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A COMPARATIVE STUDY OF BIOMASS ENERGY TECHNOLOGIES FOR SUSTAINABLE ELECTRICITY IN NIGERIAN RURAL AREAS

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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.

Keywords: biomass energy technologies, Nigeria, sustainable electricity, whole life costing

INTRODUCTION

Sustainable power generation and supply is seemingly unachievable in Nigeria despite the country's abundant fossil fuel and renewable energy resources (Energy commission of Nigeria (ECN) 2005). The reasons for this inconceivable problem include high gridlines network loses of around 40% especially in Nigeria, investment imbalance of energy infrastructures (World bank 2005; Garba and Kishk 2014) and the electricity generation cost using fossil fuel (FF) sources in the country is in excess of US$ 1,000/kW (Eberhard and Gratwick 2012). Also, there is a high investment cost factor in extending the gridline network to rural communities as they are low income earners, have low capacity utilisation and are typically a long distance from load centres, making it unattractive to investors in providing electricity to these communities (Garba and Kishk 2015; Sambo 2009).

Nigerian electricity generation and supply still represents around 4,000MW or less for a population of approximately 170 million despite completion of the privatisation of power sector in 2013 (Garba and Kishk 2015). While electricity accessibility in the country remains at 34% and 10% for urban centres and rural areas respectively (Garba

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and Kishk 2014), rural communities represent two-thirds of the total country's population, the implication therefore is that majority of the population have little or no access to electricity and have to source for alternative means to meeting their energy needs. For example, fuel wood and charcoal consumption in the country constitutes over 50 million tonnes annually (Sambo 2009; Ikeme and Ebohon 2005). This energy deficiency has affected the socio-economic setting of the rural communities, with income typically below US$1.25/day (UNICEF 2011).

Hence, rural communities' electricity needs have to be met through sustainable and economical means, typically the renewable energy technologies (RETs) particularly its decentralised system (with less or no gridlines network and without fossil fuel sources). This is because RETs have been used in providing sustainable electricity to rural areas in developing countries. Also, decentralised RETs has merits in determining when and where power energy is truly required; helps in mitigating greenhouse gas (GHG) emission associated with FF and creates more employment especially biomass source (Evans *et al.*, 2010). The most used in this respect includes solar PV, biomass and small hydropower systems (Mahapatra and Dasappa 2012).

Studies have been conducted in respect of sustainable electricity provision to rural areas in developing countries using decentralised RETs. Typically, the study by Dasappa (2011) reported that biomass is among the optimal alternative energy sources for sustainable electricity provision in Sub-Saharan Africa (SSA) given the universal availability of the resources. Demirbas (2001) argued that biomass energy technologies (BETs) are cost competitive with fossil fuel sources. 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 the most economical means of providing sustainable electricity to Indian's rural areas. They further argued that BETs (gasification) has significant advantage over solar PV system that requires only 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". While in the case of solar PV "as the operational hours increase, the system size also increases and consequently, its capital cost". Also, Garba and Kishk (2014) evaluated six major RETs (solar PV, wind, small hydropower, biomass, geothermal and ocean energy systems) using systematic review method, and a SWOT analysis for each RET was carried out in order to assess their sustainability indicators. The findings by order of priority revealed that biomass, solar PV, small hydropower and wind are the best means for providing sustainable electricity in Nigerian rural areas. However, Evans *et al.*, (2010) argued that BETs are cheaper than solar PV but more expensive than grid extension system. Hence, from the above, it is fair to conclude that BETs are the best means of electricity provision in rural areas.

Similarly, through the BETs application, it is feasible to reduce greenhouse gas (GHG) emission globally particularly from the construction industry given it's consumption of around 40% of all energy and contribute approximately 30% of global GHG emission annually (Lemmet 2009). Construction practitioners should encourage the use of BETs (using biomass boilers and gasifiers) for providing low carbon energy on site and during utilisation of completed project particularly water heating and cooking which accounts for over 80% of the total residential accommodation energy consumption in cold climates (Mandelli *et al.*, 2016) as against use of FF sources.

This study builds upon Garba and Kishk (2014) and Oyedepo (2012) recommendations that WLC evaluation of RETs in Nigeria should be conducted given the lack of reliable cost data which has affected modern RETs inclusion in the country's energy mix. Hence, this study aims to evaluate and optimize the economics of BETs in generating sustainable electricity in Nigerian rural areas.

Biomass resources and energy system

The majority of biomass resources are located close to rural areas and includes agricultural crops and their residues, animal dung, forestry residues, other energy crops, and municipal solid waste (IRENA 2012). Biomass is mostly plant derived materials, capable of being transformed to different forms of energy (electricity, heat and fuel) and can quickly be regenerated in different environments (Evans *et al.*, 2010).

Martinot (2015) reported that biomass is the fourth largest energy source after oil, coal and natural gas. By the end of 2014 bio-power global capacity was around 93 Giga watt (GW) and 75% of electricity generated from biomass was from solid biomass fuel, biogas (17%), MSW (7%) and biofuel (1%). Also, by the end of 2014, all the existing bio-power systems together produced around 1.8% of global electricity.

Nigerian biomass resources potential

According to ECN (2005) Nigeria's estimated biomass resources consumption per annum is around 144 million tonnes. Dasappa (2011) projected Nigeria's biomass resources (30% forest and agricultural residues) availability is capable of resulting into a 15,000MW capacity. It is possible to generate up to 68,000 GWh/year using only one-third of biomass resources for the country's rural communities (Garba and Kishk 2014). The forest resource is the largest biomass utilized in Nigeria for energy purposes. Biomass resources can be used to provide electricity in Nigerian rural areas without a supply chain issue; however, its supply chain should be given emphasis before adoption in these communities as it determines its cost (IRENA 2012).

Biomass energy conversion technologies

BETs conversion systems are classified under two main sections: thermochemical (combustion, gasification and pyrolysis) and biological (anaerobic digester). All the identified BETs will be evaluated except Pyrolysis. This is because "there are no commercial plants for electricity production using pyrolysis process" at the moment (Gonzalez *et al.*, 2015).

Direct Combustion (DC) converts biomass materials to heat and electricity through production of steam in a furnace or boiler and use to drive steam turbine for electricity generation (Demirbas *et al.*, 2009). Miguez *et al.*, (2012) classification based on system capacity include: fixed bed (less than 40kW), moving grate (between 40-150kW) and retort system (greater than 150kW). For the purpose of this study, (maximum capacity of 150KW) both fixed bed and moving bed grate have been selected for evaluation.

Gasification system (GAS) converts biomass through partial oxidation into a gaseous mixture of syngas/product gas consisting of hydrogen, carbon monoxide, methane and carbon dioxide (Wang *et al.*, 2008). The producer gas (PG) is of low caloric value containing from 4-6 MJ/kg compared to natural gas having 35-50 MJ/kg due to high nitrogen presence in excess of 50%. The electricity generation from a small scale GAS plant is exclusively via Internal Combustion Engines (ICE), at the moment (Bocci *et al.*, 2014). GAS is mainly classified into fixed bed, fluidised bed and entrained flow gasifier. Considering the low energy utilisation of rural communities only the downdraft -fixed bed gasifier is suitable for small scale power generation ranging from 10 kW to over 100 kW and has been fully commercialised (IRENA 2012).

Anaerobic digestion (AD) is a biological process of generating electricity via conversion of biomass resources with moderate moisture content into biogas. IRENA (2012) opined that multiple feedstocks co-digestion is the best and generally practiced strategy in achieving good biogas. Biogas is a mixture of methane and carbon dioxide with other constituents, and is mostly burned in ICE or gas turbine for electricity generation at a capacities range between 10kW - several MW (IRENA 2012).

METHODS

The purpose of this paper is to evaluate the economics of BETs in generating sustainable electricity in Nigerian rural areas. Whole life costing (WLC) approach has been used to achieve this objective, as it seeks to "optimize 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" (Woodward and Demirag 1989). In addition, WLC is suitable for both selections between mutually exclusive options and in ranking among the same set of investment alternatives. Though, it has been criticized for not taking into account returns and benefits of investment. It does allow for determining the unit cost of generating electricity from an energy source.

The WLC framework proposed by Mahapatra and Dasappa (2012) has been adapted and modified for use in the current study, as it can accommodate energy systems that require continuous fuel utilization such as biomass resources. The carbon trading incentive in this framework is not applicable in the Nigerian power sector at present; as such it has been replaced with a Feed-in-Tariff (FIT) incentive strategy in the country (details shown in table 2). Salvage value and inflation are not considered in this study for ease in decision making. The WLC framework is given by:

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

Where CF= (SC x fcon x h x fC), CM = (SC x f x MC), FIT = (L x h x n x I)

CG = capital cost of primary converter (PC), CE = capital cost of engine/generator, CF = annual fuel cost, CM = annual maintenance cost, SC = PC rating (kg), fcon = fuel consumption (kg/h), fC = unit fuel cost, MC = maintenance cost of the system, P = present worth factor, d = discount rate, n= life of the project, n1= life of each component, CR= component replacement cost, FIT = annual feed-in-tariff benefit, I = incentive benefit, h = annual operation hours, L = load (kW).

The system boundary for this study is a capacity not exceeding 150 kW. The costs of all the conversion components were sourced from the manufacturers directly. This is because, while existing literature reported widely varying figures; this did not change in this context as variations are a result of, size, location factor and technology maturity. While GAS is an emerging technology, location factors (more expensive in Europe and America but cheaper in India) are emphasised by the study of Breeze (2014) and O'Connor (2011); and Ganesh and Banerjee (2001) confirmed that "gasifiers cost in India is much lower than those elsewhere". AD components costs were only obtained through a turnkey procurement process as manufacturers are reluctant to participate under the traditional approach and small capacities.

The current prices of the biomass feedstocks have been obtained directly from the market (field survey of marketers), their weights measured and subsequently converted to unit cost/tonne. The total price of the wood supply chain including transportation is US$112.50 representing 45 units as classified in the market and each unit is approximately 105kg and sold around US$3.00. Hence, the unit cost of wood fuel is US$ 28.57/tonne. This principle has been adopted for other fuels utilised. See details of the prices, fuel consumption pattern and other parameters utilised in table 1where all costs are presented in US$ for universal understanding, even though the costs have been obtained in India Rupee (INR) for GAS and AD systems, and Chinese Yuan for DC system. It is noteworthy that 200 Nigerian Naira is exchanged for US$1

Table 1: 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

Table 2: FIT Model in Nigeria (Whole Contract Prices N/kwh) (NERC 2013)

	2012	2013	2014	2015	2016
SHP	23.56	25.43	27.46	29.64	32.00
Wind	24.54	26.51	28.64	30.94	33.43
Solar	67.92	73.30	79.12	85.40	92.19
Biomass	27.43	29.62	32.00	34.57	37.36

DATA ANALYSIS

BETs investment cost in Nigerian rural areas

Table 3 indicates the capital cost/kW for DC, GAS and AD systems ranging between US$ 1427 -US$2,247, US$ 1280 – US$2489 and US$ 3,529 – US$6,451 respectively. DC conversion components prices appears to be the most stable, because the system has been in existence for a long period of time. Martinot (2015) depicts that DC has been utilised for a long time and over 90% of the biomass electricity generated is from this system. AD is identified as the most expensive technology and cost/kW of the AD system capacities double the rates of the remaining BETs (DC and GAS) system capacities. The high cost/kW identified under all of the AD system capacities relates to the turnkey procurement route typically used. The economy of scale noticed in the exercise, is indicative that the higher the BETs capacities, the lower the cost/kW.

Table 3 also reveals the cost structure associated with BETs. The conversion systems together with their associated fittings and accessories account for between 90% -96% of the total investment cost. While other cost factors such as civil and electrical works make up the balance. It is noteworthy that the primary conversion systems (gasifiers, boilers and digesters) account for average of around 58% of the investment cost across the board; while generators average cost is approximately 34%.

Table 3: The Cost/kW of BETs systems in Nigeria's rural areas

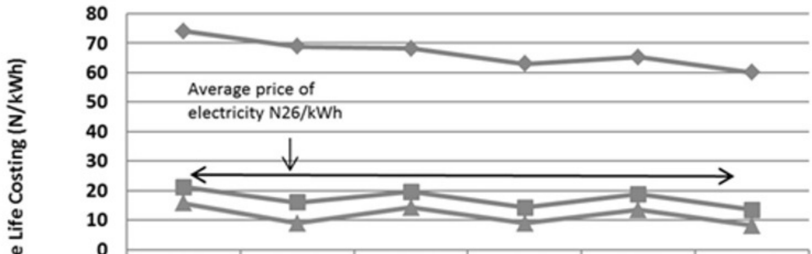
Direct Combustion (DC)				Gasification (GAS)							Anaerobic Digestion (AD)				
Boiler				**Gasifier**							**Digester**				
Capacity (kW)	**50**	**100**	**150**	Capacity (kW)	**10**	**24**	**32**	**50**	**100**	**125**	Capacity (kW)	**10**	**20**	**50**	**100**
Boiler Plant	32,525	32,937	57,115	Gasifier and accessories, chiller, wood cutter, dryer	14,301	20580	27,657	41,202	79,317	95,067	Biogas Plant and accessories (pumps, tanks & heaters)	51,000	83,000	171,000	290,000
Accessories and Fitting	12,500	13,200	13,200												
Cost of Boiler & accessories	**45,025**	**46,137**	**70,315**	**Cost of gasifier & accessories**	**14,301**	**20,580**	**27,657**	**41,202**	**79,317**	**95,067**	**Cost of digester & accessories**	**51,000**	**83,000**	**171,000**	**290,000**
Steam turbine				**ICE**							**Biogas Generators**				
Steam turbine and accessories	57,377	81,967	127,868	Gas Engine & accessories	6,599	11,920	14,443	21,798	44,183	53,433	Biogas engine	7,300	10,600	24,500	46,700
											H2S and moisture s	1,300	1,600	2,200	3,000
											Parking charges	900	1.100	1.400	1.700
Cost of steam turbine & accessories	**57,377**	**81,967**	**127,868**	**Cost of ICE & accessories**	**6,599**	**11,920**	**14,443**	**21.798**	**44,183**	**53,433**	**Cost of ICE & accessories**	**9,500**	**13,300**	**28,100**	**51,400**
Total cost of boiler & turbine	**102,402**	**128,104**	**198,183**	**Total cost of gasifier & ICE**	**20,900**	**32,500**	**42,100**	**63,000**	**123,500**	**148,500**	**Total Cost of digester & Generator**	**60,500**	**96,300**	**199,100**	**341,400**
Others				**Others**							**Others**				
Installation + commissioning	2,500	2,500	3,000	Installation + commissioning	1,000	1,000	1,000	1,000	1,500	1,500	Installation + commissioning	2,500	2,500	3,000	3,000
Civil works	2,000	2,000	2500	Civil works	1,500	1,500	1,500	1,500	2,000	2,000	Civil works	-	-	-	-
Earthing work	350	400	400	Earthing work	300	300	300	300	400	400	Earthing work	-	-	-	-
Price & Design Risk (5%)	5,120	6,405	9,909	Price & Design Risk (5%)	1,185	1,765	2,245	3,290	6,370	7,620	Price & Design Risk (2.5%)	1,513	2,408	4,978	8,535
Total cost of the system	**112,372**	**139,409**	**213,992**	**Total cost of the system**	**24,885**	**37,065**	**47,145**	**69,090**	**133,770**	**160,020**	**Total Cost of the system**	**64,513**	**101,208**	**207,078**	**352,935**
Cost/kW (US$)	**2,247**	**1,394**	**1,427**	**Cost/Kw (US$)**	**2,489**	**1,544**	**1,473**	**1,382**	**1,338**	**1,280**	**Cost/KW (US$)**	**6,451**	**5,060**	**4,142**	**3,529**

Unit cost of biomass electricity in Nigerian rural areas

Figure 1 reveals typically the WLC/kWh of generating electricity from DC; while GAS and AD systems results will only be analyzed in this section; as their figures cannot be presented due to space constraint. Under DC, 3 system capacities and 3 categories of operational hours have been considered.

The findings show that both 100kW and 150kW scenarios have WLC/kWh ranging from US$ 0.068 – US$0.11 without incentive; while with FIT the prices reduce significantly to US$0.041 – US$0.08. Both scenarios are competitive with the current electricity tariff in the country using FF options (US$ 0.13/kWh).

However, WLC/kWh for 50kW with its 3 operational hour's categories, with and without incentive, varies from US$0.30 – US$0.37. This cost range is significantly higher (over 100%) than the existing electricity tariff in the country. Also, even the usage of incentive in this case does not affect the cost in any way. The electricity consumption under all of DC system in this case is fixed (36KW) as highlighted in table 1 and has significant impact on these scenarios, particularly 50 kW. Typically, 50kW minus 36kW, the owner/investor has been left with only 14kW capacity electricity. But as you go higher the efficiency increase. More so, the fuel consumption of the 50kW scenario is the highest among all the BETs and capacities considered in this study, with over 8kg/kWh.



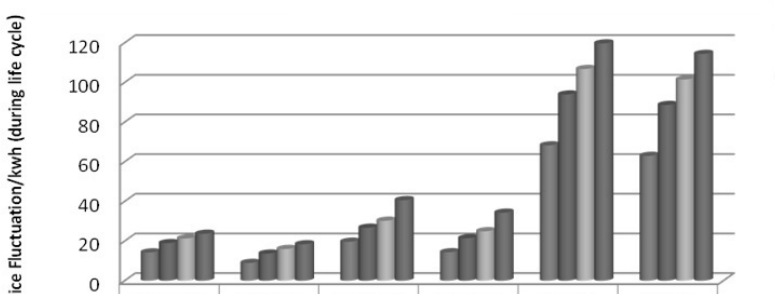
	8hr operation NFIT	8hr operation WFIT	12hr operation NFIT	12hr operation WFIT	16hr operation NFIT	16hr operation WFIT
50kW	74.08	68.78	68.21	62.92	65.29	59.99
100kW	21.26	15.96	19.62	14.32	18.8	13.5
150kW	15.71	8.93	14.23	8.93	13.49	8.19

Figure 1: WLC/kWh of Direct Combustion systems in Nigerian Rural Areas (typical)

In the case of GAS and AD, 6 and 3 system capacities have been considered respectively; and 3 each operational hour are utilised. The WLC/kWh for generating electricity under GAS (125KW – 10kW) with FIT is between US$0.015 – 0.07, while without FIT is between US$0.05 – 0.11. In the case of AD (100kW – 10kW) with and without FIT is respectively between US$0.02 – 0.10 and US$0.046 – 0.13. In both GAS and AD systems, none of the scenarios exceed the current electricity tariff in the country using FF sources (US$0.13).

Sensitivity analysis

In view of competing alternative uses of the biomass resources, there is a likelihood of feedstock price inflation. Also, given the lack of statistics in respect of biomass resource prices in relation with biomass electricity generation in the country, and the importance of feedstock over the total cost (50%) of unit of electricity generated through BETs (IRENA 2012), this section will attempt to project the likely changes 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 2: Effect of feedstock price fluctuation during whole life cycle of DC system

Figure 2 reveals the typical effect of fuel price inflation on a DC system. The current WLC/kWh of generating electricity without incentive from BETs varies for DC (US$0.068-0.11) for 100kW and 150kW only, GAS (US$0.05-0.11) and AD (US$0.046 -0.13) for the capacities under study. However, in the event that the feedstocks cost changes by 50%, 75% and 100%, using 12hours supply as the base case, the WLC/kWh of generating electricity from DC will averagely increase by 35%, 52% and 87% respectively. This is similar to other systems in the same order: GAS 13%, 20% and 26%; and AD system 10%, 16% and 21%.

DISSCUSSION

The findings in respect of BETs investment cost especially for 100 kW and above astonishingly reveals that they are cost competitive with majority of recently built fossil fuel (FF) thermal plants in Nigeria representing over US$1,000/ kW despite the fact that they are large scale (many MW) capacities compared with this study's capacities not exceeding 150kW and largely emerging technologies. Hence, BETs are suitable for self-generated energy for bungalow or block of flats accommodation given the capacities evaluated in this study. Furthermore, investment costs structure findings as highlighted in table 3 agrees with IRENA (2012) that "The converter systems usually accounts for the largest share of capital costs". However, the findings disagree with Macdonald (2011) in that the percentage contribution of the generators (secondary converters) to the overall investment cost ranges between 5% - 15% as against average of 34% in this context.

The difference between this research and Macdonald (2011) is that this study focuses on small scale capacities (kW), while his study is on many MW. Hence, economies of scale have significant impact in reducing unit cost of a system. The reason for high cost structure of the conversion systems in this case, is because all the adopted systems are automatic and mobile (especially DC and GAS); with limited permanent civil structure and electrical interconnectivity and less labour utilisation during operation considering the location of usage (rural areas). The technology that has the highest cost of conversion system is the AD, while the lowest is the GAS. This finding disagrees with Evans *et al*., (2010) that "combustion based technologies are more profitable over their life cycle than gasification and pyrolysis". Also, considering all the BETs in this context, none of the scenarios exceed the current electricity tariff in the country using FF sources (US$0.13) other than for a DC system with 50kW capacity. In addition, the findings also reveal that BETs are more economical than FF sources in Nigeria. Hence, this agrees with the study by Mahapatra and Dasappa (2012) and Garba and Kishk (2015) that BETs are cost-competitive with FF sources at present and suitable for providing sustainable electricity not only in developing countries rural areas but also urban centres accommodations without incentive. However, the findings disagree with Evans *et al.*, (2010) that "biomass power production is not cost effective at present". Furthermore, the study finds that the electricity tariff of all the BETs considered will rise in the event biomass fuel prices increase between 50 and 100%. Thus, used of a FIT incentive will assist in mitigating the effect of feedstock price increase; and also, will encourage the participation of investors.

CONCLUSIONS AND THE WAY FORWARD

Energy poverty in Nigerian rural areas resulting from the high cost of gridline network and gridlines network energy loses in the country means there is the need for adoption of sustainable and decentralised ways of electricity provision. Decentralised BETs has been identified as the most suitable means of electricity provision in these communities given the biomass resources availability in relation to their low energy consumption. All the BETs capacities considered in this context are largely economical than FF and suitable for providing sustainable electricity in these communities without incentive except DC (50kW). The investment cost/kW of BETs are as follows: DC (US$ 1427 -2,247), GAS (US$ 1280 – 2489) and AD (US$ 3,529 – 6,451) systems. Also, in the event of BETs adoption and fuel prices increase by 50%, 75% and 100%, the average inflation of WLC/kWh of electricity tariff for DC will be 35%, 52% and 87% respectively.

Similarly GAS cost/kWh will increase by 13%, 20% and 26% and AD system as 10%, 16% and 21%. Hence, utilisation of a FIT incentive will assist in mitigating the effect of feedstocks price increase, and will encourage participation of investors. More so, the FIT incentive utilised in this context is just an indicative as shown in table 2, hence its utilisation should be extended to decentralised energy systems not restricted to only the grid systems. This study is also recommending that government through construction practitioners particularly in developing countries should take advantages of utilising BETs, given the considerable biomass waste generated on construction site to generate low carbon electricity for their use. Further work includes the development of a framework for sustainable electricity provision in Nigerian rural areas. This will be reported in a future paper.

REFERENCES

Bocci, E, Sisinni, M, Moneti, M, Vecchione, L, Di Carlo, A and Villarini, M (2014) State of art of small scale biomass gasification power systems: A review of the different typologies. *Energy Procedia*, **45**, 247-256.

Dasappa, S (2011) Potential of biomass energy for electricity generation in sub-Saharan Africa. *Energy for Sustainable Development*, **15**(3), 203-213.

Demirbas, M F, Balat, M and Balat, H (2009) Potential contribution of biomass to the sustainable energy development. *Energy Conversion and Management*, **50**(7), 1746-1760.

Eberhard, A and Gratwick, K N (2012) *Light Inside: The Experience of Independent Power Projects in Nigeria*. University of Cape Town: The Infrastructure Consortium for Africa.

Evans, A, Strezov, V and Evans, T J (2010) Sustainability considerations for electricity generation from biomass. *Renewable and Sustainable Energy Reviews*, **14**(5), 1419-1427.

Ganesh, A and Banerjee, R (2001) Biomass pyrolysis for power generation: A potential technology. *Renewable Energy*, **22**(1), 9-14.

Garba, A and Kishk, M (2014) Renewable energy technology means of providing sustainable electricity in Nigerian rural areas: A review. *In*: A Raiden and E Aboagye-Nimo (Eds) *Proceedings 30th Annual ARCOM Conference,* 1-3 September 2014, Portsmouth, UK. Association of Researchers in Construction Management, 143–51.

Garba, A and Kishk, M (2015) Economic assessment of biomass gasification technology in Providing Sustainable Electricity in Nigerian Rural Areas. *In*: C Gorse and M Dastbaz (Eds.) *International Sustainable Ecological Engineering Design for Society Conference (SEEDS) Conference,* 17-18 September 2015. Leeds Sustainability Institute, Leeds Beckett University: Leeds, 554-565.

Gonzáleza, A, Ribaa, J-R, Puiga, R and Navarrob, P (2015) Review of micro-and small-scale technologies to produce electricity and heat from Mediterranean forests′ wood chips. *Renewable and Sustainable Energy Reviews*, **43**, 143-155.

International Renewable Energy Agency (IRENA) (2012) Renewable energy technologies: Cost analysis series.

Lemmet, S (2009) *UNEP Buildings and Climate Change: Summary for Decision-Makers*. Available from http://www.unep.org/sbci/pdfs/SBCI-BCCSummary.pdf [Accessed 23rd February 2016]

MacDonald, M (2011), *Costs of Low-Carbon Generation Technologies*. London: Committee on Climate Change.

Mahapatra, S and Dasappa, S (2012) Rural electrification: optimising the choice between decentralised renewable energy sources and grid extension. *Energy for Sustainable Development*, **16**(2), 146-154.

Mandelli, S, Barbieri J, Mereu R and Colombo E (2016) Off-grid systems for rural electrification in developing countries: definitions, classification and a comprehensive literature review. *Renewable and Sustainable Energy Reviews*, **58**, 1621-1646.

Martinot, E (2015) *Renewables 2015 Global Status Report*. Paris: Worldwatch Institute.

Míguez, J L, Morán, J C, Granada, E and Porteiro, J (2012) Review of technology in small-scale biomass combustion systems in the European market. *Renewable and Sustainable Energy Reviews*, **16**(6), 3867-3875.

Oyedepo, S O (2012) On energy for sustainable development in Nigeria. *Renewable and Sustainable Energy Reviews*, **16**(5), 2583-2598.

UNICEF (2011) Nigeria Statics at a Glance Available from http://www.unicef.org/infobycountry/nigeria_statistics.html#119 [Accessed 17th January 2015]

Wang, L, Curtis, L W, Jones, D D and Hanna, M A (2008) Contemporary issues in thermal gasification of biomass and its application to electricity and fuel production. *Biomass and Bioenergy*, **32**(7), 573-581.

Woodward, D and Demirag, I (1989) Life cycle costing. *Career Accountant*, 22-23.

World Bank (2005) World Resource Indicators, Washington DC. Available from http://www.worldbank.org/afr/findings [Accessed 13th May 2014]