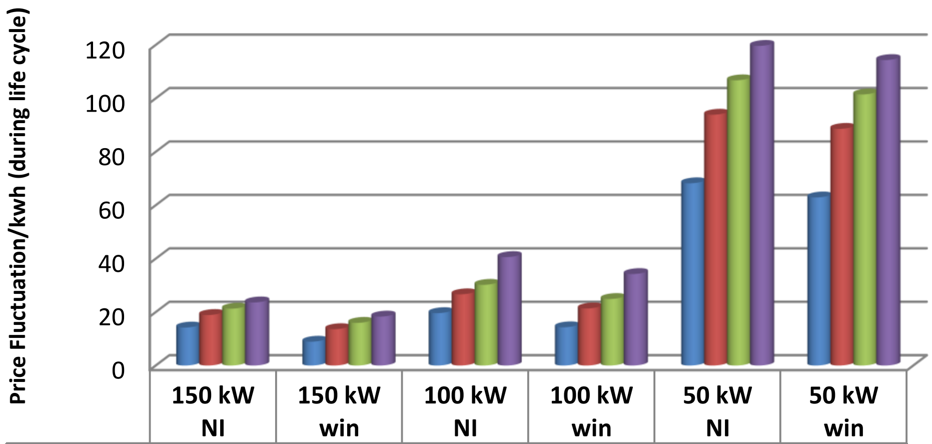
Generally, the findings also reflect that an increase in operational hours and an increase in system capacity combined can decrease the unit price of generating electricity from all the BETs considered. This is indicative of the impact of economies of scale; the more energy consumed the cheaper it becomes. Hence, it will be appropriate to use bigger capacity systems to serve clusters of nearby villages, as against smaller unit BET for each village. The cheapest electricity tariffs without incentive among all the BETs considered in this study are, by order of priority: gasification (wood) US$0.054 – 0.11, followed by DC US$ 0.068 – 0.11 (100kW and 150kW only), then AD US$0.046 – 0.13 and finally gasification (cereal straw) US$0.079– 0.13. These findings partly disagree with Evans et al. (2010) that "combustion based technologies are more profitable over their life cycle than gasification and pyrolysis". However, these findings are in agreement with Mahapatra and Dasappa (2012) and Nouni et al. (2007) in that a biomass energy system is cost competitive with fossil fuel sources in generating electricity, particularly in developing countries' rural areas. However, it also disagrees with Evans et al. (2010) who asserted that "biomass power production is not cost effective at present".

Although not all the BETs are cost competitive at the moment with the fossil fuel option currently utilised in the provision of electricity without incentive, they are largely more economical than the grid source in the country. However, with a FIT incentive in place, further participation of investors will support the development of the energy sector and the local economy where farmers will be planting for energy (not necessarily for food), and using their waste instead of burning it at the end of farming season. More so, the FIT incentive utilised in this context is just an indicative figure as shown in table 4.1 (chapter four), hence its utilisation should be extended to decentralised energy systems, not restricted to only the renewable grid systems with over 1MW capacity.

6.5 SENSITIVITY ANALYSIS

Presently, Nigeria is not using energy crops plantations for electricity generation purposes because BETs are not part of the national energy mix. Instead, existing wood and residues from agricultural and animal waste have been considered as biomass fuels for this study.

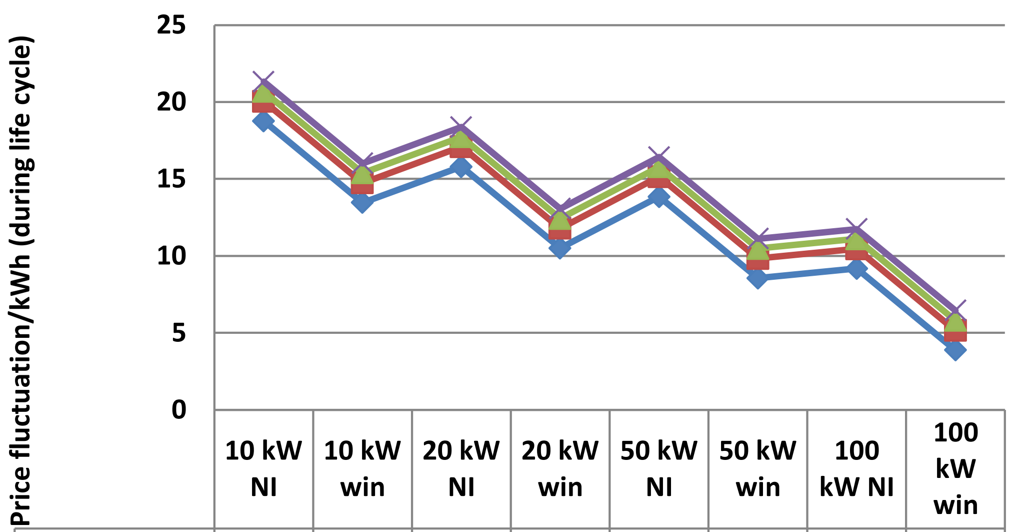
Also, in view of competing alternative uses of the biomass resources vis-à-vis BETs adoption for electricity generation in the country's rural areas, there is a likelihood of feedstock price inflation. Given the lack of data in respect of biomass resources prices in relation to biomass electricity generation in the country, and the importance of the biomass fuels over the total cost (representing over 55%) of unit of electricity generated through BETs (IRENA 2012), this section has attempted to project the likely cost increase of electricity tariff in the event of BETs adoption.



	150 kW NI	150 kW win	100 kW NI	100 kW win	50 kW NI	50 kW win
FPC 0%	14.23	8.93	19.62	14.32	68.22	62.92
FPC 50%	18.92	13.62	26.67	21.37	93.88	88.59
FPC 75%	21.28	15.98	30.21	24.91	106.76	101.46
FPC 100%	23.63	18.33	40.6	34.25	119.64	114.34

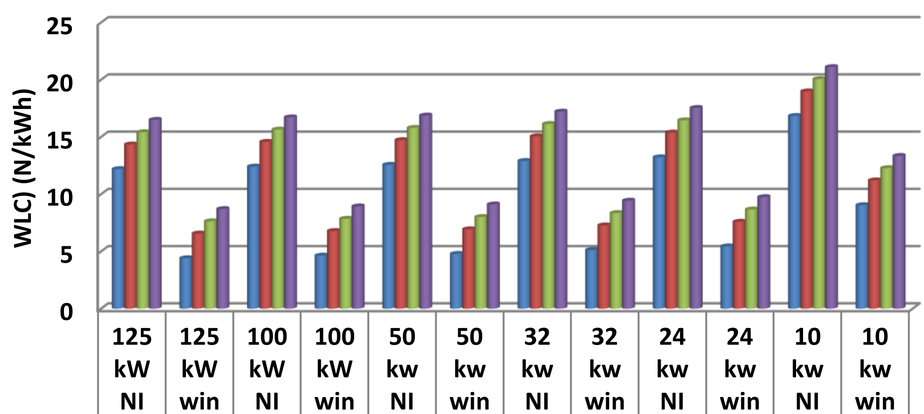
Figure 6.5: Effect of feedstock price fluctuation in WLC of Direct Combustion

The current WLC/kWh of unit of electricity without an incentive varies from US$ 0.068 – 0.11 for DC system 100kW and 150kW only, gasification (wood) US$0.05 - 0.11, gasification (cereal straw) US$0.079– US$0.13 and AD US$0.046 – 0.13 for system capacities between 125kW – 10kW. However, in the event feedstock prices increase by 50%, 75% and 100%, respectively using 12hours supply as the base case, and similar factors as considered in figure 6.5 to 6.8, the WLC/kWh of electricity tariff from a DC system will on average increase by 35%, 52% and 87%. This is similar to other BETs systems in the same order: gasification (wood) -13%, 20% and 26%; gasification (cereal straw) - 24%, 36% and 49%; and AD system -10%, 16% and 21%. (See figure 6.5 - 6.8 for details). Hence, a FIT incentive will assist in mitigating the effect of feedstock price increases in the future.



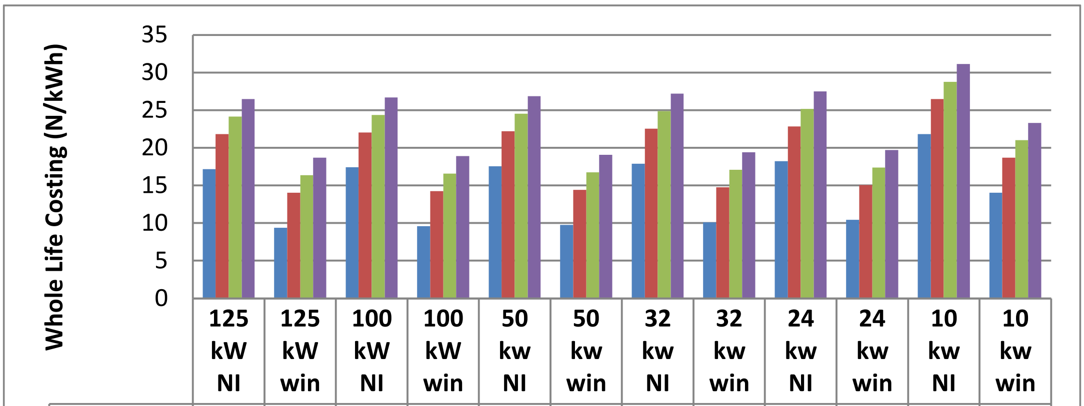
	10 kW NI	10 kW win	20 kW NI	20 kW win	50 kW NI	50 kW win	100 kW NI	100 kW win
FPC 0%	18.76	13.46	15.8	10.5	13.85	8.56	9.18	3.88
FPC 50%	20.04	14.74	17.09	11.79	15.14	9.83	10.46	5.16
FPC 75%	20.68	15.39	17.73	12.43	15.78	10.48	11.11	5.81
FPC 100%	21.32	16.02	18.37	13.07	16.42	11.12	11.74	6.45

Figure 6.6: Effect of feedstock price fluctuation in WLC of Anaerobic Digestion



	125 kW NI	125 kW win	100 kW NI	100 kW win	50 kw NI	50 kw win	32 kw NI	32 kw win	24 kw NI	24 kw win	10 kw NI	10 kw win
FPC 0%	12.2	4.4	12.4	4.63	12.6	4.78	12.9	5.12	13.2	5.44	16.8	9.04
FPC 50%	14.3	6.56	14.6	6.78	14.7	6.93	15.1	7.27	15.4	7.59	19	11.2
FPC 75%	15.4	7.63	15.6	7.85	15.8	8	16.1	8.35	16.5	8.66	20.1	12.3
FPC 100%	16.5	8.7	16.7	8.93	16.9	9.1	17.2	9.43	17.5	9.74	21.1	13.3

Figure 6.7: Effect of feedstock price fluctuation in WLC of Gasification (wood)



	125 kW NI	125 kW win	100 kW NI	100 kW win	50 kw NI	50 kw win	32 kw NI	32 kw win	24 kw NI	24 kw win	10 kw NI	10 kw win
FPC 0%	17.17	9.39	17.4	9.61	17.55	9.76	17.89	10.11	18.21	10.42	21.81	14.03
FPC 50%	21.81	14.03	22.05	14.26	22.19	14.41	22.54	14.75	22.85	15.07	26.46	18.68
FPC 75%	24.14	16.35	24.36	16.58	24.51	16.73	24.86	17.07	25.17	17.39	28.78	21
FPC 100%	26.47	18.68	26.69	18.91	26.84	19.06	27.18	19.4	27.5	19.71	31.11	23.32

Figure 6.8: Effect of feedstock price fluctuation in WLC in Gasification (cereal straw)

6.6 GRID EXTENSION SYSTEM WHOLE LIFE COSTING

It is a common practice in many developing countries that decentralised energy systems are usually considered as a temporary measure of electricity provision to rural areas; with the believe that sooner or later the grid system will be extended to these communities as part of utility company plans (Rahman et al. 2013). However, an increasing demand on the national budget from other sectors of the economy is putting pressure on government, and it is becoming increasingly difficult to provide electricity to rural communities, particularly in developing countries. More so, even the de-regulation of the energy sector is not helping in this respect, as private investors consider the energy consumption of rural communities to be too small (dominated by agricultural activities) to be anything other than low income earners .

This section aims to evaluate the whole life cost (WLC) of extending a grid system to isolated rural areas in Nigeria, and subsequently compare it with Biomass energy technologies (BETs), with a view to establishing the optimum technology for sustainable electricity provision to rural areas.

The WLC of extending a grid system includes: WLC of electricity generation, WLC of transmission and distribution lines and 11 kV/0.415 kV sub-station. However, grid extension (GE) viability depends on factors such as the distance of the grid line to load centres, expected load demand, transmission and distribution losses (up to 40% in Nigerian case, World Bank (2005)), unit cost of electricity generation at the existing grid point and poor power availability of the grid (Mahapatra & Dasappa 2012; Rahman et al. 2013). It is noteworthy that Nigerian 200 Naira is exchanged for a US dollar (official rate at the moment). The WLC for GE system can be expressed as follows (Mahapatra & Dasappa 2012):

WLC Expression for Calculating Gridline Extension System

$$WLC_{GE} = \frac{WLC_{gen} + WLC_{grid} \times X}{L \times h \times n} \qquad (2)$$

Where: $$WLC_{gen} = t_{gen} \times L \times h \times \left(\frac{1}{1-\delta_{t\&d}}\right) \qquad (3)$$

$$WLC_{grid} = C_{grid} + C_t + \left(C_{grid} + C_t\right) \times \beta \times P \qquad (4)$$

$$P = \frac{(1+d)^n - 1}{d \times (1+d)^n} \qquad (5)$$

Table 6.6: Grid Extension System Parameters

-Grid Line Cost/KM	N2,200,000 (US$11,000)
-Distribution Transformer Cost	N2,500,000 (US$12,500)
-Grid loss	30%
-Life of the project	20
-Electricity tariff (N/kWh)	N26 (US$ 0.13)
-Annual maintenance cost (% of investment cost)	1
-FIT Incentive -(see table 4.1)	-
Other Details	
-11KV line is used because the assume distance is not more than 10KM; cost is N2,200,000/KM	
- Distribution sub-station; 300KVA, 11/0.45 KV Transformer, 400A, 3TPN, feeder pillar,	

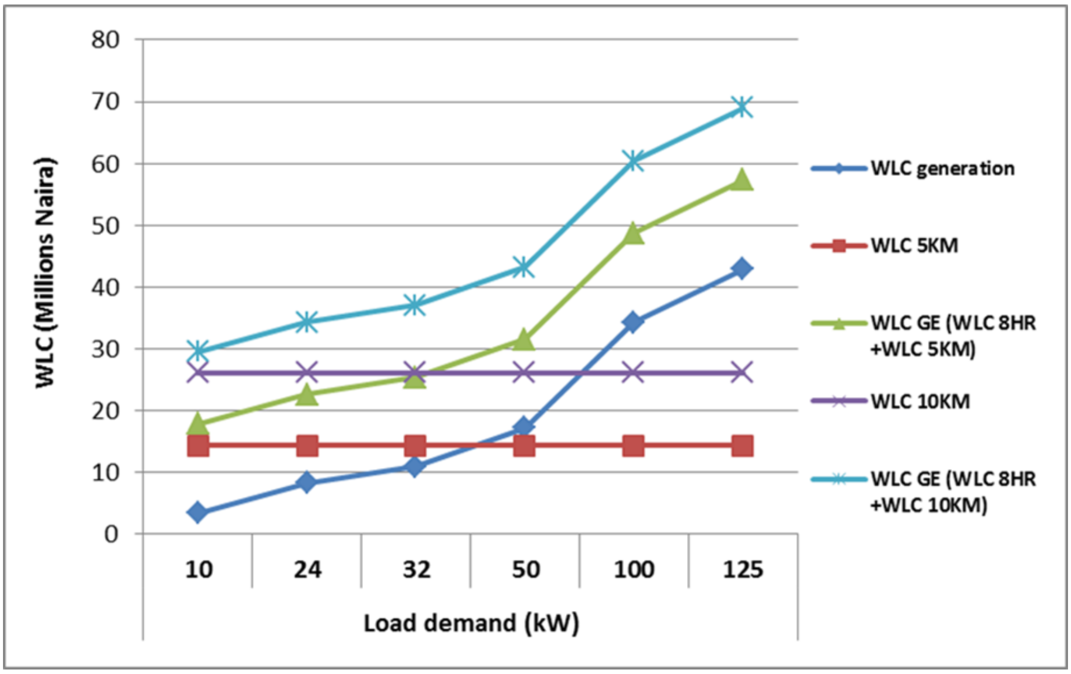
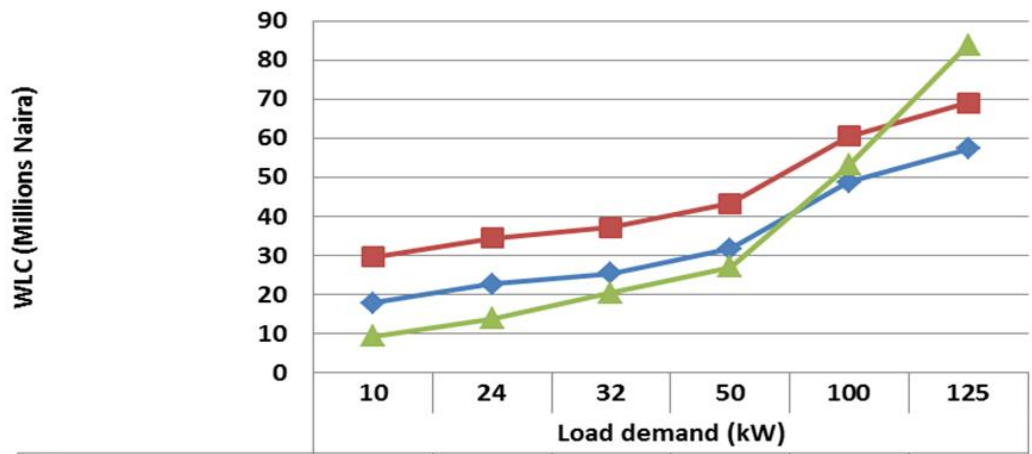


Figure 6.9: Effect of WLC of Electricity Generation over WLC of GE system

Figure 6.9 reveals the findings of evaluating WLC for a GE system using 8 hours of electricity provision as a base case and considering several system capacities. It shows that the WLC of GE is largely dependent on WLC of the gridline and transformer components particularly for smaller capacities between 10 kW and 32 kW. Also, it indicates that the WLC of generation represents just a fraction of WLC of gridline extension. Typically, the WLC of electricity generation of 32kW evaluated (using equation 3) represents approximately 76% and 42% of WLC of grid line only for 5 and 10 kilometre (km) grid length respectively. Similarly, it represents respectively only 43% and 30% of the WLC of GE (WLC of generation + WLC of grid line only) of 5km and 10km of the same capacity and the same operational hours (see figure 6.9 for details). The low cost of WLC of generation in this context results from the effect of grid system economies of scale.



	10	24	32	50	100	125
WLC GE (WLC 8HR +WLC 5KM)	17.81	22.61	25.36	31.54	48.72	57.3
WLC GE (WLC 8HR +WLC 10KM)	29.52	34.33	37.07	43.26	60.43	69.01
WLC 8hr (GAS)	9.14	13.77	20.25	26.96	53.12	83.77

Figure 6.10: Investment cost comparison between BETs and GE systems

In a bid to compare WLC values for the GE system, using the same capacities as for the gasification system (GAS) with 8 hours of electricity provision, figure 6.10 shows that the increase in investment cost for an extension between 5km and 10km of a GE system by the order of system capacities (10 kW -125 kW) ranges from 65% and 20%. This indicates that up to 65% of WLC (investment cost) of a GE system will be required when the grid line extension exceeds 5km to 10km. Hence, the shorter the distance of a GE of system capacity the cheaper its total WLC.

6.7 COMPARISON OF BETs and GRID EXTENSION ENERGY SYSTEMS

This section compares the WLC of utilising BETs and GE systems for electricity provision in Nigerian rural areas. The aim being to develop a relationship between GE and decentralised BETs systems. Hence, the analysis will enable selection of an optimum technology among BETs and GE various system capacities, having considered both the investment cost and the WLC of their operation and maintenance.

Among the BETs, gasification system (GAS) has been selected for the purpose of comparison with a GE system based on the following criteria: better capacity factor, better efficiency (Evans et al. 2010) and availability of smaller capacities compared to other BETs systems based on the data obtained from manufacturers in this study. For example, the minimum system capacity for a direct combustion system in the market presently is 50kW. Also, in largely rural areas the energy consumption pattern is low (see table 8.2, typical of electricity requirement in Nigerian rural areas). Hence, it is GAS that is suitable for these kind of communities, which is compared with a GE system using the same system capacities with 8 hours of electricity supply. Feed-in-tariff (FIT) incentive strategy has not been considered for either system in this context. This is because of the ease of decision making and also given the fact that BETs systems are also cost competitive with a GE system without the use of FIT, as evaluated in sections 6.2 and 6.4.

Given the studies conducted on six villages visited as depicted in table 8.2 (chapter 8), a majority of the power energy requirements of these communities falls below 50 kW capacity and ± 10% of 5km distance from the last point of the grid system. Figure 6.10 reveals that it is more economical to utilise GAS for electricity provision for isolated villages with system capacities between 10kW to 50kW than using GE system with a 5km distance to the villages from the grid last point. However, as the system capacity reaches 100 kW with the same distance of 5km, it is more cost competitive to use a GE system. Also, in the event a GE system reaches 10km with the same system capacity (100KW), the figures turn in favour of a GAS system. Further, the WLC of a 125 kW GAS is generally not economical, as it exceeds the WLC of a 5km GE (WLC generation of 8hr +WLC 5 KM) and the WLC of a 10km GE (WLC generation of 8hr +WLC 10 KM), by 21% and 46% respectively (see figure 6.10 for details). Hence, it is more economical to use a gasification system for electricity provision for villages with less than 50 kW capacity and less than 5km distance from the grid.

Thus, it is fair to conclude that electricity provision to rural areas via a GE is largely reliant on total energy demand in the village, number and pattern of demand operational hours, distance of the village from the load centre, and the cost of generating electricity at the last point of an existing grid. These findings agrees with Mahapatra and Dasappa (2012).

6.8 BETS ADOPTION: RISK ANALYSIS

Given that RETs are emerging technologies, particularly to sub-Saharan African countries and other developing nations, there is the need to assess the risk associated with their adoption. This is because sometimes the investment cost of RETs' assets can be prohibitive and also, the assessment can serve as a means of avoiding wastage. The risk usually associated with new technology utilisation in an entirely new environment can be significant. The risks in respect of BETs adoption are as follows:

6.8.1 Policy Changes

Several countries in sub-Saharan Africa (SSA) over the last decade have reviewed their energy policies (Owen et al. 2013) with a view to meeting sustainable development objectives. This has resulted in several policy changes. Typically, includes some form of incentive provision (similar to developed economies like EU countries). Furthermore, over the last three years, Nigeria's government has developed new energy policies and reviewed some existing ones. For instance, Nigeria's renewable energy and energy efficiency policy was signed into law by the end of May, 2015. (See chapter 4 for more details). Also, the electricity tariff in the country has been reviewed upwardly (average US$0.08/kWh to US$0.13/kWh) in February 2016. This is interesting to investors generating electricity in the country. However, the risk in this case, is the strategy of raising funds to meet the obligation of incentive provision to investors where consumers have to pay for it through their bills (as mentioned in the policy-see section 4.4 for details). This increase may result in energy consumers returning to fuelwood and charcoal utilisation because of unaffordability (particularly for rural communities) as witnessed in some SSA countries (Owen et al. 2013). Hence, a balance should be reached through reasonable incentives provision (where government contributes) to mitigate this risk.

6.8.2 Lack of Know-how

The technical ineptitude (lack of know-how) risk associated with local people managing the energy facilities, will perhaps not only limit RETs assets operation and maintenance to person from cities, but also to persons from developed or emerging countries (Dimpl 2011; Dasappa 2011). A typical case is a gasification project in Mali, where the operation of the biomass energy system constantly depends on Chinese technicians to supervise and guarantee smooth performance. This risk has made the operation of the asset expensive, and does not ensure replicability (Dimpl 2011). The mitigating strategy is to ensure appropriate training of promising persons within the communities to operate the technology. This will enable experience to be gained and ensure sustainability.

6.8.3 Fluctuation of Biomass Feedstock Prices

This is the biggest risk to the operation of BETs, as biomass fuel represents over 50% of the cost/kWh of electricity (IRENA 2012). Any increase to the price of biomass fuel will also increase the price of electricity. This may result in an inability to pay the stipend for electricity consumed by the rural communities. Thus, sustainable sourcing of biomass fuels at little or no cost, with very minimal transportation will to a large extent mitigate this risk.

6.8.4 BETs Conversion Systems Prices

Given the concern of whether or not to buy the conversion systems and the likelihood of competitors trying to obtain the cost of the products, manufacturers may not be willing to provide the appropriate cost of the conversion components. Typically, during the course of obtaining gasification conversion system prices, one of the manufacturers insisted that the researcher must provide evidence of affiliation or employment. My supervisory team had to provide a covering letter to this regard; the manufacturer still did not provide any information. This is a big risk, as it can result in wrong information provision. The strategy for mitigating this risk is to tell them the truth that it is just for academic purposes.

6.8.5 Spare Part Availability

The risk of shortage of spare parts to maintain the asset can also cause unsustainable usage; if the facility is due for minor or major maintenance that requires spare parts, without it, the facility can experience significant downtime. Mitigating the effect of this risk will mainly be prevented if a private investor is the handler, however if it is government operated, it may take considerable time before fixing such problem. For sustainability of BETs utilisation in rural areas, there must be proper assessment and management strategy of all the identified risks and good support from the government.

6.9 CHAPTER SUMMARY

The chapter evaluated the economic viability of electricity provision to Nigerian rural areas using BETs and GE energy systems. This assessment addresses investment cost and unit cost of electricity generation of both energy systems with their various system capacities using WLC approach. Gasification system has been identified as the most economical means of electricity provision using BETs, while direct combustion (DC) is the most expensive technology. Also, the chapter presented the findings of various biomass feedstocks assessments (covering cost of the fuels, market status and availability, moisture and ash contents) suitable for electricity provision for Nigeria's rural communities. Wood, wood waste, cereal straw, guinea grasses have been identified as the most sustainable biomass fuels for BETs electricity provision in the rural communities. Further, sensitivity analysis of the inflation of biomass fuels prices has been appraised; it indicated that increase in the biomass fuel prices resulted to unit price of electricity generation from BETs increase. DC is the most affected among the BETs, given that it consumes more fuel. Then comparison between BETs and GE energy systems in terms of investment cost and WLC were illustrated and presented. It is also indicative that electricity provision to rural areas of less that 50kW demand and less than 5km distance should be served using the gasification system. Finally, the risk associated with BETs adoption were assessed and management strategies were suggested. The next chapter presents the findings of the interview analysis.

CHAPTER SEVEN

INTERVIEW ANALYSIS AND DISCUSSION

7.1 INTRODUCTION

This chapter presents the findings of both exploratory study and semi-structured interview methods using content analysis. The findings result in three themes arising from the exploratory interviews and four themes from the semi-structured interviews. Also, the chapter informed development of a paper (which was later accepted as book chapter) (Garba et al. 2016a) presented in Sustainable Ecological Engineering Design for Society (SEEDS) conference, Leeds. Other findings based on interview methods were also presented.

7.2 EXPLORATORY INTERVIEW (PHASE 1)

Following the analysis of the exploratory study using content analysis as described in chapter five, this section assesses the outcomes of the themes that emerged: state of the art, constraints and appropriate renewable energy technologies (RETs) for sustainable electricity provision in Nigerian rural areas within the boundary of the literature on global development of RETs.

7.3 THEME 1 (EXPLORATORY): STATE OF THE ART OF RETS IN NIGERIA

Modern RETs have contributed considerably to global total energy representing 10.1% by the end of 2013. Also, by the end of 2014, RETs (including large hydro) have contributed approximately 23% of global electricity generated (REN21 2015). However, after three decades of the establishment of RETs research centres and its adoption for utilisation in Nigeria, modern RETs have not yet become part of Nigeria's energy mix, other than the contribution of large hydro- approximately one quarter of the total national grid supply (Ohunakin et al. 2012; Sambo 2009). From the data analysed, three elements/variables have been identified as being related to Nigerian RETs recent development: policy, technology development and RETs application.

7.3.1 Policy

One of the major issues of RETs development in Nigeria is policy (Ajayi & Ajayi 2013; Mohammed et al. 2013) identified as the first sub-theme to emerge from the primary research. Policy has been the main driver of RETs globally. This is evident in several countries, where governments have developed policy instruments for driving RETs. Policy has become a game changer for RETs in terms of energy generation and supply in many countries. Typically, by mid-summer 2015, RETs had contributed approximately 25% of the total electricity generated in the United Kingdom, which exceeded the amount of energy generated from coal (fossil fuel) for the first time (DECC 2015). Similarly, by the end of 2014, German renewable energy sources were ranked first with a 27.4% share of the German energy industry (Energiewende 2015).

On the RETs policy issue in Nigeria, 3 of the 13 interviewees agreed that RETs are at the policy development and reform stage. According to interviewees 1 and 2 "*RETs are at policy development and reform stage*" and "*Most RETs development in Nigeria is on the policy side*" respectively. This may not be unconnected to the fact that there are no robust policies attractive enough to investors (Shaaban & Petinrin 2014; Ajayi & Ajayi 2013), although the renewable energy master plan (REMP 2005) was reviewed and updated between 2007 and 2012.

The response from interviewee 1 showed that "*RETs Policies have been developed but they are not robust enough to attract investors*". Interviewee 10 added that "*There is RETs policy in the country but it hasn't been fully implemented*". This finding partly agrees with Shaaban and Petinrin (2014) that "an implementation plan is yet to be developed and no explanation has been given for lack of implementation of this laudable policy". Thus, government should review RETs policy with a view to attract private sector participation and encourage the sector to be part of the country's energy mix, particularly for rural areas.

7.3.2 Technology development

As with the development of RETs locally, not much has been achieved. 11 out of 13 interviewees (representing 85%) believe that the local production of RETs components is seriously lagging behind.

According to interviewee 11 "*In terms of renewable energy technology development we are lagging behind*". Interviewee 4 added "*Majority of RETs are still at testing stage of technology development three decades after establishment of energy centres in the country*". Interviewee 10 opined that, this problem may be connected with "*globalisation and lack of trust is hindering the development of indigenous technologies in Nigeria; that is why there are so many technologies that have been developed to experimental level, but have to prove their commercial viability*". Interviewee 11 shared a similar view, "*we are unable to commercialise the RETs that are produced in the country*".

The existing practice in the country indicates that the majority of Nigerians prefer to procure their RETs components, particularly solar PV modules, from China, even though Nigeria is currently producing solar PV components, through the National Agency for Science and Engineering Infrastructure (NASENI), with a 7.5MW capacity (Garba & Kishk 2014). According to interviewee 11 "*Nigerians are importing solar PV from China at half price of what NASENI produce*". It is noteworthy that China has sufficient production capacity to provide the entire global solar PV module demand (Martinot 2013). Hence, economies of scale certainly contribute to the relative cheapness of Chinese solar PV units.

Interviewee 5 opined that "*Nigeria is yet to commence electricity generation from solar thermal system (STS)*". However, "*the technology can be obtained from energy research centres in the country*" interviewee 11 added. Interviewee 5 confirmed the state of development in the energy centre where he works: "*There are much effort on inverters and charge controllers because they are easier to produce than solar cell*". He added: "*these are the fundamental things you have to master for solar application to be sustainable*".

It should be noted that, other RETs are at various stages of development in Nigeria. According to most interviewees (1, 2, 5, 6, 7, 8, 9 and 12 who are either researchers in energy centres or academia), they have previously observed that pockets of RETs to generate electricity are at various experimental stages. Typically, interviewee 6 said "*Biomass to electricity generation is at experimental stage*", and "*Biogas to electricity is almost existence none, but design and development stage yes*" interviewee 1 added. Also, in terms of biogas used as cooking gas, interviewee 6 confirmed that their energy centre has the capacity to achieve this "*The centre can develop biogas digester for cooking: family size between 5 – 8 persons and 30m^3 for community use*". However, this has not yet been achieved at a larger scale.

The development of wind systems in Nigeria has proceeded in a similar way to the biomass system. According to interviewee 10 "*few works have been done to familiarise with how to design the wind turbine, but producing wind turbine and having capacity in the country I am unaware of it*". Interviewee 11 said "*Wind turbines are not manufactured in Nigeria, we only import them into the country*". This finding partly agrees with Ajayi (2009) "Government has thus far not done anything to encourage wind energy development and its utilisation in Nigeria---------as at today, no foreign or indigenous wind energy vendors are available in the country". However, interviewee 5 commented on the little progress made so far "*Sokoto Energy Research Centre (SERC) has previously produced small modern pilot wind turbines of approximately 500W and installed at the centre*". He further explained that "*this achievement was made in collaboration with Engineers without Borders"… they are trying to equip the laboratories in the centre to be able to carry out aerodynamic tests effectively*".

Small hydropower (SHP) technology has been in existence in Nigeria for over 8 decades and it is the first of the modern RETs used for electricity generation (ECN 2005). According to interviewee 11 "*In term of technology development we are lagging behind except for mini/small hydropower*", while adding that "*the development of SHP utilisation may be connected with the fact that, Africa's hydro regional centre is located in Nigeria and the country has its national hydro power research centre situated in Ilorin*". Interviewee 4 added that "*SHP laboratories together with NASENI are collaborating with a Chinese organisation to locally train people to build small hydro turbines*". Hence, it is indicative that the technology in the country is still evolving. Finally, interviewee 12 was optimistic that it is feasible for Nigeria to develop RETs because: "*biogas is not a hi-tech technology, wind is a bit hi-tech, and then solar PV we can package the panels*".

7.3.3 RETs application

Generally, all the 13 interviewees agreed that essentially only two of the modern RETs are utilised in the country, with the main one being solar PV. According to interviewee 5, "*Solar PV application is the largest among the modern RETs presently in the country*". Also, interviewees 2 and 8 added: "*solar PV appears to be the most acceptable out of all RETs in the country*" and "*solar PV has reached maturity stage*" respectively. In respect of electricity generation from modern RETs, it is indicative that solar PV is the most widely utilised across the country. Solar PV is being used for different applications such as street lighting, rural electrification; powering telecommunications base (cell) stations, ATM machines, cottage hospitals and even at household levels. This is in agreement with literature as in Sambo (2009), Mohammed et al. (2013) and Shaaban & Petinrin (2014).

The total installed capacity of the solar PV application in the country is difficult to ascertain despite its wide utilisation (due to the lack of accurate records in the country), but can be regarded as being small compared to other countries in the region. However, Clean Technology Fund Investment Plan (CTFIP) for Nigeria (2014) projected that approximately 1MW of solar PV units are in used in the form of decentralised systems. In addition, approximately 1.2MW capacity has just been installed in the country by the Japanese government in order to boost power for water supply at Lower Usman Dam Water Treatment Plant, Abuja (Kusaoke 2016).

The progress made in respect of solar PV application perhaps is connected with factors such as the energy regulatory agencies advice to the government for its use, the existence of adequate resource potential in the country, more stable resources than other RETs, global accessibility, the development of the technology in the country and its operational experience. According to interviewee 11 "*Energy Commission of Nigeria (ECN) had to convince the then civilian government dispensation in 1999 to use solar PV as part of its quick-win constituency projects under the Millennium Development Goals agenda*".

7.4 THEME 2 (EXPLORATORY): CONSTRAINTS OF RETS IN NIGERIA

Five concepts emerged in respect of this theme and are classified as follows: economic, policy, human, technology and socio-cultural constraints. Renewable energy technologies (RETs) are emerging technologies trying to penetrate a market already dominated by fossil fuel (FF) energy sources. As such, they are mostly still at a relatively early developmental stage. The few RETs that have reached maturity are experiencing a price reduction regime, especially solar PV (Renewable Energy Handbook 2010; Baurzhan & Jenkins 2016). However, despite the price reduction of these technologies, they are still unaffordable to the majority of people in developing countries, especially the rural communities in Nigeria that live below US$1.25/day (UNICEF 2011).

7.4.1 Economic constraints

This constraint is among the major challenges of RETs development (Frondel et al. 2010; Alazraque-Cherni 2008). High cost of the RETs components has been identified as the leading issue in this context. 9 of the 13 interviewees agreed that high investment cost is a major constraint in expanding the usage of RETs; the lack of financial institution support combined with vested interests in selling FF have been emphasised by three and one interviewees respectively as being part of the contributory factors. See table (7.1) for details.

Furthermore, in spite of ongoing RETs components cost reduction every year, particularly for solar PV components, RETs still remain unaffordable to a majority of the people because of the high investment cost. Interviewee 8 commented that "*Compared to 10-15 years ago, the cost of solar PV has reduced drastically, but it is still unaffordable for most of the people*"---. *While people are willing to buy, the capital cost of doing so is very difficult to come by*". Interviewee 6 observed that "*high initial cost has been one of the major hindrances to fuel wood energy alternatives, since for fuel wood option, what you just need is to gather wood at the back of the house free-of-charge*". Also, interview 7 added "*Because of high investment cost, solar thermal cooker costing N20,000.00 (approximately US$100) with payback period of six months and minimum of 10 years lifespan, people could not afford to pay for the initial down payment to procure it*". This finding agrees with Mohammed et al. (2013) "soaring upfront investment expenses of renewable energy development is sometimes responsible for them being ignored by potential investors". However, interviewee 1 said "*Yes it's a huge investment but after that investment, 25 years later, you will still be reaping the benefit*". "*If government can provide incentives, then it could be afforded by them, but for now only few people request for it*" interviewee 7 commented. Details on the strategies for addressing this problem are presented in the semi-structured interview analysis section (theme 4).

7.4.2 Policy Constraints

The following barriers are identified in this section preventing diffusion of RETs by order of priority: lack of RETs robust (deliverables and strategic) policies, lack of regulatory/professional institutional framework, and lack of community content. The least in this context is the lack of RETs market development. See table (7.1) for details.

<u>Lack of robust RETs policy</u>

This constraint remains the chief constraint in developing RETs in Nigeria, particularly in its rural areas; interviewees unanimously agreed in this respect. See details in Table (7.1). Similarly, this problem has been identified in the exploratory study section (theme 1) above, "the state of RETs in Nigeria" as an important issue.

Nigeria has several energy policies: NEP (2003), REMP (2005), EPSRA (2005) and NREEEP (2015) and some have been reviewed previously. See sections (4.2-4.5) in chapter four for details. However, there are indications that these policies are not mature enough to encourage investors' participation. This indicates that something is missing and needs to be addressed urgently if meaningful progress is to be made. According to interviewee 10 "*There is RETs policy in the country but it hasn't gone some distance toward implementation; the missing gap is the end phase of that policy which is deliverable and strategic policy (fiscal incentives)*". Interviewee 1 said "*There is still a need for policy reform to attract investors*"; he added that: "*government alone cannot develop RETs, because the capital resources are huge and there are competing interests*". "*It is investors through public private partnership arrangement that develop RETs*" interviewee 11 opined. These findings also agree with Suberu et al. (2013) that government has previously been the major financier of RETs, but currently private investors predominantly finance RETs capital projects.

Some interviewees suggested that even the most talked about incentives system in the country (feed-in-tariff (FIT) system) is inadequate for utilisation. According to interviewee 3 and 5 "*proposed FIT system in Nigeria is still inadequate and remain about the lowest in the world*" and "*the major constraint of solar PV has to do with incentive policy*" respectively. From the NERC (2013) proposal, the lowest and highest tariff as at today are small hydro (US$ 0.15)/kWh and solar PV with (US$ 0.43)/kWh respectively. This disagrees with Celik et al. (2009) where the lowest among European Union Countries was € 0.15/kWh (for a capacity <12kW) in France, and the highest was € 0.22/kWh (for a capacity >100 Kw) in Spain, both being for solar PV as at 2009. These rates have since been reduced further as reported in section 7.10.6 (subsidies provision and utilisation) in this chapter.

Furthermore, interviewee 6 stressed that, "*There is no energy policy in the country, because it is a borrowed policy. The current energy policy is even not empirical, it is based on rule of thumb*". Perhaps this may be connected with the lack of development in the sector and meeting up with the goals and objectives as scheduled in the REMP (2005). Suggested strategies for addressing this constraint can be located in theme 4 (under semi-structured interview analysis).

Table 7.1: RETs Constraints in Nigeria

Variables (Constraints)	No of Interviewes
Economics	
-High Investment cost	9 (69.23%)
-Lack of financial institution support	3 (23%)
-Vested interest in selling fossil fuel	1 (8%)
Policy	
-Lack of RETs robust (deliverables and strategic) policies	13 (100%)
-RETs budgetary allocation limitation by authority (Inadequate funding)	2 (15%)
-Lack of community content (engagement)	8 (62%)
-Lack of regulatory/professional framework	7 (54%)
-Non-guaranteeing of DISCOs to transmit RETs at low voltage	1 (8%)
-Lack of monitoring strategic objectives	2 (15%)
-Lack of education and training	5 (39%)
-Lack of RETs records/data base	2 (15%)
-Lack of RETs market development	1 (8%)
Human Capacity	
-Proliferation of quackery practice	11 (85%)
-Lack of technical knowledge and skill (manpower know-how to develop and maintain	9 (70%)
Technology	
-Lack of domestication of the technology	5 (39%)
-Transmission and distribution network deterioration	3 (23%)
-Sub-standard components/equipment	6 (45%)
-Lack of confidence in local technology	1 (8%)
-Spare part materials unavailability	1 (8%)
Social-cultural	
-Lack of technology/information awareness	8 (62%)
-Poor maintenance culture	2 (15%)
-Lack of confidence (doubting) of the RETs in the country	5 (39%)
-Availability of conventional energy resources	2 (15%)

Lack of community content and engagement

Considering the aim of this research work is the implementation of sustainable electricity in Nigeria's rural areas, 8 out of the 13 interviewees expressed concern on the way government runs RETs projects in rural areas, particularly the lack of engagement with communities regarding the operation and maintenance of the technologies. For instance, interviewee 10 said "*The way government is operating rural electrification is unsustainable. This is because they just dump the RETs facilities and it costs the community nothing*"; adding that "*there is nothing behind it that makes it sustainable, not even a business case*". It is clear that if there is nothing behind it that makes it sustainable, it will be abandoned. Therefore, community engagement is necessary, where people will be paying a stipend for operating and managing the system and invariably taking charge of what government has provided for them.

To worsen the situation, technicians from the cities are usually the people managing the RETs in rural areas. Interviewee 5 stressed that "*when you just employ workers from cities and send them to the villages, they are certain that at the end of the month, whether the plant works or not, they are going to receive their salary*". That is more reason why you need local people's participation in order to operate and maintain the systems for sustainable usage. Similarly, interviewees 6 and 10 agreed with the above view.

Lack of regulatory/professional institution framework

This barrier represents a third of the problems under "policy barriers", as it emanates from a lack of a robust RETs policy setting and it eventually gives birth to multiple problems such as sub-standard (low-quality) RETs' components, quackery practice proliferation, lack of consultants' involvement in contract procurement system, and RETs contracts awarded to politicians as a means of "appreciation". See Figure (7.1) for details. Also, this problem was mainly raised by interviewees working in the energy regulatory sector and at energy research centres.

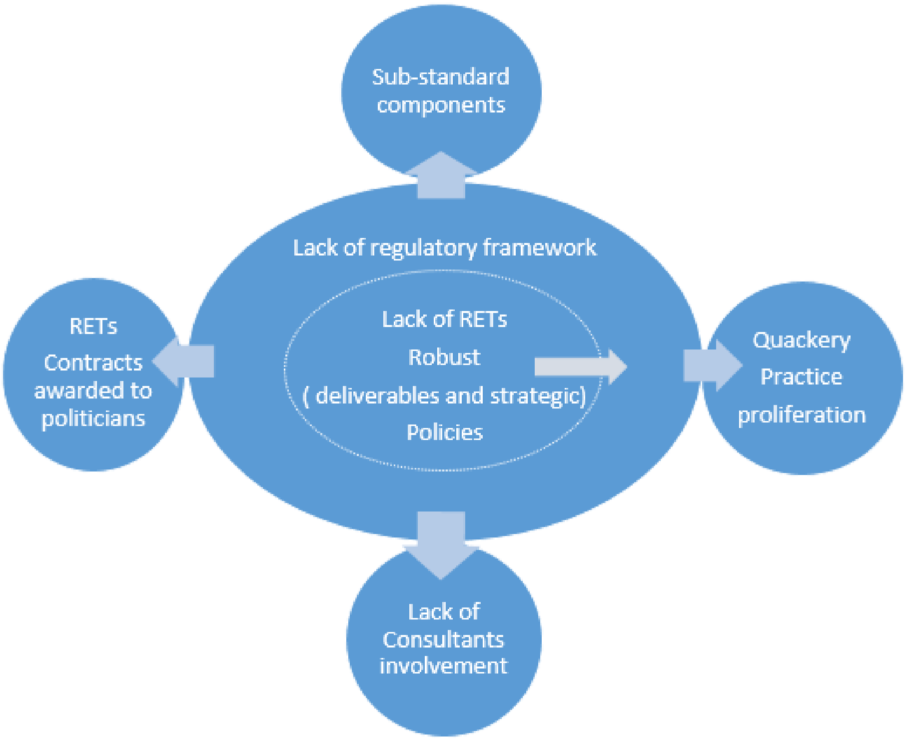


Figure 7.1: Effects of Regulatory Framework Deficiency

As previously highlighted in section 7.3.2, Nigeria has commenced production of solar PV components but due to the lack of a regulatory framework, now virtually all the solar PV components are being imported. All the interviewees unanimously agreed that importation of solar PV components is directly affecting the development of local manufacturing capacities, this is apart from the influx of sub-standard components. Interviewee 5 added that "*There is no approved policy that says villages above certain kilometre from load centres, RETs should be adopted for their electricity source*".

On the lack of consultant involvement in the contract award system, interviewee 5 said, the state government do not appoint consultants to supervise the RETs contract to ensure quality projects. He also argued that one of the biggest issues is the awarding of contracts to politicians. "*Politicians that you cannot talk to even if they are doing the wrong thing".* He stressed further that "*there must be a mechanism for checking that all specifications provided in a projects are complied with*".

7.4.3 Human Capacity Deficiency Constraints

Two barriers have been identified in this section; proliferation of quackery practice in the RETs industry, and Lack of technical knowledge and skill (manpower know-how to develop and maintain the RETs).

<u>Quackery Practice proliferation</u>

Lack of sound technical knowledge and skill may be among factors responsible for quackery practice proliferation in the Nigerian RETs market given the latent energy demand in the country. The effect of this problem has now superseded the lack of technical knowledge as depicted in table (7.1). Approximately 85% of the interviewees agreed that quackery practice has now become an endemic problem regarding RETs (particularly solar PV) in the country. The effect of this problem has caused some state governments, particularly Zamfara, Jigawa and Lagos states, to scrap use of their existing solar PV technology (used for street lighting), as expressed by interviewees 1, 2, 3, 5 and 6.

Interviewee 4 stated that "*quackery practice has caused inappropriate installation of solar PV; majority of solar street lighting projects by the states government have been abandoned; for instance Zamfara state*" and "*the reasons include poor installation, and batteries were installed in the sun and subsequently affected by temperature extremes*". Interviewee 2 stressed that "*There are instances when houses almost got burnt, if not because of quick intervention. Quackery practice is a major problem causing lack of interest in investing in RETs*". He added that "there are a lot of abandoned solar PV projects in the country" as result of this challenge. Interviewee 1 supported the view "*That was the reason some states in Nigeria replaces their entire solar PV base street lighting with fossil fuel based system*".

Furthermore, interviewee 3 commented that "*This problem even affected World Bank Street lighting solar PV pilot project in Lagos state, following the adaption of local content policy using indigenous companies*". He further emphasised that "*Sub-standard products and quackery practice are the two major problems of RETs in Nigeria*". With the level of development and wide awareness, people living in the cities, would have perhaps adopted RETs, particularly solar PV, without the need for policy support given the latent energy demand in the country. However, a lack of trust of these technologies, may be connected to quackery practice proliferation in the country, which is then hindering RETs progress.

Lack of RETs technical knowledge and skill

Technology emancipation of any country is based on the ability of the citizenry to be able to develop and maintain their indigenous technology. In Nigeria, there are limited people with ability to develop, operate and maintain RETs.

9 out of 13 interviewees agreed that this barrier is a serious constraint. The technical knowledge and skill deficiency is causing a lack of progress and resource wastage in the country. Interviewee 1 stressed that "*lack of knowledge has led to wasted resources*", and "*adoption of the technology is predicated on the technical knowledge and education*". However, a few interviewees said RETs know-how exists in Nigeria but is limited to some persons and institutions. Typically, interviewee 10 agreed that "*RETs know-how is not existing in the rural areas, but there are institutions particularly universities and private persons that have acquired the RETs knowledge*". While interviewee 11 opined that "*even in our universities, how many people have degree in RETs; close to none*". This further raised concern over limitation of RETs developers in the country. Harnessing the right people with the RETs know-how is the main issue now. Interviewee 12 stressed that "*technology development capacity is a big issue, getting people that have right expertise is another case and the right policy is not really there*".

Interviewee 1 commented that "*Even if NASENI is producing solar PV, have they come out to train people on how to maintain the solar panel? No*". He added that "*persons installed solar PV street lighting, but the installation angle is not correct; how is it going to work*? *Look at street lighting in the country; the accumulation of dust reduces efficiency, due to lack of cleaning*". These problems are mainly related to a lack of installation and maintenance know-how. In the light of the above, there is the need for government to develop its own RETS experts, with a view to develop and sustain the use of RETs.

7.4.4 Technology Constraints

Five major barriers have been identified in this section. The most significant ones in terms of priority include sub-standard components, lack of domestication of the technology, transmission and distribution network weaknesses. The remaining two barriers were each identified by a single respondent. These two constraints are new, as far as the knowledge of the researcher has been able to establish. They are indicated in table (7.1).

Sub-standard components importation

Existing practice in Nigeria indicates that imported sub-standard products (particularly solar PV) have flooded Nigeria's RETs market, despite Nigeria being a producer of these components. This is a situation "*where vendors import solar PV components into the country without standard checking and certification before utilisation*" interviewee 5 opined. Interviewee 4 declared that "*We are importing everything up to batteries and inverters despite some of the technologies exist in the country*". "*Everybody is importing everything to the country, and so many products are just for market purpose and they are not meant to last longer*" interviewee 9 added.

Lack of Domestication of the Technology

Domestication of technology is vital to adopting a technology. Interviewee 1 said "*until you own the technology, the technology has no life. Even if NASENI is producing solar PV, we should be aware that solar PV is just one of these technologies. So when technological awareness is missing, domesticating the technologies becomes a problem*". According to interviewee 12 "*Technology development capacity is a big issue; in fact is one of the most important thing which government should really focus attention on, if we want to develop the RETs*". Interviewee 1 added that "*Do you know why solar PV is now being adopted everywhere in the country, because Nigerians can now couple and install solar cells*". However, interviewee 2 opined that "*even the solar PV that is more pronounced across the country, it is experiencing difficulties, due to lack of sustainable manufacturing in the country*".

Interviewee 10 opined that "*globalisation is preventing development of indigenous technology"; he added "If we open our market to global economy, we are not going to develop RETs capacity in the country*".

Transmission and Distribution (T & D) Grid Deterioration

It is not surprising that this constraint came third in this research work (rural areas electrification) due to it being a major national problem as earlier studies have identified. Interviewees perhaps do not consider it a major issue in Nigeria's rural areas electricity problem, even though there is a significant electricity loss peculiar to Nigeria as result of the deterioration of the T & D infrastructures of up to 40% (World Bank 2005, Dasappa 2011).

Interviewee 3 highlighted that "*The bulk of Nigeria electricity problems now does not rest on the generation, it rest on the T & D; it is what determines the amount of electricity generated*". He cited the instance that: "*The current operational transmission infrastructure stood at approximately 5,000MW. So even if 10,000MW is generated, we can only wheel about 5,000MW due to the existing capacity of the T & D. So there is no point generating above 5,000MW; otherwise it will be a waste*". Interviewee 9 added "*Our grid is bad and cannot accommodate more than existing capacity generated*".

Also, interviewee 4 revealed that "*Nigerian grid network doesn't heal itself very fast, while some automated grid does. Once power supporting the grid goes off abruptly, it now overloads the remaining power source*"----------and " *If Nigerian grid has a lot of RETs, we will have a lot of system collapse because of intermittency, that is why we are limiting RETs to 10% cap as proposed by renewable policies, because we don't have a strong grid*".

7.4.5 Socio-Cultural Constraints

Lack of awareness has been identified as a major constraint in this respect, as 9 of the 13 interviewees unanimously emphasised. More so, this is the first time that the following barriers are reported: cultural addiction, availability of FF resources (no need for paradigm shift) and poor maintenance culture (endemic issue in the country). See table (7.1) for further details.

Lack of Awareness

Awareness constraint may be the reason for a considerable lack of progress regarding use of RETs in Nigeria. According to interviewee 1, there was a time questionnaires were administered in this instance: "*It reveals that not up to 20% actually understood RETs sources from a sample of 1500 questionnaires administered*"; adding that "*some respondents even highlighted batteries and inverters as RETs sources*". This exercise was conducted in urban centres, where awareness would reasonably be expected to be higher than in rural areas lacking access to modern mass media. This finding agrees with Ajayi (2009).

Lack of awareness also affects even government officials in their policy making, as they cannot differentiate between RETs and other energy components. Typically, interviewee 4 reported that "*Nigerian government put higher import duty on car batteries importation with a view to discourage importation into the country; but solar batteries are not produce in Nigeria. Unfortunately, they could not differentiate between solar and car batteries; hence, they tax solar batteries, despite the existing policy support to the contrary*". Similarly, interviewee 10 stated that "*Initially ministry of power and utility company (NEPA) didn't believe in RETs (solar) in providing electricity. It took many conferences/ workshops to sensitise its management with the intervention of foreign partners to convince them*".

The lack of awareness is more pronounced in the rural areas. According to interviewee 2, even when rural communities were asked how they would respond if the biofuel technology was given to them free to replace their fuel wood stoves "*Many people refused to accept biofuel technology because it will change the taste of their food*". This problem emanates from a lack of awareness.

7.5 THEME 3 (EXPLORATORY): RETS FOR PROVIDING SUSTAINABLE ELECTRICITY FOR RURAL AREAS

This theme seeks to identify the most suitable RETs for providing sustainable electricity in Nigerian rural areas. Five major RETs were identified by interviewees as possible means for delivering sustainable electricity to Nigerian rural areas. See figure (7.2) for details. Solar PV and biomass energy systems are the choice of most interviewees. This is followed by the choice of small hydropower system (SHP) and the least in this context is the wind energy system. The underlying reasons for the selection of these RETs include: resources availability, level of development, high capital cost and policy support.

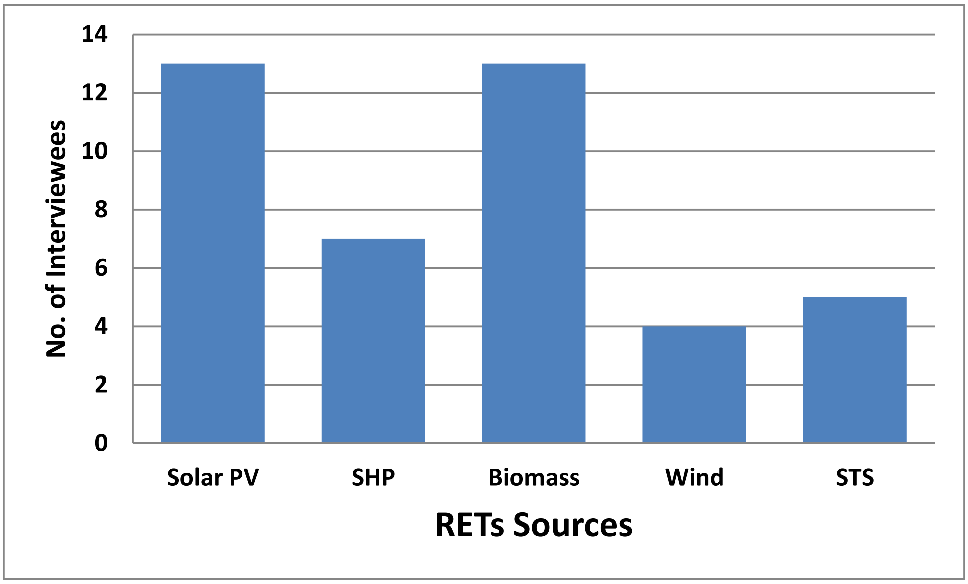


Figure 7.2: RETs Suggested for electricity Provision in Nigerian Rural Areas

7.5.1 Energy Resources Availability

The focus of the interviewees at this stage is the availability of the resources. According to interviewee 2 "*The major reason for selecting solar PV, biomass and SHP has to do with availability of the resources across the country*". Adding that "*Solar PV is quite accepted in Nigerian energy market, SHP technology can easily be understood and utilised, and there are operational experiences in the country; while biomass, we have a lot of agro-allied resources in the country rural areas*". Interviewee 5 was more specific: "*I am emphasising on solar PV, because there is no single area in the country especially in the north that you don't have availability of solar radiation but wind is very site specific and highly unpredictable compared to solar radiation*". This view was shared by interviewee 8, but added that "*Nigeria has a lot of rivers, water fall but unutilised up till now*". The views of the interviewees agree with studies by Shaaban and Petinrin (2014), Mohammed et al. (2013a), ECN (2005), Sambo 2009 and Garba and Kishk (2014).

7.5.2 Level of development

The level of development of some RETs in the country may be connected with the pattern of selection for application in the rural areas. Also, this essentially relates to RETs acceptability in Nigeria. According to interviewee 6 "*The proven technologies that can make impact and penetrate these communities without much stress include solar PV, biomass and solar thermal system (STS) (for drying, water heating, cooking)*". Similarly, this is the view of interviewees 7, 9 and 13. Interviewee 4 opined that only four most viable RETs are available and include "*solar PV, wind, SHP and biomass; it is hoped that necessary policy instrument can be made available to support them*". However, interviewee 11 commented that "*You can only obtain STS in research centres in Nigeria or import it*". Furthermore, all the interviewees (5, 6, 7, 8 and 9) that selected STS are working with energy research centres in the country. This reflects that they have understood the benefits of this technology in terms of provision of sustainable electricity and agricultural products processing within such communities (considering the majority are farmers).

7.5.3 High Capital Cost

High capital cost is problematic in two respects. Firstly, there is a problem of affordability, which is largely associated with RETs that are considered more expensive than a grid extension system (Evans et al. 2009). Secondly, there is a problem of relativity (to the resulting cost saving). The reason for low selection of STS by interviewees perhaps because of high capital cost. According to interviewees 4 and 12 in this respect, "*STS will be more viable but more expensive*" and "*STS is a bit expensive than solar PV, but it has efficiency than solar PV*" respectively. Furthermore, STS' high cost vis-à-vis solar PV will be the deterring factor; solar PV has already been deemed the most expensive among the commonly used RETs for electricity provision in the rural areas (Mahapatra & Dasappa 2012; Evans et al. 2009), let alone STS.

7.5.4 Policy Support

As with policy support strategies, Nigeria has an incentive strategy that supports utilisation of all the identified RETs except STS, but only for grid systems above 1MW capacity (NERC 2013). According to interviewee 13 "*There is also provision for the feed-in-tariff (FIT) for RETs electricity in the country even though it does* *not extend to rural areas electricity*". Based on the existing practice in the country, RETs components are enjoying fiscal support such as import duty and tax exemption.

Given the analysis above, and by order of priority, the following RETs: Biomass, solar PV, STS and SHP are the most suitable for rural electricity provision and should be supported by relevant policy instruments in the country. This finding partly agrees with Garba & Kishk (2014) "Biomass, hydro and solar sources are appropriate for use in Nigeria's rural areas". Wind energy system has not been considered because of intermittency and high unpredictability when compared to other RETs. Furthermore, given the benefits of biomass over solar PV system, such as only requiring additional fuel as operational hours are increased, but "the increase in its load demand does not require increase in the gasifier rating, as the gasifier turndown ratio is quite high". While in the case of solar PV "as the operational hours increase, the system size also increases and consequently, its capital cost" (Mahapatra & Dasappa 2012); also, as reported by Baurzhan and Jenkins (2016) that it will be 2030 before solar PV becomes cost competitive in SSA countries having FF sources. Hence, the biomass energy system has been selected as the most appropriate for sustainable electricity provision in rural areas.

7.6 PHASE 2: SEMI-STRUCTURED INTERVIEW OUTCOMES

On account of the outcome of the exploratory study, biomass energy technologies (BETs) are deemed the most suitable RETs for providing sustainable electricity in rural areas, hence this initial conclusion is subjected to further assessment. Further details have been sought from the interviewees using the semi - structured interview approach. In this context, interviewees were asked to offer detailed assessments of BETs in respect of sustainable electricity provision in rural areas. The responses of the interviewees indicate that 77% of them support the use of BETs, while 3 interviewees were against its application (though mildly, and details have been presented below). The next section(s) presents semi-structured interview findings, classified under the following themes: BETs electricity provision drivers, enablers, and constraints of utilisation in Nigerian rural areas, and strategies for advancing RETs.

7.7 THEME 1 (SEMI-STRUCTURED): DRIVERS OF BETS

The following presents motives of some of the interviewees in respect of BETs application in rural areas. Interviewee 3 was of the view that the drivers of the utilisation of BETs is its inclusion in the National energy policy and universal availability of biomass resources. Interviewee 11 was of the view that the drivers include reduction in CO_2 footprint, rising energy demand and conflict neutral energy source through the use of BETs.

7.7.1 Rising Energy Demand

Given the rising energy demand occasioned by the growth in population particularly in the country's rural areas in relation to the long gestation period of most carbon-based power plants in the country, it is indicative that the existing practice of a centralised grid using fossil fuel energy system may not meet the immediate energy demand of these communities. Interviewee 11 said "*To install and test run similar capacity of Egbin (gas) thermal station, we need about 36 months; while similar capacity to Mambilla hydropower station, may require six years or more*". Interviewee 8 opined that "*Due to the developmental period, we need something of immediate outcome such as RETs to meet the rising energy demand in the country over the coming years, looking at the rate at which the population is growing*".

7.7.2 Biomass Resources Availability

According to interviewee 6 "*Biomass has always been rural areas friendly, because that is where you find most of the raw materials and the technologies are not so complex to manage*". Interviewee 5 also expressed similar view that "*It is very feasible, because we have a lot of resources and that is the major one. Once you have the fuel, the next stage is technology*"; adding that "*There is biomass electricity generators already developed globally*". Interviewee 13 observes that "The driving force is the biomass resources availability in these communities and the energy policy that encourages the generation of electricity from such technology in a sustainable way". "*There is a lot of waste from animal husbandry, in addition to agricultural waste*" according to interviewee 8. This finding agrees with Mohammed et al. (2013), Shaaban and Petinrin (2014) and (ECN 2005).

7.7.3 Conflict Neutral Energy Source

Interviewee 3 says that renewables are conflict-free energy sources "*once you have them, nobody can shut the atmosphere from sun radiation and biomass plantation photosynthesis*". This is in agreement with Owen et al. (2013) "Domestically-sourced biomass can help diversify domestic energy supply, leading to increased energy security and independence from imports". Similarly, BETs can enable other Nigerian regions to have access to electricity given the unabated youth restiveness in the Niger delta region as result of neglect of the region.

7.7.4 Climate Change Mitigation

Given Nigeria is the second largest gas flaring country in the world (Oseni 2012), the adoption of BETs by rural communities in the country will help in mitigating climate change effects considering their enormous electricity needs. Interviewee 11 argued that "*Biomass system utilisation for rural communities will curb greenhouse gas emission in the country*". This finding agrees with Shunmugam (2009) and Owen et al. (2013) "Biomass is potentially carbon-neutral and can replace fossil fuels sources especially in power generation".

7.7.5 Disagreement with BETs Application in Rural Areas

3 of the 13 interviewees disagree with BETs utilisation in Nigerian rural areas. Their reasons for rejecting BETs include the lack of biomass technology in the country, deficiency in local know-how, location peculiarity and policy issues. However, their disagreement with its utilisation was not far-fetched, in that there is some evidence to support their reasoning.

Typical views include, interviewee 1 indicates that "*Nigerian rural areas are not mature enough for biomass electricity generation. Although, the potentials exist but the maturity is not*". Interviewee 10 added that "*Anything that needs monitoring in Nigerian rural areas poses some challenges and even the basic investment that is required to have kerosene stove, let alone RETs ownership*". Interviewee 7 argues that "*Biogas for electricity generation is not viable at the moment; the yield for the gas generation is not insignificant*". This latest response may not be unconnected with the existing practice in the country, where biogas is mainly used as heating gas for school laboratories and cooking gas in the prison yards.

Furthermore, interviewee 1 stressed that "*If such an investment is to be located in rural areas, then it will require monitoring; hence, it will require people from these communities, to manage it. Do they have the technology, its know-how and even awareness? No*". He added that: "*You will find that, it (biomass) will be very expensive and abandoned in the long run and subsequently go back to wood burning*". Based on the existing practice in Nigeria, this problem is not only peculiar to BETs. It is a general problem to RETs. See section (7.4 – constraints of RETs in Nigeria) for details. Hence, there is a need for the practice and experience to be gained with a view to developing the RETs (especially BETs).

Despite the reservations of critics of BETs utilisation, as expressed above, they still agreed that biomass is good for rural communities but under certain conditions. For instance, interviewee 1 agreed that "*Biomass utilisation is a very good idea but, there are sustainability questions to be answered particularly in terms of cost competitiveness with fossil fuel (FF) and environmental benign*". Thus, biomass is now cost competitive with fossil fuel based electricity generation, especially in the developing countries rural areas (Mahapatra and Dasappa 2012; Garba and Kishk 2015; Garba et al. 2016b; Nouni et al. 2007; Dasappa 2011). Evans et al. (2010) however, disagree with this assertion.

Interviewee 7 also suggested that "*If there is a proper organisation, biomass is good but relying on the dwindling forestry resources, no*". "*Biomass should only be used in most suitable locations*" interviewee 10 added. All of the above concerns have already been covered by (NREEEP 2015) despite the relegation of BETs by NEP (2003) among other RETs and FF sources in Nigeria.

Furthermore, some *interviewees advocated the benefits of using BETs. Interviewee 6 said "Biomass has tripod advantages that include sanitising the environment, produce gas for cooking and electricity generation and the wastes are used as organic fertiliser*". "*You can create a business case by growing grass, corn and any visible waste can be bought; thus, you are creating a chain of business for people"* interviewee 12 added. Interviewee 10 stressed that "*Bio-*

digester can be used to solve waste problems that arise from bush burning, plants and animal waste often disposed in our open abattoirs and farmlands".

Also, interviewee 11 advocated that "*The critics of biomass that, it is not totally renewable should be ignored, this is only because they want to sell their oil*". He then asked: "*Have you been informed about what they have gone through before they can get oil up to this level*"? Interviewee 13 added that "*Based on whole life cycle assessment, solar and wind still have elements of pollution*". This agrees with Manish et al. (2006) that their GHG emission is not zero percent. The finding also agrees with Owen et al. (2013) that efforts to develop biomass system policies are always frustrated by the biomass antagonists.

7.8 THEME 2 (SEMI-STRUCTURED): ENABLERS OF BETS

For successful development of BETs in Nigeria's rural areas, there are certain things that need to be taken into consideration. Interviewee 5 suggested that certain prerequisites need to be considered for BETs to work in rural communities, for example "*adequate water supply, the need to train local people to handle the facilities and appropriate siting of biomass plant based on availability of biomass resources*".

7.8.1 Water availability

It is necessary to build BETs plants where there is an adequate water resource. According to interviewee 5 "*If you build a BETs plant in a village where only a hand dug well is available for feeding their animals and communities utilisation, there might be problem of water shortage and eventually could lead to abandonment*". Interviewee 6 stressed that "*Areas and locations with good water level or close to water sources, and have the biomass resources can have the technology implemented*". Hence, water is a key factor for implementing BETs and should be given due consideration.

7.8.2 Appropriate Technology

Interviewee 6 agreed that "*BETs cannot be everywhere, but should be used where it has economic advantage and with little or no hindrances in terms of implementation*". "*If you site it where they have little or no source for resources, then in the end, you will be left with no result*" interviewee 5 added. Interviewee

5 further suggested that "*When setting this technology, the policy should be based on adequate raw materials availability in a particular location*".

7.9 THEME 3 (SEMI-STRUCTURED): CONSTRAINTS OF BETs

7.9.1 Supply chain issue

Available literature (eg. IRENA, 2012) reported that supply chain difficulty is among the major problems of BETs. This was also identified in this study; all the interviewees unanimously agreed. Typically, interviewee 5 opined that "*Our people are used to easy technologies, the protocol of collecting these resources and mixing them to utilise the gas may prove difficult*". Similarly, interviewee 6 said "*Supply chain difficulty has to be put into consideration, because it's a fundamental problem*". "*I know we have a lot of biogas digesters in the energy centre, though not all of them are working because of fuel supply issue*" interviewee 8 stated.

7.9.2 Significant land requirements

Interviewees were of the view that an enormous land requirement is a key constraint to BETs use. According to interviewee 8 "*When BETs become operational, waste procurement may prove difficult at times and there may be need for energy plantation, which utilise large amount of land*". While interviewee 3 opined that "*energy plantation requires massive land requirement and high water needs during energy plantation and generation*". This finding agrees with Manish et al. (2006) that "land availability may constrain sustainability of biomass based systems"

7.10 THEME 4: STRATEGIES FOR ADVANCING RETS IN NIGERIA

Many strategies have been suggested by interviewees to advance the use of RETs in the country's rural areas. Typically, interviewee 1 said the way forward is "*re-engineering the RETs constraints for effective adoption in the country's rural areas*". More so, the combination of the following recommended strategies could effectively lead to the development and sustenance of RETs in Nigeria. Interviewee 6 added that "*there is no known alternative for RETs now, everybody must key for it, if you want to get the best out of energy system*".

"*Decentralising energy system is promising and is the future*" Interviewee 12 added.

Given the data analysed in this respect, it is indicative that most of the suggested strategies are either directly or indirectly connected to policy. See figure 7.3 for details. A typical reason for the above assertion is that even domestication of technology requires enabling policy and environment for investors to come into the country. Hence, there must be a robust law or policy that is attractive for business growth and protects investors. This argument also applies to economic subsidies provision and other forms of incentive. The sub-themes identified can be found in Table 7.2; and details are presented as follows:

7.10.1 Policy Review

In this context, three variables have been suggested by interviewees as a means of developing RETs in the country's rural areas and are as follows. See Table (7.2) for details.

<u>Policy review and Implementation</u>

Nigeria's renewable energy policy (Renewable Energy Master Plan) has been in existence since 2005 and has undergone review twice (2007 and 2012). Despite these reviews, there is still the need to review the current policy to capture new realities. Typically, "*According to the policy book by 2015, five RETs will have been in the country's energy mix, unfortunately this is not the case*" interviewee 5 commented. In fact, currently, there is not any modern RETs electricity connected to the grid in the country, except the small hydropower (SHP) that has been in existence since 1923. Hence, there is the need to review the existing RETs policies to capture realities regarding factors such as target dates and development objectives.

Also, interviewee 1 suggested that, there is the need for the "*execution of the policies*". Interviewee 5 added that "*there must be full policy and we must be ready to implement it, because sometimes a lot of these policies just remain on paper*".

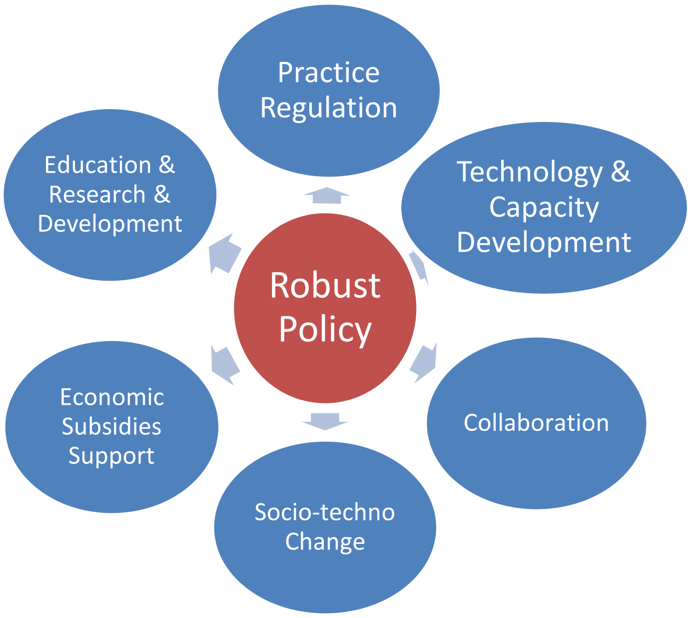


Figure 7.3: Relationship between Robust Policy and other RETs Strategies

Similarly, the incentives strategies currently in use in the country (particularly the feed-in-tariff (FIT)) should be reviewed so as to cover rural areas electricity generation. Currently, FIT is meant for incentivising grid connected electricity generation for capacities between 1MW -30MW only (NERC 2013). However, the majority of the rural communities are low energy consumers with capacity demand mostly below 1MW and are largely not connected to the grid. On this basis, current policy is against global best practice principles where even 4kW capacity can generate and supply to the grid through a smart metering system.

Furthermore, with the only incentive being licence fee exemption for rural areas electricity generation, investors may not be interested in providing electricity to these communities. Hence, Nigeria's incentives policy for rural areas electricity provision should be reviewed and implemented. Interviewee 10 suggested that, the country's RETs incentives strategies should also be reviewed to cover "*The front end and back end (fiscal incentive) sets of strategies that are required to actually implementing RETs in the country*" This finding agrees with Sopian et al. (2011) "Investment taxes and incentives strategies need to be well formulated to attract more international manufacturers and encourage local industries utilising the renewable energy technology".

Promoting awareness

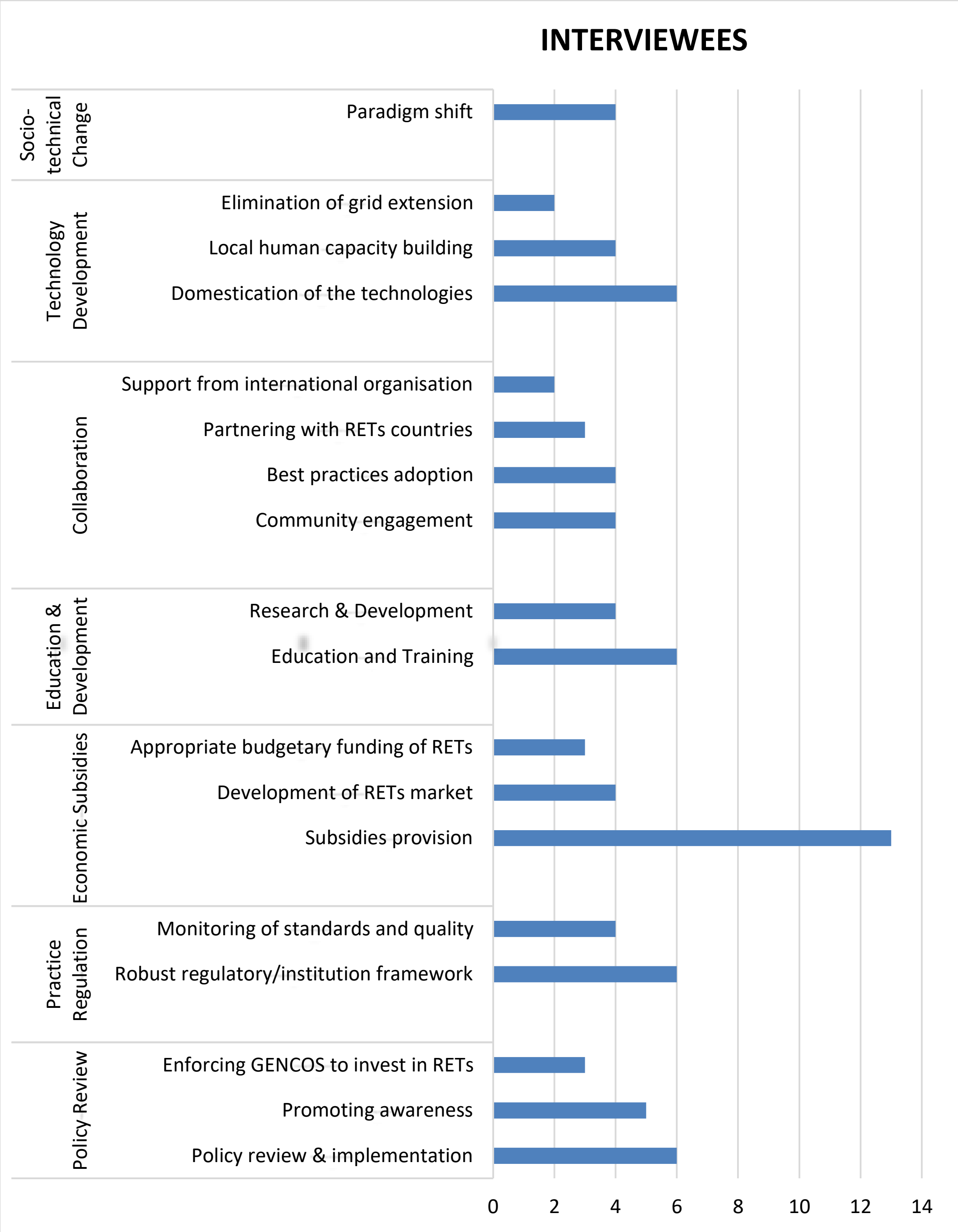
As highlighted in section 7.4 (theme 2 -constraints of RETs in Nigeria), a majority of Nigerians are unaware of RET systems. Thus, for Nigerians to be more aware of how these energy sources work interviewee 1 suggested that "*there is need to promote awareness, beginning with RETs education from primary and secondary schools*". For substantial RETs development, interviewee 6 recommended that "*there is need for massive awareness drive in term of RETs, that they are applicable, reliable, sustainable and economical competitive with conventional energy source*": adding that "*all these factors need to be known by the general public for us to be able to remove barriers to stimulate RETs and create demand in the society*". Interviewee 7 added "*public will appreciate and accept RETs if they know the advantages both economically and socially*". This strategy will inform the society on the use and benefits of RETs, particularly sustainable development agenda (carbon footprints).

Furthermore, while RETs are fast developing globally in term of application and technological advancement, in Nigeria "*Some people are still uninformed, despite the advocacy that has taken place, they still take it as something at experimental level, which is not so*" interviewee 13 commented. Hence, government and its agencies should continue to advocate for the use of these energy systems in the country.

Enforcing GENCOS to invest in rural RETs (Renewable Obligation)

It is a globally recognised strategy to compel investors in the energy sector to partake in generating sustainable electricity through RETs. This is also feasible in Nigeria by enforcing Generation Companies (GENCOS) to generate part of their electricity from RETs sources, or to buy from renewable generators in the country and deliver it to rural areas. Interviewee 3 recommended that "*this strategy should be included in our policy as well, especially through the use of renewable obligation (RO), where GENCOS would be forced to invest in RETs and deploy it to rural communities*". Interviewee 6 added that it is also possible to improve electricity generation capacity in the country "*through the contribution of RO to meeting the 10% CAP of RETs electricity to the national grid as instructed by NERC*".

Table 7.2: Strategies for Advancing RETs in Nigerian Rural Areas



7.10.2 Practice Regulations

In line with the findings in section 7.4 (theme 2-exploratory study), both quackery practice proliferation and sub-standard products have been identified as part of major problems hindering development of Nigeria's RETs. Also, 6 interviewees suggested that through a robust regulatory/institutional framework, real RETs practitioners will manage and regulate the practice. Similarly, 4 interviewees agreed that through proper monitoring of standards and quality of RETs components by the standard organisation of Nigeria (SON), these threats can be mitigated. See details below:

Robust regulatory/institutional framework

According to interviewee 13, there is the need to put energy law in place to guide the practitioners and practice, "*such that if there is a law, it will guide the practice and in the process of failure, the person(s) could be seen*". Interviewee 1 said for effective incentives deployment and utilisation, "*there is need to develop robust regulatory and institutional framework with a view to be accountable on all the spending*". Interviewee 4 added that "*We need regulatory mechanism for the practice of RETs in Nigeria, as obtained in other industry that includes the use of qualification and experience*". This strategy and with proper due diligence should be encouraged to strengthen both regulatory and professional institutions in the country such as SON and the Nigerian Society of Engineers respectively. Hence, this framework will combat the menace of quackery practice and recklessness in awarding contracts to unqualified persons for RETs projects.

Monitoring of standards and qualities of RETs components

Given the effect of sub-standard components as highlighted in section 7.4 (theme 2), interviewee 2 suggested that "*All RETs components must be part of equipment that SON must check to ensure they meet minimum standard expected, before importing same into Nigeria*". Otherwise the lack of trust for RETs in the country will persist. This is possible by establishing a standard laboratory for testing all RETs components as obtained in developed countries (Oyedepo 2012). This is possible as drug and food sectors in the country have benefited from a similar practice through the National Food and Drug Administration and Control (NAFDAC).

Interviewee 6 stressed that "*Monitoring the standard and quality of the RETs components by the agency concern will reduce the wide gap of prices submitted by contractors in project tendering process*". As it is cheaper to import RETs components (particularly solar PV unit) as against those produced in the country.

Eventually, this practice will encourages local RETs components development and procurement.

7.10.3 Technology and Capacity Development

In this context, the following strategies were suggested by interviewees by order of priority: domestication of the technology (local production), local human capacity building, and elimination of the grid extension approach.

<u>Domestication of the technology (local production)</u>

It is important for a nation to have some of its major facilities and components developed locally. This strategy helps in generating employment, supports technological emancipation, sustains capacity building and supports the meeting of sustainable development objectives. Interviewee 1 opined that "*domestication of the technology is vital to adopting the technology*". Interviewee 8 emphasised that "*this is one of the means of bringing down the cost of RETs*". Also, this will help in reducing GHG emissions, given the limited transportation involved. This finding partly agrees with Sopian et al. (2011) "Attracting the manufacturers to invest locally can reduce the cost of renewable energy technology components where import taxes would be avoided".

Interviewee 12 added "*Domesticating RETs is very important. In fact, is one of the most important thing government should focus on, if we are to develop RETs*". This strategy is in line with the current administration's political will as expressed by Nigeria's president (Mohammed Buhari) that there is "readiness to improve Nigeria's industrial sector by strengthening local investment and discouraging importation of foreign goods" (Okakwu 2015).

<u>Local human capacity building</u>

It is fair to conclude that even if the technologies are domesticated, without mass human know-how in the country on the part of those who will man these technologies in terms of operation and maintenance, there still remains a major issue. This lack of capacity and knowledge of RETs in the country may turn investment into waste; as existing practice in the country has shown. According to interviewee 1 "*lack of knowledge leads to resources wastage*". Interviewee 6 supported the above view, "*Whatever is to be achieved, critical mass of human* *resources is necessary. Even if the infrastructure is readily available, and don't have human resources that can manage it, then there is a problem*". Continuous capacity building of the stakeholders is necessary through "*massive training of trainers and quacks, and continuous professional development on operational and maintenance requirement, given RETs are emerging systems*" interviewee 7 opined.

Elimination of grid extension to isolated rural areas

Provision of a centralised energy system to rural areas is usually deemed prohibitive, particularly in the context of connection to the grid via an extension (Mahapatra & Dasappa 2012). Interviewee 12 recommended an action of "*eliminate grid extension to the rural areas, since it's very expensive; and instead just develop the rural grid*", and added that "*you can have your decentralised grid systems and the pockets of communities can be connected together through mini grid*".

Interviewee 5 suggested that "*low energy consuming villages should be identified and recognise relevant RETs to makes it as a policy that all these villages will be supplied through the decentralised RETs*".

7.10.4 Collaboration

The suggested ways for advancing rural RETs used in this context were made perhaps based on the previous experiences and practice(s) of the interviewees. This is because they were mainly practical suggestions. Table (7.2) depicts that both community engagement and best practices adoption are the most recommended, being closely followed by partnering with successful RETs countries.

Community engagement

For sustainable electricity provision in Nigerian rural areas at the moment, the government needs to participate in setting up these facilities as there is a lack of incentive to encourage investors' participation and the state of the economies of rural communities is not sufficiently healthy to fund such facilities. According to interviewee 8 "*there must be interaction between government support and rural communities' involvement*"; added that "*initial investment cost can be provided* *by government, while the continuous running of the facilities should actually be taken up by the local communities*". Interviewee 13 supported the view "*government has to take the driver seat*".

For RETs sustainability in these communities "*Those communities involved must be carried along, because they are in best position to operate and maintain the facilities; and they must be trained to handle it*" interviewee 5 stated. Adding "*That is why at the centre, whenever there is a pilot project, it usually includes training of the local people for minor repairs and maintenance*".

More so, it is better for the communities to operate and manage the projects by paying a stipend to the source generator for fuel and minor spare-parts for maintenance purpose. Interviewee 5 suggested that "*People should pay for what they consume through community development organisation*". Interviewee 8 also stressed this strategy, "*This is the current practice in Yauri solar/wind hybrid projects*".

Furthermore, interviewee 11 commented on the current strategy in the country, "*immediately the projects is implemented, it is handed over to the local government; traditional rulers are involved, so that the community will feel that sense of ownership of the project. They can be encouraged to contribute stipends towards its operation and maintenance*". This finding agrees with Sunderbans India solar PV (2003) "The most effective partnerships have been forged between the state and the community. In these relationships, the village committees have been successful in managing the entire scheme under the technical supervision of the state".

<u>Best practices adoption</u>

Given RETs are emerging technologies in the country and are experiencing difficulties, there is the need to look at best practices in other countries where RETs have succeeded, with a view to develop the RETs in Nigeria. According to Interviewee 2 "*The country should look at best practices all over the world to be able to learn from them especially with respect to financing as well as maintainability*". "*This will really help, and will rapidly facilitate the electrification projects in the country using RETs*". Interviewee 2 added

Partnering with successful RETs countries and organisations

Partnering has been a strategy utilised in many sectors such as education and science among others in developing capacity by countries or organisations globally. Consequently, there is nothing stopping Nigeria from continuously seeking partnering agreements with well-developed RETs countries for the development of the Nigerian RETs sector. Interviewee 12 was of the view that there is the need to "*learn lesson from RETs developed countries, especially on case by case basis*" and "*Nigeria can send people there for training and collaboration and they can now learn from their successes to create a pattern for the country*". This agrees with Sambo (2009), in 2002, ECN collaborated with UNIDO with objective being to "Formulate strategies to provide access to clean and reliable energy services to the rural populace for promoting rural industrialisation, which in turn will lead to employment generation and rural development". This is in agreement with Sopian et al. (2011), "Partnership and/or joint ventures with international companies will upgrade local capacities".

7.10.5 Education and Development

There are two main sections in this respect: education and training on the one side and research and development on the other side.

Education and Training

Interviewee 1 suggested that "*There is need to develop our RETs education curriculum to make the students understand, know what the technologies are all about and will also help in domesticating the technologies*". This is on-going in the country as, according to interviewee 5 currently "*RETs academic curriculum has been developed through collaboration between Sokoto Energy Research Centre (SERC), Kaduna polytechnic and National Board for Technical Education with a view to develop technicians in handling RETs*", he added that "*this will help in combating quackery practice proliferation in the industry*". Interviewee 1 supported the idea that the benefits of an education curriculum in our schools is "*eliminating quacks in the market and practice*". This same view has been reported by Sopian et al. (2011) "Educational programs are able to provide the technical knowledge and improve the level of competency of service providers, Engineers, Architects, Technicians and Academia".

Furthermore, for sustainability purpose, interviewee 10 suggested that there is the need for "*an education programme within the communities, where you identified some promising persons that could be taught how to fabricate and repair the RETs /stoves if it gets spoil*". This will mitigate the dependence on far away persons (city-based) to come and fix it for them.

Following the lack of modern RETs capacity in the country, there is a need to focus on the training of personnel at every stage of RETs development. Interviewee 12 suggested that "*energy research centres and universities in the country should be compelled to train human capacity in respect of RETs*". Interviewee 5 affirmed that "*SERC and National Directorate of Employment have collaborated before in training unemployed graduate in design, installation and maintenance of solar PV, biomass system etc*". In addition, interviewee 7 says that "*Continuous professional development should be encouraged on regular basis, considering the dynamism of the technologies*" that will help in "*training the trainers*" interviewee 11 added.

<u>Research and Development (R & D)</u>

Interviewee 12 recommended that "*Universities should be commissioned and more research centres should be established to drive RETs*". More funding should be dedicated in this respect because it is resource consuming, but it pays dividends in the end. Interviewee 12 added "*R & D is very important in developing RETs and government needs to invest more money in to it*". This is very necessary in Nigeria, given developed economies are contributing substantial resources in this respect. Although there are existing energy research centres in the country working on different RETs, there is the need to improve on their existing capacities. Typically, in this study, it is indicative that the country has had biogas available to cooking technology for over a decade now but the question remains as to why can't they improve on their facilities to generate electricity from the same technology? Hence, there is a need for improvement in R & D schemes in the country.

7.10.6 Economic Subsidies Support and RETs Market Development

In this section, three strategies have been suggested as means of developing RETs in the country's rural areas, these include:

Subsidies Provision and Utilisation

Considering RETs are emerging technologies in the country, the lack of energy infrastructures in the rural areas, coupled with demanding needs of other sectors of economy vis-à-vis continuous dwindling revenue generation on the side of government, there is the need to encourage investors' participation through provision of subsidies for developing rural areas electricity.

This strategy is the most frequently identified means of developing RETs in the country; all the interviewees unanimously recommended it. Typically, interviewee 8 said "*The issue of subsidy is very important for diffusing RETs in Nigeria or rather to attract people into accepting RETs system*". Interviewee 4 added that "*there are resources to develop our RETs capacity; all that is required in place is a robust policy that will provide incentives to allow us develop and have experience*". For sustainable electricity in Nigeria's rural areas "*government must provide subsidies and soft loans in pursuing RETs growth. Subsidies were utilised in many countries that have successfully developed their RETs*" interviewee 13 opined. Interviewee 9 recommended that "*investors should be offered incentives such as renewable obligation, FIT and other encouraging benefits*" and also "*relaxing of importation duty for investors*". This is in agreement with Ajayi (2010) "The government needs to develop incentives such as tax holidays for renewable energy (RE) investors, provide low or interest free loans to aid RETs investment, develop appropriate FIT for grid connected renewable electricity, legalise the right to connect renewable electricity to the national grid, and the obligations for national electricity utility to purchase RE".

Interviewee 12 added "*FIT system has succeeded in so many European Union countries such as Netherland, France, Spain, Germany and UK in diffusing RETs*". This agrees with Sopian et al.(2011) "FIT is the most effective way to promote the uptake of renewable energy yet devised after investment subsidies------ Germany's FIT has successfully created over 300,000 direct employments and created over 200 companies related to solar energy". In fact, some of these countries have either removed/reduced subsidies for some RETs given the level of achievement. A typical case is the recent (2015) cut of 65% of the solar PV incentive by the UK government (DECC 2016).

Interviewees 1, 5, and 6 were of the view that in the context of Nigerian rural areas all kind of subsidies should be implemented at all levels of RETs development, because of the socio-economic setting of these communities. This will encourage investors to move into these communities. However, the stages of deploying these subsidies differs among the interviewees.

Development of RETs market

Nigeria's RETs market has achieved limited development. In view of this, interviewee 11 opined that "*There is RETs market in Nigeria, but it is yet to be developed*"; adding that "*banks, insurance companies and co-operative societies can assist in the market development*". He further suggested that there is the "*need to re-orientate our banks on investment size, because they prefer very big refinery with a view to making more profit, but it's not so with bio-refinery, solar and wind projects*". This finding partly agrees with Sopian et al. (2011) "To initiate any renewable energy project, funders and investors play crucial roles in financing the project. Funders need to support infrastructure projects by providing loans to project developers".

Interviewee 5 recommended that "*commercial banks should have desk office, where they concern themselves with financing RETs projects; that will encourage investors in participating*". However, interviewee 1 opined that "*Nigerian commercial banks cannot fund RETs because of high interest rate, which is up to 35%*". More so, given "*RETs is a grey area in Nigeria that is why banks will not be interested in participating. They want their returns in couple of months and anything more than that, they will not participate*" interviewee 11 said. Hence, the small solar PV market in the country should be sustained and improved upon. This approach should also be extended to other RETs such as biomass technologies and small hydropower market for rural areas utilisation.

Appropriate budgetary funding for RETs

Interviewee 11 suggested that "*encouraging National assembly members and state government to support RETs in their budget for rural areas electrification will help in the growth of rural areas RETs*". In line with the above, "*State government and national assembly members are now taking some of their constituency projects (under millennium development goals) in the field of solar* *energy*" interviewee 13 added. The country's RETs sector is not properly funded by government compared to fossil fuel source (Sambo et al. 2010). Hence, there is the need to support RETs by all the three levels of government in the country. Ajayi and Ajayi (2013) reported a similar view; the amount set aside in the budgets between 2011 and 2013 for RETs by the federal government of Nigeria are insignificant and this needs to be improved if the RETs generation targets are to be achieved.

7.10.7 Socio-Cultural Change

Paradigm shift

Interviewee 10 opined that "*availability of fossil fuel energy resources is the biggest issue in the energy sector in Nigeria, because if we don't have conventional energy resource, we will be compel to look for alternatives*". "*Our people are used to easy fossil fuel technologies*" interviewee 5 commented. This may be connected to cheapness and an already established market for fossil fuel generators; a majority of households in the country possess at least one. Hence, they need to be encouraged in utilising RETs and be aware of the benefits in view of sustainable development principles. Also, the idea of how many capacities will RETs provide as expressed by the utility company in the past needs to change.

More so, interviewee 2 suggested that "*We need a paradigm shift from the existing energy system provision and when we have it, a lot rural dwellers will have access to sustainable electricity*." Interviewee 3 added that "*RETs presents us the way forward and great opportunity to use decentralise generation to actually electrify the various rural communities*"; adding that "*people are resistant to change especially in rural areas*".

7.11 DISCUSSION OF THE RESULTS

The findings from the analyses of interviews conducted using the content analysis method, mainly on the subject of the contribution of RETs in Nigerian energy mix, clearly evidence that there exists a disagreement on the progress so far made by modern RETs globally, as reported by REN21 (2015). While REN21 (2015) depicts that modern RETs contributed over 6% (excluding large hydro) of global electricity generated by the end of 2014, in the case of Nigeria, over the same period, modern RETs have not made any meaningful progress in forming part of the country's energy mix. This is despite the resources committed to its development since its establishment of its energy centres over 3 decades ago.

Furthermore, regarding the state of the art of RETs in Nigeria, this study finds that Nigerian RETs are still at the crawling stage of their development (policy development and review), with only solar PV components being produced and utilised for decentralised electricity generation among modern RETs (except small hydropower). This finding agrees with Suberu et al. (2013b) that "The development of the different kinds of renewable energy technologies is still at an early stage in SSA countries (Nigeria inclusive)".

Given the lack of reasonable RETs progress in Nigeria, the study was able to identify inhibiting factors to the desired growth of RETs in Nigeria. They include: lack of robust RETs policy to attract investors, high investment cost of components, lack of regulatory framework, quackery practice proliferation, lack of technical know-how, sub-standard components (low-quality products peculiar to solar PV), lack of domestication of the RETs, and lack of awareness. These findings partly agree with Ajayi (2009), who reported only four major challenges of wind and other renewable energy application in Nigeria (low financing, apathy of government and agencies to develop RE systems, lack of awareness and technical ineptitude). The findings also agree with Mohammed et al. (2013) "Nigeria is still in need of a market-oriented policy that will increase RE investors' participation in constructive development of the available resources".

7.12 CHAPTER SUMMARY

This chapter discussed the state of the art of RETs development in Nigeria and addressed the current development of RETs in the country, based on policy, technologies and their applications. The chapter identified that RETs are still at crawling stage of development. Also, solar PV is the only RET with manufacturing plant and widely utilised in the country. The constraints preventing RETs development in Nigeria's rural areas have been identified and are classified under headings of economic, policy, human capacity, technology and socio-cultural. The chiefs among these constraints include lack of robust policy, high cost of RETs components, quackery practice proliferation and imported sub-standard (low-quality) RETs components. Biomass energy technologies (BETs) has been identified as the most suitable RETs for providing sustainable electricity to rural areas based on: energy resource availability, level of development, high capital cost and policy support. Furthermore, drivers, enablers and constraints of adopting BETs in rural areas have been presented. Finally, relevant strategies for advancing the development of RETs in rural areas have also been illustrated, and include: existing policies review and implementation, practice regulation, education, training and development, collaboration, economics subsidies support and socio-cultural change. The next chapter explains the development, evaluation and testing in the field of BETs implementation framework for rural areas application.

CHAPTER EIGHT

IMPLEMENTATION FRAMEWORK FOR BIOMASS ENERGY TECHNOLOGIES

8.1 INTRODUCTION

This chapter presents the development of a renewable energy technologies (RETs) principally Biomass energy technologies (BETs) implementation framework for sustainable electricity provision in Nigerian rural areas. Considering the lack of reliable cost data and any appropriate decision making framework relevant to implementing RETs in the country, the utilisation of RETs among the existing energy mix in the country has thus far been affected negatively. A BETs implementation framework has been developed for decision making in selecting appropriate technology among the potential BETs for use in the country's rural areas with regard to sustainable electricity provision.

Considering that sustainable electricity provision to Nigerian rural areas is the main aim of this study, the study focused not only on cost criterion but also on sustainable development goals (economic, environment and social), renewable energy technologies screening, and resource availability. This is with a view to selecting robust technology for sustainable electricity provision. The reasons for inclusion of RETs screening and biomass resources is because BETs cannot be sustained without sufficient biomass resources (Manish et al. 2006; Bocci et al. 2014). Also, the pathway to the sustainable provision of electricity is through the ever improving technologies; hence they are considered for efficient and effective electricity provision (Rahman et al. 2013; Okoro 2015).

8.2 THE IMPLEMENTATION FRAMEWORK (BETs in Nigeria)

This framework consists of 2 phases and 6 stages as outlined below and presented in details in figure (8.1):

<u>Outline of the Framework</u>

Phase One:

- Survey Stage
- Evaluation of Technologies

- WLC Evaluation
- Non-financial Assessment
- Result and Decision

Phase Two:

- Financing Options Assessment

8.2.1 Phase One- Identification of Available Options

<u>Stage 1 - Survey</u>

<u>Determining electricity requirement</u>

The electricity need of the rural communities have to be examined and established through a physical visit to the villages. Given the majority of these communities have a small population, a physical survey is required to determine each household's kilowatt (kW) need, by identifying total numbers of rooms, each room's electrical requirements: power point(s), fan(s), and lighting points among others. Collectively, the households' electricity needs, together with community services and productive uses represents the total electricity (in kW) required by the community. (See table 8.2 for case studies of villages' average electricity requirement). The study of existing practice has indicated that some developers assume a system capacity based on literature when 'sizing' electricity generation plant (such as "X" MW can provide electricity to "y" number of houses). However, given the usual case of a low energy need in rural areas and a scattered and small population, it is essential to avoid over provision (causing lack of value) or under supply (which causes disruption to the system by new customers and/or non-technical losses as a result of illegal usage of the electricity) of the capacity. However, provision of additional KW will be necessary to accommodate any genuine usage increase in the future. The outcome of this stage (required KW) will be required during the design stage of the framework implementation and, given the use of a physical survey approach, there is now a viable alternative to the traditional 'guesstimate' approach. See table 8.1 for estimated average electricity load demand in the country's rural household based on the data from the physical survey. Also, coverage fraction 1 refers to individual household apply the load need independently; while factor 0.02 refers to 50 households using the water. This is similar to fridge, where 1 is assumed for every three households (Mahapatra & Dasappa 2012).

Survey of Biomass Resources Availability

One of the major requirements of RETs utilisation in a given location is the availability of its resources. For decision making purposes, different forms of renewable energy resources available in a given rural area have to be established; such that the most available, economical and fit for purpose will be selected, bearing in mind the resources characteristics in relation to available technologies. A survey should highlight levels of resources availability (e.g universal, partial (two or three suitable resources) and limited (one suitable source) availability and for specific technology utilisation level. In this context (BETs use), wood, residues from agricultural, forestry (logging) and animal husbandry have all been proposed as biomass feedstock for electricity generation applications. Having determined the availability level of the resources in the villages and within a reasonable distance, then their suitability for each BETs should be assessed, in terms of physical and chemical characteristics of the biomass feedstock such as ash content and moisture contents. These criteria should also form part of the decision making process. This is with a view to reducing maintenance cost and improving smooth operation of the equipment (conversion systems). See section 6.3 for details of biomass resources availability and their characteristics in the context of Nigeria. Also, see Evans et al. (2010), IRENA (2012), Asadullah (2014) and Bocci et al. 2014 for more details.

Table 8.1: Average estimated load demand in a typical Nigerian rural household

4 rooms Apartment	Unit numbers	Rating (w)	Coverage fraction*	Loads (w)
Lighting (internal)	4	14	1	56
Lighting (external)	1	20	1	20
Fans	2	75	1	150
Television	1	60	1	60
Fridge	1	90	0.33	30
Drinking water (pumps)	1	3730	0.02	74.6
Total connected				**390.6**

Stage 2 - Evaluation of Available Technologies

This section contains three steps, which include:

Identification of Available Technologies

There are currently various RETs suitable for electricity generation. In the case of BETs, the commercially available technologies suitable for small scale utilisation include thermo-chemical (Direct combustion and Gasification) and biological (Anaerobic digestion) systems. They are both detailed in the literature chapter (sections 3.7–3.11). The identification in this context is focused on technologies that are commercially available, not pilot stage technologies (in the case of pyrolysis).

Determining Total Electricity Output

In this stage, key indicators are the capacity factor and the efficiency of each technology. The efficiency and capacity factors of each technology are evaluated with a view to ascertaining the actual electricity each technology can generate within a specific time and over its entire life. In most cases manufacturers provide the total electricity output of their product, but it may not be correct (inaccurate or exaggerated), so the experience of practitioners (concerning actual real-world outputs) may assist in this respect. For example, the capacity factor of a gasification system in this case is approximately 80% as suggested by manufacturers, and this is applicable to all sizes in this context. This claim by manufacturers is confirmed by the study of Dasappa (2011) and Nouni et al. (2007). Nonetheless, the technology has a level of efficiency better than that of a direct combustion system (Demirtas 2001; Evans et al. 2010).

Technology Screening

Having tentatively identified appropriate technologies in relation to suitable biomass resources available in these communities, there is then the need to technically screen the selected technologies. The selection of appropriate technologies shall be based on the assessment of decision criteria that include technology (conversion system) maturity, ease of operation and maintenance, availability and dependability (Okoro 2015; Rahman et al. 2013). The selection process should also take into account the location/point of utilisation, the system capacity, and even technical manpower availability to man the equipment. This evaluation is required to be completed for each identified technology. The decision for selecting optimum technologies should be on the basis of technical ability (based on the experience and judgement of technical stakeholders), and the ability to evidence its contribution to meeting the required sustainable development goals (economy, environment and social).

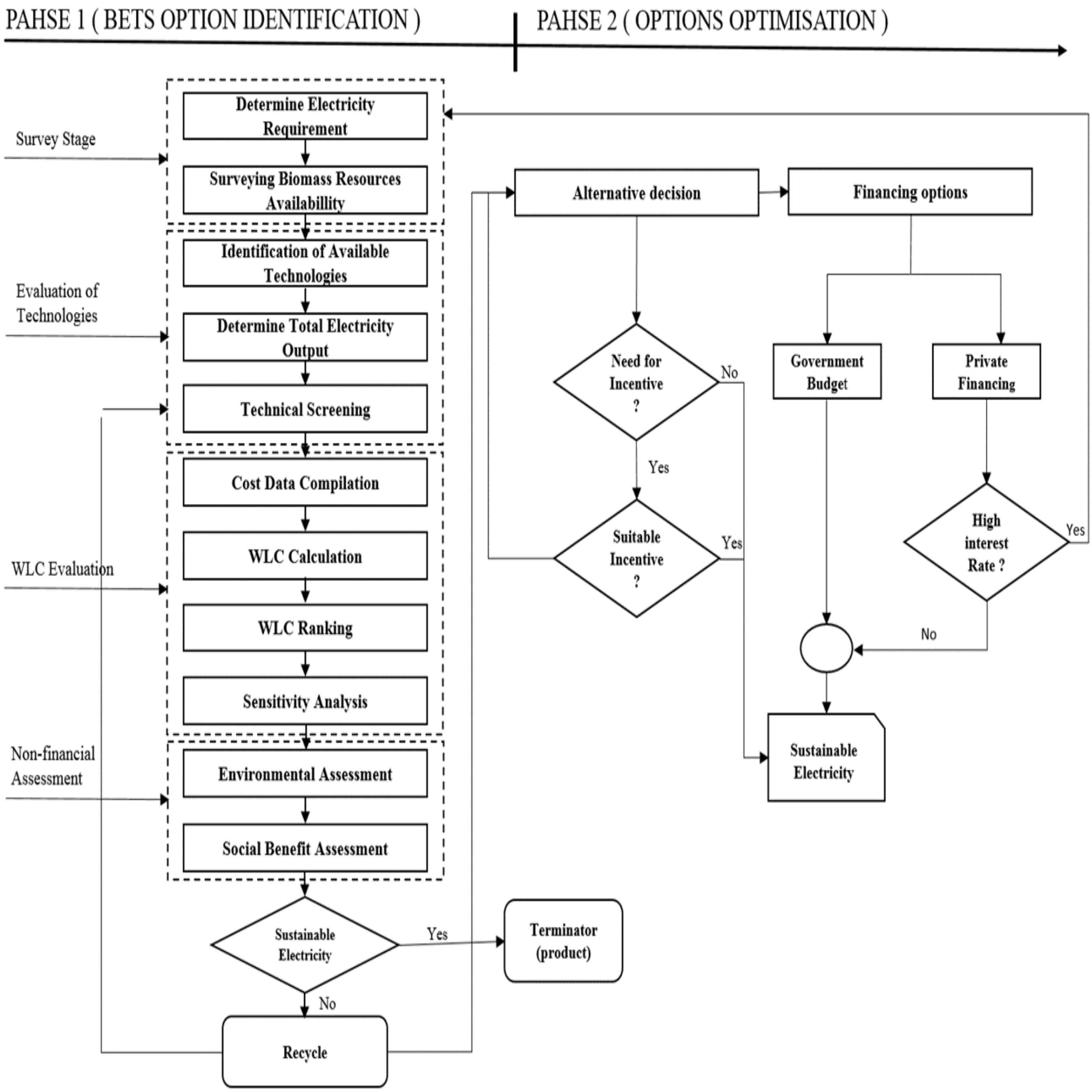


Figure 8.1: Developed BETs Implementation Framework for Rural Areas

Stage 3- Economic Evaluation

WLC evaluation of capital cost and operation and maintenance

Evaluating the investment cost and operating and maintenance cost of a chosen technology over its entire life is at the hub of this decision making process. The approach selected for the BETs economic assessment in this context is Whole Life Costing (WLC). (See details of the WLC approach explanation in chapters four and five). Garba and Kishk (2015), Garba and Kishk (2016) and Garba et al. (2016b) present a practical application in this context.

Following the selection of appropriate technologies, each BET option is assessed on the following decision criteria:

- The evaluation of investment cost with a view to determining the cost implication of each project. The actual cost of the project needs to be sought from manufacturers rather than relying on secondary information such as literatures, tender documents etc. during the decision making process. The required costs in this case include those for primary and secondary conversion systems (including their fittings and accessories), along with cost of installation, and transportation cost (where necessary).

- The operation and maintenance (O & M) cost assessment is required using WLC. Given that O & M cost in this context is over 50% of the entire life cycle expenditure (see section 6.4 and 6.5 for details; also Garba et al. 2016b; Ganesh & Banerjee 2001; Mcdonald 2011; IRENA 2012), there is a need to ascertain the estimated cost of O & M during the total life cycle for optimum decision making. The required data for evaluation relevant to O & M costs include fuel consumption pattern of each technology, cost of feedstock, discount rate, present value factor, the major and minor maintenance period, and the life span of each BETs, as it varies among the BETs (typically, direct combustion is 25 years and gasification system is 15 years). Technology lifespan can significantly influence the decision making process (see section 6.4 and study by Garba et al. (2016b), and MacDonald (2011) for more details). These values, along with sensitivity analysis outcomes, form the basis of a decision matrix for optimum technology selection.

- Determining the unit cost of generating electricity for each technology has to be undertaken using WLC. However, this is not possible without knowing the investment cost, O & M cost, actual output of the system (capacity factor) and efficiency of each technology. Breakeven is usually established (through the use of WLC) and the profit decision is then made based on the financing options available.

- The outcome of the decision making process entails saying 'yes' (proceed) or 'no' (do not proceed). If the electricity tariff is determined as suitable, the proposal should proceed to the assessment of the relevant non-financial criteria (social and environmental assessment). However, if there exists a problem, such as an unacceptably high electricity tariff (at this point no incentives that may be available are considered), then there will be a need to re-examine the entire process commencing from the biomass resources availability stage; this may lead to a change of technology and/or design option. Alternatively, the stakeholder can move straight to phase 2 of the framework and see whether or not the financial options available and/or any incentive strategies in place are sufficient to allow the project to proceed (on the basis of achieving a minimal profit on top of the estimated electricity tariff).

Stage 4 - Non-Economic Evaluation

Environmental (Greenhouse Gas Emission and other criteria) Appraisal

On the basis of the provision of electricity to rural areas in a sustainable manner is the aim of this study, with environmental protection as the main focus of concern in the context of achieving sustainable development goals, any BETs chosen needs to be able to provide low carbon electricity by reducing greenhouse gas (GHG) emissions, particularly CO2, and minimize impact on the eco-system. Achieving these outcomes requires each BETs GHG emission reduction strategy, and its effect on the eco-system, to be compared with other current sources of electricity provision such as coal, oil and natural gas. Relevant literature assists in this respect by identifying the most effective GHG emission reduction technology. The experiences/expertise of technical stakeholders is of further value in this context. For this reasons, wood, residues from agricultural, forestry and animal husbandry are proposed for use to mitigate the effect on the environment and also utilise local resources to minimise transportation cost (Fan et al. 2011; Evans et al. 2010).

Social Benefits Assessment

Considerable numbers of people see a decentralised RETs electricity system as a temporary measure based on existing practice in Nigeria. This is due to a lack of awareness of such a system's contribution in providing sustainable electricity to rural areas in developing countries. The benefits of utilising BETs include providing electricity for the community (as per solar and wind energy systems), creating businesses such as energy crop plantations, selling of unutilised residues, and creating employment via activities such as working on the farms, collecting residues, and operating/maintaining BETs electricity generation plants among other factors. Therefore, all of these criteria need to be evaluated with a view to achieving maximum benefits. More so, determining the acceptability of the BETs system in this respect to the community should be undertaken through the use of interview or focus group methods. These methods will assist in establishing how a proposed BETs system will benefit the community positively (bush burning mitigation) or negatively (application of biomass resources for their other utilisation such as animal feeding, soil stabilization, thatch houses etc).

Stage 5 - Result and Decision

Analysis

Following the rated values of the decisions determined in each phase, the total score of each technology type is summed up based on appropriate decision criteria and the agreed scoring pattern explained under section 8.3 (framework evaluation and validation) and as presented in table 8.4. The optimum technology is selected bearing in mind the entire sustainable development goals (ability in reducing more GHG emission, provide cheaper electricity, employment generation for the community and help in cleaning up their environment) and other criteria in the framework.

Decision Making

The outcome of the foregoing exercise guides the making of a decision as representing either an optimal case, good case or worst case scenario. This is premised on the total scores of each technology and their ranking confidence (see table 8.4 and section 8.3). The selection preferences are firstly the optimum technology (a single technology clearly scoring higher than others), secondly the good case scenario (where multiple alternatives score equal/close points) and thirdly the worst case scenario (where no BETs technology achieves a viable score). In the latter case, perhaps there might be need to re-assess the whole process or significant sections such as the WLC evaluation, or a change of technology among other criteria. However, if there is a clear cut score at this point there should not be a need for recycling the process or a move to phase 2 (financing options and incentives strategies in place in the country) of the framework.

8.2.2- Phase Two: Optimisation of Options

Stage 1 - Financing Options and Incentive Strategies Availability

Financing Options Assessment

If going through the framework recycling process will not yield a meaningful outcome, implementing phase 2 of the framework becomes necessary. This emphasises the need to assess the optimisation options available during implementation so as to determine which strategy/strategies (such as financing options and/or incentives strategies) is appropriate to be utilised when the selected technologies have been determined to be otherwise not economically sustainable. Even though investors typically seek credit facilities from commercial banks to finance their projects at a single digit interest rate in developed countries, this is not the case in Nigeria, where up to 35% interest is charged. Hence, any alternative means of financing available in the country need to be explored: equity capital, co-operative societies, insurance companies, crowd funding (though not yet legislated), and public private partnership are all options among others. Financing options are among the determining factors for achieving suitable electricity tariff in the considered category of communities. Hence, viable (low interest) financing options should be identified, given that the rural communities are low electricity consumers and low income earners. By identifying such options a sustainable price of generated electricity is achievable.

Incentive Strategies Evaluation

The evaluation of those incentive strategies already existing, such as Feed-in-Tariff (FIT), fiscal policy waiver (import duty, licensing fee waiver for rural RETs projects), and free land provision shall be undertaken with a view to achieving a sustainable electricity tariff. These incentives significantly encourage the participation of investors and are often adopted for sustainable electricity provision in rural areas. However, the FIT strategy is currently used in Nigeria only for grid generation systems upwards from 1MW capacity.

8.3 FRAMEWORK EVALUATION AND VALIDATION

A BETs decision support implementation framework, as presented in figure 8.1, is evaluated through the use of a multi-case studies approach. Also, in this section the decision making difficulties associated with the selection between RETs and grid extension (GE) systems in the provision of sustainable electricity to rural communities are made explicit.

Even though a grid extension system utilising a fossil fuel source is not a sustainable means of providing electricity particularly to rural areas, its assessment in conjunction with BETs in this context is necessary; the majority of the population sees GE utilisation as the best means of electricity provision to villages, based on their consideration of decentralised RETs as a temporary measure particularly (Rahman et al.2013; Dasappa 2011). The economic value of both BETs and GE systems has been evaluated using the WLC approach as presented in sections 6.4, 6.6 and 6.7. In this context, an assessment of the sustainable viability of both systems through the BETs decision support implementation framework developed has been undertaken. This takes into account relevant sustainable development goals and other criteria as highlighted above.

In order to achieve a suitable evaluation and validation, an appropriate level of measurement is required; ordinal scale style has been utilised in ranking the identified technologies from low (1) to high (3). For example, when evaluating the maturity of technology criterion, 3 will be assigned for matured technology, 2 for emerging and 1 for a pilot stage technology. The assigned numbers are essentially numerical stickers that evidence a difference between the technologies from a suitability perspective by stakeholders (Naoum et al. 2007). All the criteria and indicators used in this context have equal weight, except the economic assessment indicator that continues to phase 2 in order to allow further evaluation during the implementation stage.

8.4 CASE STUDIES

This section presents the outcomes of six completed case studies. The purpose of the case studies is to evaluate and validate the suitability of the BETs implementation framework in assisting decision makers to establish the optimal technology, for providing sustainable electricity to rural communities when selecting between BETs and GE systems.

<u>Determining electricity requirement of the villages</u>

Four out of the six villages are located in Funtua local government area and the remaining 2 villages are situated under Dandume local government area; both are part of Katsina state, northern Nigeria. The villages visited are at a distance of ± 10% 5km from the last grid point, with load between 10-100 kW (see table 8.2 - electricity requirement of the villages and other details).

Table 8.2: Case Studies of Electricity Requirements of Six Villages in Nigeria

Load/Community	Gwaigwaye Danmallam (FT)	Makwalla (FT)	Unguwar Makera (FT)	Unguwar Tirmi-Tirmi (FT)	Unguwar Bango (Dan)	Unguwar Bido (Dan)
Number of households	226	145	94	24	94	66
Numbers of rooms	678	415	334	74	298	222
Average rooms	3	2.86	3.55	3.08	3.17	3.36
Households with two wives	147	82	54	16	159	119
Distance from the last grid point (Kilometre)	5.4	5.6	5.4	5	4.5	5
Average estimated load/household (W)	**376.6**	**376.6**	**390.6**	**390.6**	**390.6**	**390.6**
Actual Community Load requirement (kW)	85.1116	54.607	36.7164	9.3744	36.7164	25.7796
Projected community load need (community services, productive use & future expansion (+ 25%) - KW	**106.3895**	**68.2588**	**45.8955**	**11.718**	**45.8955**	**32.2245**

Note: 376.6 represents estimated 3 rooms' apartment household's load

The researcher visited the villages by himself and reported to the chiefs of the villages. The purpose of the study was explained to the chiefs (called mai-ungwa), seeking their assistance in the carrying out of the investigation (survey). Some of the chiefs joined the researcher in conducting the interview (assessment). In order to simplify the exercise, each household's head was asked the following questions: how many numbers of wives, numbers of rooms, utility rooms (such as store for keeping grains) among others. Where the head of household was not available, a representative of the household acted on his behalf. The small size of the households in these communities enabled revisiting or follow up visits, especially in cases where the head or representative were not available or where further data was required. Through this, the total numbers of households together with their number of rooms was established. The data served as the basis of determining an estimated kW of each village by multiplying the total households with the estimated average electricity load demand proposed as presented in table 8.2; this is along with the energy needs for community services and productive uses.

Survey of Biomass Resources Availability

The forms of biomass resources and their level of availability were obtained through direct observation, shadowing and interview methods. The researcher observed universal availability of trees (wood), rice and sugar cane farms around the villages under Funtua local government. This is because the communities are largely "fadama" (water logged land). Also, the researcher observed that villages in Dandume local government areas have in common universal availability of trees (wood), cows, rice and large areas of arable land. Likewise, in all the six villages visited, the communities were asked the following questions:

- What forms of crops s/he usually plants? (5 years record were taken),
- What are the quantities harvested/year over the same period?
- Does the community have opportunity to plant during the dry season (not rainy season only)?
- Does the village have a stream or river in the neighbourhood that enables perennial plantation?

The findings reveal that there is universal availability of biomass resources in all the villages, but particularly villages around Funtua local government. The biomass resources identified include; trees (wood), maize, guinea corn, rice, sugar cane, soya beans, millets, cows, sheeps/goats, cotton, beans among others. These findings agree with Rahman et al. (2013) that "The main economic activity in rural areas is agriculture". It also agrees with ECN (2005), Sambo (2009), Garba and Kishk (2014), Mohammed et al. (2013), and Shaaban & Petinrin (2014) that a majority of Nigerian rural communities are farmers, and agriculture business is their means of livelihood.

Given that this study has proposed biomass residues and wood waste as the operating fuel, the total biomass resources of the community vis-à-vis waste generated from the resources were established. This is with a view to determining the total quantities of waste from the annual harvest of their farm produce. The quantities of biomass residues are determined by the left-over or unusable part of the resources (little or no value). A typical example from the case studies is when a bunch of sugar cane containing 25-35 sticks are averagely sold N1,200.00 (US$6) weighing between 70kg-80kg; having consumed the sugar cane, the waste (bagasse and cane envelopes) remaining from the bunch was between 18-20 kg representing approximately 25% of the total initial weight. This agrees with IRENA (2012) but disagrees with Mckendry (2002) that waste (bagasse) is up to 50%. More so, three different waste availability patterns has been established in these communities: universal (multiple biomass resources and generally available), partial (two or three resource types only) and limited (perhaps only one resource that is suitable for utilisation). A Typical case is Gwaigwayen Danmallam (the village with the biggest energy demand) which practices continuous planting throughout the year, therefore biomass residues availability is classed as universal. This is similar to other communities given that the majority of them are farmers. See Table 8.3 for annual estimates of biomass resources harvested and level of availability. It is indicative that from these resources significant biomass wastes stream can be generated and can provide electricity throughout the year. All these were established during the survey sessions.

Table 8.3: Estimated Biomass Resources in Gwaigwayen Danmallam (typical)

Source of Waste	Quantity	Unit
Maize	1630	tonne
Guinea corn	765	tonne
Millet	68	tonne
Soya Beans	540	tonne
Beans	102	tonne
Cotton	120	tonne
Rice	80	tonne
Sugar cane	450	tonne
Cows	1500	NR
Goats/Sheep	3000	NR

Identification of Available Technologies

Following the determination of biomass resource availability levels (universal, partial or limited) in these communities, assessing their suitability for utilisation in the BETs is necessary. For example, direct combustion (DC) uses many biomass resources as possible fuel, while gasification system (GAS) accepts limited biomass fuel such as wood, charcoal and partially rice husk (Mahapatra & Dasappa 2012; Deliyannus 2012). Also, given that all the communities have cows, sheep and goats in reasonable quantities, anaerobic digestion (biogas) has been considered as appropriate. All the identified technologies such as DC, GAS and biogas system are currently available at a commercial scale and are suitable for small scale electricity generation (Garba & Kishk 2015; IRENA 2012; Bridgwater 2002). These technologies have been evaluated with a view to determining their suitability in these communities. See table 8.4 for details.

Table 8.4: Sustainability Assessment of BETs and GE systems

S/No	Indicators and Criteria	Options Considered (Four villages with less than 50 kW)			
		Direct Combustion	Gasification	Anaerobic Digestion	Grid supply
	Survey Stage				
1	Electricity Needs (majority of rural areas)	3	3	3	3
2	Local (biomass/fossil) resources availability	3	3	3	0
3	Biomass resources suitability (acceptance of various fuel)	3	2	2	0
	Technologies Asssessment				
4	Technology Maturity	3	2	2	3
5	Operationability & Maintenability (indigenous skill availability)	1	1	2	3
6	Dependability	3	2	2	1
7	Availability (procurement & deployment	3	1	1	3
8	Efficiency	1	3	3	3
9	Capacity factor (ratio of actual output over designated ouput)	1	3	3	2
	Economic Evaluation				
10	Investment Cost	2	3	0	1
11	Operation and maintenance cost	1	2	3	1
12	Financing options/Incentive strategy	1	1	1	3
13	System life span	3	2	2	2
14	Sensitivity analysis (effect of biomass/ fossil fuel price increase during life cycle)	1	2	3	1
	Environmental Assessment				
15	GHG emission reduction	1	2	3	0
15	Farm/bush burning syndrome mitigation				
16	Effect on eco-system	2	2	3	1
	Social Acceptance Assessment				
17	Farmers-Herdsmen conflict mitigation	2	2	3	2
18	Health improvement (indoor smoke reduction)	3	3	3	3
19	Employment generation	3	3	3	1
20	More income/earning	3	3	3	1
21	Sustainable (organic) fertiliser	2	2	3	0
22	Community Acceptance	2	2	2	3
23	Food and fabric shortage	1	1	2	3
		48	**50**	**55**	**40**

<u>Determining Total Electricity Output</u>

The electricity outputs of the selected technologies were obtained in the course of finding the cost of conversion systems (equipment) from the manufacturers.

The obtained values assist in the technical screening of the technologies. The electricity outputs of the technologies stated by manufacturers were then compared with the case studies reported in the literature, especially those of Fans et al. (2011), Evans et al. (2010), Demirbas (2001), Nouni et al. (2007) and Dasappa et al. (2011). This is with a view to determining the actual "real – world" output as against the often exaggerated manufacturers output. In addition to this, the capacity factor and efficiency of each technology were also compared.

Technical Screening

Having identified suitable technologies and their actual load output vis-à-vis appropriate biomass fuel, the technical screening of each technology was conducted based on the following criteria: ease of operation and maintenance of conversion system (equipment), dependability, maturity, availability and total electricity output criteria of capacity factor and efficiency of the equipment. This screening was conducted by the technical stakeholders based on their experience and review of relevant literature. Each technology screened has been based on its technical ability and evidence of contribution to meeting the sustainable development goals requirements. The technology that scaled through these steps, are adjudged good as they have undergone detailed assessment and evaluation. (See table 8.4 for detailed assessment). In this context, technology and criteria with highest mark represent the best option and good score.

WLC Evaluation

The economics of the identified technologies were assessed using the WLC approach. This was done by the collection of investment cost orf primary and secondary conversion systems of all the BETs from various manufacturers; GE system capital cost data were obtained from the Nigerian open market, as they are readily available in the country. Various other costs were obtained from many manufacturers especially for BETs. The costs from emerging countries were found to be lower compared to those from developed countries, hence these lower costs were adopted. In terms of investment cost, the most economic technology among the BETs is gasification, followed by direct combustion and lastly anaerobic digestion (biogas). Furthermore, the GE system is more cost competitive than the biogas system and its cost is largely dependent on the distance between the village under consideration and the closest point of a grid system (the WLC of electricity generated from that last grid point impacts on the overall cost). See sections 6.2 and 6.6 and the study by Garba et al. (2016b) for more insight. Investment cost evaluation in this context did not include land acquisition cost (as land cost is extremely low relative to income in these locations), import taxes (as Nigeria has a subsidy in this respect for RETs) and other minor costs.

In terms of the operation and maintenance of each technology, the following information were obtained: biomass fuels costs (open market), discount rate (Nigerian central bank), O & M cost (from literature such as IRENA 2012; Mahapatra & Dasappa 2012), life span (from manufacturers, however this was compared with reported case studies, e.g. Dasappa et al. 2011), total electricity output (taking into account capacity factor and efficiency of the technologies, and data obtained from manufacturers' manuals) and FIT incentive strategy (from National Energy Regulatory Commission (NERC) 2013). The technology with the lowest O & M cost is biogas, followed by gasification, then GE and lastly direct combustion (DC). However, based on the suggestion by Fellows and Liu 2008 that, when evaluating a model or framework, a new set of data should be collected, the researcher collected new sets of cost data for biomass resources and subjected them to evaluation and validation.

The evaluations of WLC of BETs involved collection and collation of all the costs and revenues of each technology over its life cycle, which were then divided by the total electricity output during that life cycle. Any available incentive(s) may then be added to the decision making process. This provides the unit cost of each technology (gasification has the cheapest electricity cost/kWh, followed by biogas and then DC). (See details of the typical evaluation under sections 6.4 and 6.6, and studies by Garba and Kishk (2015), Garba & Kishk (2016), Garba et al (2016b), Mahapatra and Dasappa (2012), IRENA (2012), Nouni et al. (2007) and Rahman et al. (2013)).

Sensitivity analyses were undertaken so as to focus on the changes to biomass fuel cost during the life cycle, and any change of fuel type, given biomass fuel cost constitutes over 50% of the total life costing of all the BETs. The sensitivity analysis guides the decision makers by identifying where emphasis should be placed. The assumed biomass fuel price inflation rates adopted during the life cycle are 50%, 75% and 100%, with each causing the proposed electricity tariff of BETs to increase. The technology that experienced the highest increase in electricity tariff during the life cycle is direct combustion, followed by gasification system and then the biogas system. For more detail, see sections 6.5 and other studies by Garba and Kishk (2015) and Garba et al. (2016b). Similarly, any increase in fossil fuel (FF) price and other energy policy uncertainties are shown to cause changes to the electricity tariff of a GE system, as has been experienced in Nigeria in recent time. Typically, the average unit price of electricity from a grid system by 2015 was US$ 0.08/kWh and by February 2016, the average price changed to US$0.13/kWh, indicating that the dynamism of the market is worth projecting into the future so as to provide a better decision.

Greenhouse Gas (GHG) Emission Appraisal

GHG emission levels of all the BETs have been assessed and compared with the current major sources of electricity generation in the country (centralised grid system using FF sources). This is espoused in the work of Evans et al. (2010), Rahman et al. (2013), and Manish et al. (2006) amongst others. In this context, residues from agricultural activities, forestry and animals were considered for utilisation; their utilisation significantly reduced the level of GHG emission expected compared with energy plantation using chemical fertiliser and utilisation of a GE system. Also, considering the fact that these residues are locally sourced with limited/no transportation, this implies that a CO_2 emissions associated with transportation will be reduced (Fan et al. 2011). Although it is claimed that biomass electricity generation is carbon-neutral, it has to be acknowledged that in some instances it still emits GHG during the conversion processes (Evans et al. 2010; Adams et al. 2015). Among the BETs, the biogas system is the option with the lowest GHG emission over its life cycle (0.01-0.03 kg CO_2 /kWh (Rahman et al. 2013)); followed by gasification (approximately 0.04 kg CO_2 /kWh) and direct combustion (0.05 kg CO_2 /kWh) (Gustavsson & Medlener 2003). Evans et al. (2010) reported that "The average carbon emission of biomass power generation is 62.5 gCO_2/kWh. The highest emission, 132 gCO_2eq/kWh is less than one third of the lowest natural gas and one fifth of the lowest coal fired power station emissions proven at present".

Social Benefits Assessment

There exist impacts associated with the utilisation of biomass for power energy provision in the areas of sourcing resources, conversion systems for electricity generation, the utilisation of electricity, social benefits, and others. These require to be assessed for better understanding. During the survey stage of the case study, the benefits and concerns associated with biomass application were explained to the communities; generation of employment, more income from selling of their residues (agriculture and animal), mitigate environmental degradation, sustainable electricity generation, organic fertiliser provision among others; and negatively is the food shortage (if energy crops are used). Subsequently, they were interviewed to establish their areas of preferences; e.g. which social benefits do you prefer? Their responses were codified by assuming numerical figures, which were then of help in determining the most preferred criteria vis-à-vis the BETs. The most selected benefit among these criteria is organic fertiliser, and the least is the indoor smoke reduction. This may be connected with the high cost and difficulty experienced in obtaining chemical fertiliser in the country. Likewise the levels of acceptability of these technologies have been assessed; anaerobic digestion (biogas) and grid system are the most acceptable. This is because of organic fertiliser associated with biogas system, as farmers they feel they 'know' this product, as opposed to the fact that the ash content from DC and GAS systems is also a good source of fertiliser. Also, their reason for selecting a GE system is because of its permanent nature. There is still a lack of awareness that a decentralised biomass system can provide permanent and sustainable electricity.

In contrast to its benefits, the social concern in the proposed RETs framework implementation has to do with the Nigeria set up, a situation where the systems in the country have been grossly compromised due corruption, nepotism and sectionalism. Typically, the privatization of the power sector in the country, a situation where the unbundled companies (generations and distributions) that bought up the utility company were mainly organizations without the technical know-how and financial capacity (largely politicians). This condition has put the country's power sector backward prior to privatisation. Hence, the proposed RETs implementation framework may suffer the same challenge. However, with the researcher's tenacity and close follow up, these social constraints may be minimised for the appropriate implementation of the framework.

Result & Decision

Based on the assessment under each criterion and rankings made which were subsequently collated, the most sustainable technology is the biogas system (scored the highest mark), despite the fact that it is the technology with the highest investment cost. This outcome requires the decision-maker to go to phase two to consider using available incentive strategies to improve viability. The Biogas system is closely followed by the gasification system (lowest investment cost) but this has deficiencies with respect to other criteria. The least sustainable is the GE system, despite its low investment cost compared to a biogas system. Therefore, a biogas system is the most optimal option based on sustainability criteria, while gasification and DC are good case scenarios, and GE is the worst case scenario in this respect. Financially, gasification is the most economical option, while the worst case is the biogas system. See sections 6.2 and 6.4 and Garba et al. (2016b) for details.

Incentive Strategies/Financing Options Availability

Considering the identified suitable technologies based on sustainable development objectives and other criteria, the most sustainable technology is also the one with the highest investment cost.

Given that BETs are emerging technologies in the area of electricity provision when compared with a heavily subsidised GE system (Badcock & Lenzen 2010), the majority of countries provide incentives for its development. In Nigeria, based on NERC (2013) policy, a feed-in-tariff (FIT) of up to N37.36 (US$ 0.19)/kWh of biomass electricity for 2016 was set (the current electricity tariff is approximately N 26.00 (US$ 0.13/kWh) in the country). This level of FIT is to encourage investors' participation in providing sustainable electricity generation. The WLC assessment uses both motivational scenarios (with and without incentives) as, given the high investment cost, it has been determined that without a FIT incentive biogas system electricity tariffs are largely cost-competitive with urban grid electricity systems in Nigeria (see section 6.4 for details). However, if incentives are utilised in rural areas' electricity provision, it is postulated to guarantee participation of investors. The rural communities are low income earners which, when coupled with their low energy consumption pattern, requires a mix of incentives to attract investors. Other incentives in the country include fiscal policy waivers (such as license fee exemption, import duty exemption which is up to 21% for others) and free land provision.

In addition, the range of financing options available during implementation is a very important factor to consider, particularly in Nigeria, where commercial banks' interest rate is up to 35%. This results in other financing options with lower interest rate being suggested for consideration: equity capital, co-operative societies, insurance companies, and crowd funding among others. Based on the assessment, the most suitable among these financing options is crowd funding (even though not legislated yet in Nigeria as compared to countries like Britain) as this generally imposes the lowest interest rate (around 10%), followed by co-operative societies' (up to 15%). The idea of crowd funding was suggested to these communities, explaining that the benefit is beyond getting electricity in that interest can also be earned on investment. There was considerable scepticism initially, largely because of their experience relating to previous strategies that have failed (typically, contribution (saving) strategy for fertiliser procurement).

With the foregoing funding system, it is feasible to secure low interest rate funding in combination with incentives, thus making possible successful BETs implementation in rural areas with the associated benefits of sustainability.

On the issue of food security, the communities feel waste utilisation for electricity generation will not affect them negatively. A typical comment by some of the people is "didn't the study suggested the used of residues, why is the researcher bringing the issue of food shortage again".

It is also worthy of note that employment creation resulting from the adoption of a biomass system is higher than that resulting from systems using fossil fuel sources; people employed per MW/year of electricity generation is double that of fossil fuel sources (Owen et. al. 2013; Evans et al. 2010). However, to practitioners, this has resulted in a perception that biomass energy system more expensive compared with fossil fuel sources (as it involves more ‘employees’). However, this perception possibly does not consider that labour costs in these communities are exceptionally low (around US$ 5/day). Nonetheless, any accumulation of labour cost will increase a system’s O & M cost, hence there is a need for caution.

8.4 BETS IMPLEMENTATION FRAMEWORK TESTING

This is the final and crucial stage of the framework, as it seeks the opinion of RETs experts and other stakeholders (especially the consumers of the framework).

Testing Methods

A telephone interview method was used to obtained feedback from the respondents. The experts are largely the same persons interviewed during the semi-structured interview stage, but at this final stage only 9 persons participated. This is to ensure quality of input. The chiefs of the six villages visited (during the case studies reported earlier) were consulted and interviewed. The framework was sent to the RETs experts through their various email addresses and feedback from each was obtained through telephone conversation. For the chiefs, both framework delivery and feedback were obtained through telephone interview only.

Feedbacks

The feedback obtained contained the following:

- The majority of the respondents (experts) raised concern on the process used in arriving at a village-level electricity requirement (initially only household electricity requirement was taken into account) but suggested the need to include energy for productive services and community applications. This feedback is in agreement with the submission of Mandelli et al. (2016).

- The experts also commented on the level of the education of rural people that will utilise the framework; as the use of the framework requires basic scientific knowledge. However, the framework is well understood by experts and is suitable for application in these communities.

- Similarly, the experts expressed concern regarding the incentive provision in the country, particularly that largely these kind of policies are hardly implemented appropriately.

- In the case of rural areas chiefs, largely they complained of a lack of understanding of the BETs (especially the aspect of conversion systems). They indicated fear that, they will require the assistance of more knowledgeable person(s) (experts) to explain the processes to them. This tallies with the concerns raised by experts as explained above.

<u>Action Taken</u>

- Energy for productive and community use have been added to the village energy needs (15% of the total household electricity requirement was projected). In addition, 10% was estimated to cover any genuine future expansion. It is noted that rural households consume the larger percentage of the energy utilised in the rural areas than other utilisation like community services and productive uses.

- The last two feedbacks can only be solved through training; this has formed part of recommendations highlighted in chapter nine.

Limitation of RETs Implementation Framework

The major concerns with the implementation of the proposed RETs framework was the limited number of both RETs experts and the rural communities interviewed. Also, the inability to carry out real life economic evaluation exercise of BETs in the rural areas as a result of lack of domestication of the technologies in the country has limited the .

8.5 CHAPTER SUMMARY

The development, evaluation and analysis of the framework (BETs) was undertaken by going through the 6 stages and 12 steps. The input of people in the village setting were obtained from the selected villages (six of them) that served as case study and validation. The BETs implementation framework has been developed through the selection of appropriate biomass feedstock and conversion technologies, and support through suitable incentive strategies. The framework was subsequently evaluated and validated using six villages as case study. The benefit of the framework is ensuring successful energy provision in rural areas.

CHAPTER NINE

SUMMARY, CONCLUSIONs, and RECOMMENDATIONS for FURTHER RESEARCH

9.1 SUMMARY

The research work that underpins this study aimed to investigate the viability of renewable energy technologies (RETs) and to develop RETs implementation framework in providing sustainable electricity to Nigeria's rural areas. This involved identification of the most appropriate RETs for use in rural areas, constraints of utilising RETs and the strategies for advancing RETs in the country. Also, an economic evaluation of the identified RETs has been carried out. Finally, a biomass energy technologies (BETs) implementation framework for the rural areas has been developed, evaluated and validated. The following represent the key outcomes of the study for each of the study approach/methods:

A) Interview Method:

- Following an assessment of the state of the art of Nigerian RETs, it is indicative that the existing RETs policies in the country are still at developing stages.

- Solar PV remains the only RETs that has any in-country manufacturing capability and utilisation for electricity generation (decentralised only) currently in the country (except small hydro that has been in existence since 1923).

- The study identified constraints inhibiting the development of RETs in Nigeria by order of priority: lack of robust RETs policy to attract investors, high investment cost of the RETs components, quackery practice proliferation, sub-standard components (low-quality imported products peculiar to solar PV), lack of awareness and lack of technical know-how.

- Biomass energy technologies (BETs) has been identified as the most suitable RETs for providing sustainable rural areas electrification.

Wind energy is the least frequently system selected by the interviewees, and was also identified by SWOT and sustainable indicators analyses as the least appropriate RET.

- The major strategy for advancing RETs suggested by the interviewees is the total review of national energy policies, particularly those aspects most relevant for the country's rural areas.

B) WLC Approach

- All the BETs capacities considered in this study are more economical than fossil fuel (FF) sources and are suitable for providing sustainable electricity in rural communities without the need for incentives, with the exception of direct combustion (50kW) capacity.

- BETs capital cost/kW capacity patterns are as follows: direct combustion (DC) (US$ 1427 -2,247), gasification systems (GAS) (high rate; US$ 2,252-3,604, medium rate; US$ 1,289-2,489 and low rate; US$594-1,594) and anaerobic digester (AD) (US$ 3,529 – 6,451) systems. Despite these technologies being largely emerging systems they (especially gasification) are cost-competitive with FF sources recently built in the country.

- Sensitivity analysis revealed that if feedstock prices increase during adoption by between 50% and 100%, the average inflation of cost/kWh of electricity tariff for DC, GAS and AD systems will respectively increase between 35% and 87%, 13% and 26%, and 10% and 21%.

- The findings also reveal that it is more economical to use a gasification system for electricity provision for villages with less than 50 kW capacity (demand) and located less than 5km from the grid. However, as the system capacity reaches 100 kW, with the same distance of 5km, it is more cost-competitive to use a grid extension (GE) system.

9.2 CONCLUSIONS

The power energy deficiency in Nigeria's rural areas, which arises from the high capital cost of gridline networks and generation facilities, gridlines network energy losses and other factors in the country, evidences the need for adoption of decentralised and sustainable forms of electricity provision. The use of decentralised BETs has been recognised as the most suitable means of electricity provision in such communities, given the biomass resources availability vis-à-vis the communities' low energy consumption pattern. All the BETs capacities considered in this context are found to be cost-competitive with FF energy sources, and are suitable for providing sustainable electricity in rural areas without the need for incentives, except for DC (50kW) capacity. Also, BETs capital cost/kW capacity relationship is encouraging: DC (US$ 1,427 -2,247), GAS (US$594-3,604) and AD (US$ 3,529 – 6,451) all figures are for systems having capacities not exceeding 150kW. Also, in the event of BETs adoption and fuel prices increases of between 50% and 100%, the resulting average inflation (in terms of WLC/kWh) of the electricity tariff for DC systems will be between 35 and 87%. Similarly, GAS cost/kWh will increase between 13 and 26%, and an AD system will increase between 10 and 21%. Hence, utilisation of a FIT incentive will assist in mitigating the effect of feedstock price increases, and encourage investors' participation given lack of any energy infrastructure in these communities. More so, the FIT incentive utilised in this study (as in table 4.1) is simply indicative, hence its application should be extended to decentralised energy systems, not restricted to only the grid systems. Hence, all the objectives in this study have been achieved.

Also, the findings of the sustainability assessment of commonly used RETs carried out using a systematic review (using the concept of SWOT analysis and sustainability indicator of the commonly utilised RETs), along with the findings of the applied interview methods, evidenced biomass as the most appropriate and desirable energy system for a decentralised rural setting. Biomass is followed by solar PV, small hydro and lastly wind energy system as the least appropriate. The interview method analysis also revealed that, at the current state of the development of Nigerian RETs, the existing RETs policies are still at developing stages.

Several of the interviewees' comments evidenced an unexpected perception of BETs as also possibly serving a socio-political purpose; as an alternative energy source to FF in providing decentralised electricity for rural village(s). BETS may contribute to a reduction in youth unrest in areas such as the Niger Delta region (given the long-standing supply disruption to the country's thermal plants). This is because BETs resources can be found everywhere in the country's rural communities in one form or the other. Hence, more supportive policies should be developed for BETs system so as to encourage its appropriate development for Nigeria's rural communities.

As solar PV remains the only RETs that is both manufactured in Nigeria and utilised for electricity (decentralised) currently in the country, with other RETs (biomass, small hydro, wind and solar thermal system) being at either the pilot or experimental stages of development (only obtainable in the energy research centres), there is the need for caution; as solar PV represents the most worrying energy system given its components in the country's RETs market are largely sub-standard (low-quality) and usually installed by low-knowledge or quack practitioners. Hence, this is discouraging RETs utilisation and growth in the country.

Regarding the constraints preventing the development of RET in Nigeria, the lack of a robust RETs policy (policy constraints) and the high investment cost to produce the RETs components (economic constraints) in this context are the leading barriers. More so, policy and economic constraints are synonymous in this context; the respondents (interviewees) largely referred to the lack of any incentive provision to produce and/or procure the RETs components in the context of both types of constraint. Hence, the high cost of RETs components remains the biggest barrier for both manufacturers, investors and consumers. This is followed by quackery practice proliferation, sub-standard components (low-quality products, typically for solar PV), know-how deficiency, lack of domestication of RETs, and a lack of awareness. Regarding the awareness barrier, the general lack of local content and engagement has affected the development of RETs in rural areas, as such facilities are usually operated and managed by the people from cities. Hence, if there is a fault, the local community have to wait for these people to come to fix the facility.

The study identified new challenges that have not been reported before in the literature: lack of confidence in local technology, inability to transmit RETs at high voltage in the country, spare-part materials unavailability, lack of a national RETs record/data base, and a lack of the monitoring of strategic plans and objectives.

The study also identified the following strategies as key facilitators of advancing the adoption of RETs in rural areas by order of priority: economics subsidies provision, domestication of the RETs, robust regulatory/institution framework (to combat quackery practice proliferation and importation of sub-standard components), education and training, and policy review and implementation among others.
Finally, the BETs implementation framework has been developed, evaluated and validated using six villages as case study; this guarantee successful sustainable energy provision in the country's rural areas. Hence, all the objectives in this research have been achieved.

9.3 CONTRIBUTIONS
The main contributions of this study include:

- Identification of biomass energy systems as an alternative means of sustainable electricity provision to rural areas. This has been achieved through systematic review (using SWOT analysis and sustainable indicators of commonly RETs) and interviewing of RETs practitioners in Nigeria.

- Development of a biomass energy technologies (BETs) implementation framework in providing sustainable electricity to rural communities, through facilitating the selection of suitable biomass feedstock, appropriate technology among BETs (based on an economic evaluation), and support through appropriate and robust incentive strategies.

- Previous studies in respect of RETs utilisation for sustainable electricity provision in Nigeria focused largely on the RETs resource potential, utilisation and policy development, with minimal attention to the economic evaluation of the RETs particularly BETs. The current research has bridged this gap by concentrating on the economic assessment and optimisation of subsets of BETs in the country with a view to achieving sustainable and affordable electricity provision to rural communities.

- Development of SWOT analysis and sustainability indicators for commonly used RETs to support informed decision making by the stakeholders. Both concepts are entirely new to Nigeria's energy industry. Also, this is the first time a SWOT analysis tool has been used for assessing RETs.

- The interview method has critically analysed the state of the art of RETs in Nigeria, including constraints preventing its development and strategies for advancing RETs utilisation in the country, particularly its rural areas.

- The research findings have been presented in peer-reviewed international conferences and published in proceedings, and some of the papers have been accepted for Journal publication and book chapter (See appendix B for details). The publications will assist those persons involved in the future energy policies review suggested by this research, and represent contributions to knowledge regarding the crucial development of BETs in the context of the provision of electricity to rural communities, both in Nigeria and elsewhere.

9.4 RECOMMENDATIONS

Based on the research work reported in this thesis, the following recommendations are advanced:

- Complete review of existing energy policies in the country, particularly those that relate to rural areas, with a view to introducing the provision of robust incentive strategies (not limited to feed-in-tariff only).

- Decentralise the existing FIT strategy beyond the grid system. This will encourage participation of investors to boost the energy infrastructure in rural areas. Development of strong institutional and regulatory frameworks to mitigate quackery practice proliferation and address the ready availability and use of sub-standard (low-quality) components in the country.

- Include due-diligence processes throughout the whole contract awarding system. Government should endeavour to domesticate RETs and set-up strategies that develop human capacity know-how in respect of RETs.

- A business case approach should be introduced where the communities pay a stipend for what they consume (to ensure sustainability).

- Communities should be allowed to operate and manage the facilities rather than employing persons from far places.

- This study is recommending BETs full utilisation in rural communities all over the country, but with the caveat that such utilisation is strongly supported by experienced experts in the industry. Such experts would support a policy prerequisite of setting biomass plants based on the adequate availability of biomass and water resources in rural communities far from the grid.

- Finally, in the context of the BETs implementation framework developed by this research, training will be required for those rural persons who will need to be able to use the framework. Such training will require to be in a form that reflects the level of education typical of such persons (as identified by the RETs experts interviewed and even the rural persons consulted during the BETs implementation framework evaluation and testing stage). Hence, an appropriate form of training should be organised as part of the support for its adoption.

- Further research work includes the development of BETs financial evaluation model application (apps) to assist in making appropriate choice based on criteria such as resources potential, economics of conversion systems, policy support and finance types availability. The model should allow changes to be made to the variables considering variability of biomass resources, its conversion systems and even location of application for universal availability.

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INTERVIEWS QUESTIONS AND CONSENT TO PARTICIPATE FORM (APPENDIX A)

A1: EXPLORATORY STUDY (INTERVIEW)

Research Aims

To investigate the viability of renewable energy technologies (RETs) and to develop a RETs implementation framework for providing sustainable electricity to Nigeria's rural areas

Personal Data

Can you tell me your names?

What is the name/activities of your organisation?

What is your qualification/years of working experience?

What is your role in this organisation?

What is the state of renewable energy technologies (RETs) in Nigeria?

Assessing Level of RETs utilization in Nigeria

Have you ever come across or experienced utilization of any modern RETs in Nigeria?

If yes, which forms of RETs have you come across, where are they located and the capacity of the technolog (ies)

Examining constraints preventing RETs utilization in Nigeria

Following lack of progress of RETs diffusion in Nigeria, what are the constraints to RETs implementation in the country's rural areas?

Identifying appropriate RETs for rural areas electricity provision

What forms of RETs are appropriate for sustainable electricity provision in the country's rural areas?

A2: SEMI-STRUCTURED INTERVIEW

Research Aims

To investigate the viability of renewable energy technologies (RETs) and to develop a RETs implementation framework for providing sustainable electricity to Nigeria's rural areas

Biomass Electrification in Rural Areas

What are your reasons for support or against biomass energy systems in the country's rural areas?

What are your requirements for diffusing biomass energy systems?

Way Forward

What are the strategies for advancing RETs deployment in the country's rural areas?

A3: INTRODUCTORY AND CONSENT TO PARTICIPATE FORM

My name is Abdulhakeem Garba, a PhD student with the Robert Gordon University, Aberdeen, Scotland. I am undertaking a research title: "Renewable Energy Technologies Assessment for Sustainable Electricity Provision in Nigerian Rural Areas".

I have been provided with the information concerning this research and understood that the data obtained shall be treated anonymous for the purpose of this research. The interview will be conducted based on the Robert Gordon University ethics policies as contained in the link below:

www.rgu.ac.uk/file/research-ethics-policy-pdf-146kb

I have been given the opportunity to ask questions and have them answered to my satisfaction. I agree to be interviewed by ___________________ for the purpose of this research contributing towards a PhD degree thesis and paper publications afterward.

I also understand that I may withdraw from this research up to six (6) weeks after undertaken the interview. I give my consent to the provision of my views, and information during this research. I agree to have the interview tape recorded.

I would like to receive a copy of any publications that are based on these interviews?

YES NO

If yes, please provide an email or mailing address below.

____

Name: ______________________

Signed: _____________________

Date: _______________________

APPENDIX (B)
ABSTRACTS OF PUBLISHED PAPERS

Following the research work that underpins this study, five papers have been published in referred research conferences. Among these papers one has been accepted as a Journal paper and one as a book chapter by Springer publishers

B1: RENEWABLE ENERGY TECHNOLOGY MEANS OF PROVIDING SUSTAINABLE ELECTRICITY IN NIGERIAN RURAL AREAS - A REVIEW

Garba, A. and Kishk, M.

Proceedings of 30th Annual ARCOM Conference, 1-3 September 2014, Portsmouth, UK, Association of Researchers in Construction Management, 143-151.

Following the failure of the Power Holding Company of Nigeria (PHCN) and fossil fuel source applications for the provision of electricity in Nigeria, the country has been experiencing power energy shortages for over three decades now. More than 65% of the population lack commercial electricity, particularly in the rural areas. This has caused socio-economic problems involving relocation of manufacturing companies to neighbouring countries, unemployment, and endemic rural-urban migration. The research that underpins this paper aims to investigate the potential of Renewable Energy Technologies (RETs) in the provision of sustainable electricity in Nigeria's rural areas. This has been motivated by the strategic value of RETs in identifying when and where electricity is actually required thereby eliminating/reducing the high cost of gridline network and offering a more sustainable alternative to fossil fuels. A systematic review method has been used to examine various RETs regarding their viability and applicability in Nigeria. The sustainability of various RETs is then evaluated using SWOT analysis to screen the technologies to be used in an energy supply mix in Nigeria's rural areas. Biomass, hydro and solar sources are appropriate for use in Nigeria rural areas. The utilisation level of RETs in Nigeria is extremely low except for hydropower source. The major problems of RETs implementation are lack of implementable energy policy, government apathy towards development

of RETs and the low purchasing power of majority of citizens. Further work includes the application of whole life costing (WLC) to assess and optimise the economic performance of the identified RETs.

B2: Economic Assessment of Biomass Gasification Technology in Providing Sustainable Electricity in Nigerian Rural Areas

Garba, A. and Kishk, M.

Proceedings of the International Sustainable Ecological Engineering Design for Society (SEEDS) Conference, 17-18 September, 2015, Leeds Beckett University, Leeds, 554-565. <u>This paper has been accepted for Journal Publication by Greenleaf Publishing</u>.

Renewable Energy Technologies (RET) in general, and biomass source in particular, remains one of the means of providing sustainable electricity to rural areas in developing countries. This is because of its strategic value in identifying when and where electricity is really required thus, reducing/eliminating the high cost of grid network. The majority of Nigeria's rural dwellers are farmers and use little or none of their residues at the end of the farming season. Nigeria has also been experiencing dwindling power supply at both national and rural level with accessibility representing only 34% and 10% respectively. The rural areas are the most affected causing significant disruption of their socio-economic settings. Considering the enormous biomass resources in these communities, and they constitute approximately 65% of the country's total population, it is feasible to provide sustainable electricity to these communities through Biomass Gasification Technology (BGT). Cost has been found to be the major constraint in adopting RETs. Hence, this paper aims to evaluate and optimise the unit cost of generating electricity through BGT in Nigerian rural areas. Whole Life Costing approach has been used to evaluate various capacities of BGT. The findings reflect that cost/kW of BGT ranges between US$594(NGN118, 800)-US$3,604(NGN720,800) for capacities between 125kW-10kW. The Net Present Value(NPV)/kWh of generating electricity has been calculated for several scenarios including 125kW, 100kW, 50kW, 32kW, 24kW and 10kW system capacities under 3 different operational hours (8, 12 and 16), with and without feed-in tariff(FIT) incentive is from US$0.015-US$0.11(NGN3.08–N21.79). The only scenario that exceeds the current unit price of generating electricity from fossil fuel source in Nigeria which is averagely US$0.083(NGN16.50) is 8 hour operation without FIT at 10kW capacity. More so, in the event fuel wood price increases by 50%, 75% and 100%, the average increase in WLC/kWh will be 13%, 20% and 27% respectively.

B3: A techno-economic Comparison of Biomass Thermo-chemical Systems for Sustainable Electricity in Nigerian rural areas

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Proceedings of 5th International Renewable Power Generation Conference, 21-23 September 2016, London, UK, The Institute of Engineering and Technology.

Biomass thermo-chemical systems (BTCS) source remains one of the means of providing sustainable electricity to rural areas in developing nations. Due the dwindling power generation and supply in Nigeria representing between 10 and 34%, the rural communities are mostly affected in their socio-economic activities. Given the massive biomass resources in Nigerian rural areas, it is feasible to provide sustainable electricity to these communities through BTCS. However, cost has been found to be a major constraint in adopting BTCS. The research works that underpin this paper aim to assess the economics of BTCS in generating sustainable electricity in Nigerian rural areas. Whole Life Costing (WLC) approach has been used to evaluate and optimise various capacities of BTCS. The findings reveal that the cost/kW of system capacities between 150kW to 10kW for combustion and gasification systems, range between US$1427-2,249 and US$1,280-2,489 respectively. The WLC/kWh of generating electricity from the same set of technologies, in order of system capacities above, ranges between US$0.041-US$0.37 and US$0.015-US$0.11. This is considered under 8, 12 and 16 operational hours, without and with Feed-in-Tariff (FIT) incentives. All scenarios evaluated are cost competitive with existing fossil fuel (FF) electricity sources in the country at US$0.13/kWh, except the 50kW combustion system, with and without FIT that exceeds the current electricity tariff in Nigeria.

B4: Models for Sustainable Electricity provision in Rural Areas Using Renewable Energy Technologies- Nigeria Case Study

Garba, A., Kishk, M. and Moore, R. D.

Proceedings of 2nd International Sustainable Ecological Engineering Design for Society (SEEDS) Conference, 14-15 September, 2016, Leeds Beckett University, Leeds. <u>The first author has been awarded the highly commendable paper at the conference by CIBSE. The paper has also been accepted as Book chapter by Springer to be published in (Building Information Modelling, High Performance Design and Smart Construction Book)</u>

Sustainable electricity generation and supply in Nigeria has been a perennial challenge even though the country is one of the world's leading exporters of oil and a member of organization of petroleum exporting countries (OPEC). The reasons for this problem include persistent vandalism of energy infrastructure, high cost of gridline network and weak transmission and distribution facilities. Existing capacity only provides electricity to 34% and 10% of urban centers and rural areas respectively. Decentralized renewable energy technologies (RETs) may be a sustainable and economical alternative for meeting electricity demands of the rural communities representing two-thirds of the total country's population. This research thus investigates alternative RETs that may provide sustainable electricity to Nigerian rural areas. Interview method was used. The findings reveal that the most suitable RETs in order of priority are biomass, solar PV, small hydropower, solar thermal and wind energy systems. In addition, biomass energy systems (BES) being the most selected, has been subjected to further investigation; unlike the National energy policy under representation of BES, 77% of the interviewees agreed that BES utilisation in the country's rural areas are suitable and desirable. Also, for implementation of BES, all the identified drivers and enablers should be taken into consideration. However, some identified constraints to adoption and development of BES include supply chain limitation, substantial land and water requirements for set-up and processing. Thus, this study recommends that the existing rural areas energy policies be reviewed.

B5: A COMPARATIVE STUDY OF BIOMASS ENERGY TECHNOLOGIES FOR SUSTAINABLE ELECTRICITY IN NIGERIAN RURAL AREAS

Garba, A., Kishk, M. and Moore R. D.

Proceedings of 32th Annual ARCOM Conference, 5-7 September 2016, Manchester, UK, Association of Researchers in Construction Management, 2, 1209-1218.

Biomass as a Renewable Energy Technology (RET) is used to provide sustainable electricity to rural areas in several developing countries. As a result of dwindling power generation and supply in Nigeria representing between 10 and 34%, the rural communities have been negatively affected in their socio-economic activities. Considering the vast biomass resources in Nigerian rural areas, it is feasible to provide sustainable electricity to these communities through Biomass Energy Technologies (BETs). However, cost has been found to be a major constraint in adopting BETs. The research aims to evaluate the economics of BETs in generating sustainable and affordable electricity in Nigerian rural areas. Whole Life Costing (WLC) approach has been used to evaluate various capacities of BETs. All the BETs capacities evaluated except 50kW combustion system are cost competitive with existing fossil fuel sources used in generating electricity in Nigeria at US$0.13 without incentives. In the event of biomass fuels price increases between 50-100%, WLC/kWh of some scenarios will exceed the existing electricity tariff.