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Economic Assessment of Biomass Gasification Technology in Providing Sustainable Electricity in Nigerian Rural Areas

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Abstract

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.

Keywords: Biomass Gasification Technology, Nigeria, Sustainable Electricity, Whole Life Costing.

Introduction

A decade after privatization of Nigeria's power sector (2005) with a bid to increase energy accessibility through participation of private sectors, the current electricity generation capacity is less or equal to the figure (4GW) at the commencement of the privatisation. The country supply accessibility at both national and rural areas represents only 34% and 10% respectively (Ikeme & Ebohon 2005). This was further confirmed in April, 2015 by the current Nigeria Minister of power that "Power generation in the country has risen above

4,000 megawatts after hovering between 3,000MW and 3,800MW since January this year. The country's peak generation was 4,011.4MW, while energy generation was put at 3,540MW and the energy sent out was 3,465MW". This is for a population of approximately 170 million. The major causes of this inconceivable condition of the Nigeria energy sector include investment pattern and limitation, economy of gridline network, insecurity (vandalism) of energy infrastructure, transmission and distribution losses (technical and non-technical) and climate change effect (Eberhard & Gratwick 2012; Iwayemi 1994).

This lack of improvement continues to significantly affect Nigerians by disrupting socio-economic settings particularly in its rural communities where approximately two-thirds of the total country's population reside (Bugaje 2006; Ikeme & Ebohon 2006). Thus, utilisation of fuel wood and charcoal (FWC) has become the main source of energy and constitutes between 32%-40% of Nigeria's total primary energy consumption (Sambo 2009).

The electricity problem of Nigeria's rural areas may not be unconnected to centralised electricity supply system used in the country. This is due to investment factor in extending gridline network to rural areas following low capacity utilisation, low load density, distance of the transmission and distribution from load centres to existing grid point and high cost of electricity generation given the high price of fossil fuel (FF) energy sources (Mahapatra & Dasappa 2012); also, grossly insufficient supply of natural gas (<1/3 of the required 1.2 billion cubic feet/day) to the existing thermal station in the country (Ohunakin et. al. 2011). There is also high-energy loss peculiar to Nigeria as result of deterioration of the transmission and distribution facilities (Sambo 2009), up to around 40% (Dasappa 2011; World Bank 2005).

It is acknowledged that Renewable Energy Technologies (RETs) remain the one and only means of providing sustainable electricity to rural areas. Also, RETs can be utilised where fossil fuel sources in conjunction with centralised grid systems are uneconomical; and suitable for powering small scale demands for low income earners peculiar to rural areas. RETs mostly come in modules, which allows capacity increase if necessary in the future. However, RETs have limitations which include high capital cost, intermittency of sources (peculiar to solar, wind), investment deficiency, inadequate policy framework and unregulated electricity production from biomass may lead to food and fabrics crisis (Sopian et al. 2011; Alazraque-Cherni 2008; Shunmugam 2009 & Kaundiya et al. 2009).

It can be inferred from the above that the major problem of RETs is the high capital cost, as it is unaffordable to the majority of the people even in developed countries, let alone for people in developing nations especially Nigeria's rural communities that live below $1.25/day (UNICEF 2011). Otherwise, why are the authorities providing economic incentives for its application? "Renewables are still expensive and cannot compete on commercial basis with other non-renewables without government support" (Otitoju 2010). Hence, the new realization in electricity generation should be sustainable and affordable to the rural households. Although, there are reasonable amounts of RETs literature in Nigeria, very few researches have been undertaken on economic evaluation of RETs in the country. Oyedepo

(2012) suggested that further research in Nigeria's RETs should cover "life cycle costing and cost-benefit analyses tool and should be undertaken with urgent priority".

In spite of all policies set by the Nigerian government, like rural electrification funds (to expand electricity access in affordable means) and consumer assistance (to protect poor consumers and low income earners), it can be assumed that these programme are not yielding meaningful progress yet, considering the numbers of communities without electricity in the country. Following sustainability assessment of RETs in Nigeria's rural areas based on the study by Garba & Kishk (2014), the research reveals that biomass energy source is the best means of providing sustainable electricity for these communities. The adoption of a decentralised biomass energy source in conjunction with emerging gasification technology in mitigating electricity poverty in Sub-Saharan African rural areas, Nigeria inclusive perhaps may be a more viable option in view of their energy demand characteristics. Furthermore, biomass resources are generally available, without supply chain problems and at less or no cost. Hence, this paper aims to evaluate and optimise the unit cost of generating sustainable electricity through biomass gasification technology (BGT) in Nigeria rural areas.

BIOMASS ENERGY

Biomass energy source is the only renewable and organic petroleum substitute. Biomass resources are in different forms and include animal dung, energy crops, forestry and agricultural residues and Municipal solid waste (Zheng et al. 2010). It is the fourth largest energy source after oil, coal and natural gas and accounts for around 14% of global primary energy source (Martinot 2013; Zheng et al. 2010). Biomass is 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). Biomass either in solid, liquid or gas form can be used for electricity generation, heating and fuel (Moriarty & Honnery 2011; Martinot 2013). This is possible through thermochemical (combustion, gasification, and pyrolysis) and biological conversion processes (IRENA 2012; Demirbas 2001; Bocci et al. 2014)

Biomass application for electricity generation has increased consistently by an average of 13TWh/year from 2000-2008 (Evans et. al. 2010). Biomass electricity (bio-power) global capacity was approximately 83GW by the end of 2012; generating electricity around 350TWh. Bio-power is majorly (90%) generated from solid biomass fuel and the remainder is from landfill gas, biogas and synthesis gas. All the existing commercial bio-power system together produced approximately 1.4% of electricity generated worldwide. The USA is the leading country in generating electricity from this source with capacity of 15GW (18%) and around half of the total capacity is located in Europe (Martinot 2013). However, biomass demerits include inefficient energy gain following conversion, food price increase, huge water application, deforestation etc (Shunmugan 2009; Moriarty & Honnery 2011). For more on biomass problems see Bocci et al. 2014 and Ganesh & Banerjee 2001.

Nigeria Biomass Resources

Nigeria's biomass resources include agricultural residues, animal residue, forest biomass and municipal solid waste. The country's biomass resource potential is approximately 1.2

Petajoule (PJ) as at 1990 but this does not include MSW, biogas and a few other sources (Akinbami 2001); while ECN (2005) projected the resources to be around 144 million tonnes per annum. Considering the Nigeria's vegetation pattern (including forest and savannah), the large parts of the country is cultivatable, particularly in the northern region, and also where there is animal dung/droppings and plant residues. The southern part of Nigeria produces a substantial amount of fuel wood in view of its vegetation arrangement. "Nigeria rural areas biomass resources can generate electricity up to 68,000 GWh/year at 30% availability. However, biomass-effective supply chains and overall affordability will ultimately decide its viability for electrical generation" (Garba & Kishk 2014). Even though at the moment, biomass resources cost little or no price in the rural areas, there is likelihood of feedstock (fuel) cost increasing in the near future in view of the competing utilisation requirements from other sources (animal feed, soil stabilisation etc) whenever the application of the BGT presents itself.

Following lack of commercial energy in the majority of Nigeria's rural areas, these communities use traditional biomass means FWC to meet nearly all their energy needs. This represents in excess of 50 million metric tonnes consumption annually and is in excess of afforestation replenishment programmes in the country (Sambo 2009). Sambo (2009) further argued that the deforestation rate is approximately 3.6% annually. The reduction in forest resources in the country have made fuel wood to be scarce in the rural areas and these communities, particularly women and children, have to travel far in to the forest spending over 4 hours to collect fuel wood for their daily meals. This fuel wood collection is unsustainable considering the time spent, less efficiency (between 5- 12 %), and health effects due to indoor cooking as a result of fuel wood application, which is causing lung problems to over 1.5 million women in developing countries annually. Also, this act is preventing the children from going to school, thereby increasing the illiteracy level in these countries (Sopian et al. 2011; Kennedy-Darling et al. 2008).

Biomass Energy Conversion Technologies

There are numerous technologies available to convert biomass to electricity but these are mainly classified under two headings and include thermochemical (combustion, gasification and pyrolysis) and biological (bio-digester) means. The thermochemical technologies such as combustion, gasification and pyrolysis convert biomass to produce fuel in the form of steam, gas and liquid oil respectively to be utilised in powering plants like Internal Combustion Engine (ICE), gas turbine, generator and fuel cell (Bocci et. al. 2014; Dasappa 2011; Demirbas 2001). Combustion based technology is not suitable particularly for power plants lower than 5MW and has high fuel consumption regime. A small scale gasification system of less than 200kW, using ICE provides superior efficiency around 35% (Dasappa 2011; Fan et al. 2011; Evans et al. 2010). Financially, pyrolysis is the most expensive technology at the moment and has a high operating cost (Evans et.al. 2010). Gasification technology is the emerging biomass conversion technology and is being adopted to improve efficiency and reduce capital cost of biomass electricity generation systems. Also, it can use varieties of feedstock as fuel and cost competitive with FF based power plant (Demirbas 2001). Dasappa (2011) argued that in view of the enormous requirements for generating electricity in Sub-

Saharan Africa, a biomass gasification system is among the best alternatives for the African rural communities.

BIOMASS GASIFICATION TECHNOLOGY (BGT)

Gasification is a thermo-chemical process that 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 major combustible elements of the product gas (PG) are hydrogen, carbon monoxide and methane constituting approximately 45% of the gas (Breeze 2014). The PG is of low caloric value (LCV) containing between 4-6 MJ/kg compared to other fuels such as natural gas between 35-50 MJ/kg due to high nitrogen presence in excess of 50% and other non-combustible constituents.

There are three main gasification technologies including fixed bed, fluidised bed and entrained flow gasifier (IRENA 2012). Considering the low energy utilisation of rural communities only the fixed bed gasifier will be discussed. This is because downdraft gasification technology is basically suitable for small scale power generation ranging from 10 kW to over 100 kW and has been fully commercialised. Also, it has relatively clean gas and low tar (< 10 g/Nm^3) reached in this arrangement; even though the particulates in the gas can be high. Biomass residence time in this configuration is high leading to a high char conversion of approximately 95%. Overall efficiency is low and requires homogenous feedstock to achieve excellent output (Bocci et al. 2014). The entrained gasifier is only used for large application, ranging from 100MW -1,000MW (IRENA 2012); while for application of over 1MW a fluidised gasifier configuration is considered (Bridgwater 2002). BGT can generate electricity at any given time provided there is biomass feedstock availability. It can also provide energy similar to fossil fuel sources for lighting, powering of domestic appliances like refrigerators, television, as well as for industrial applications.

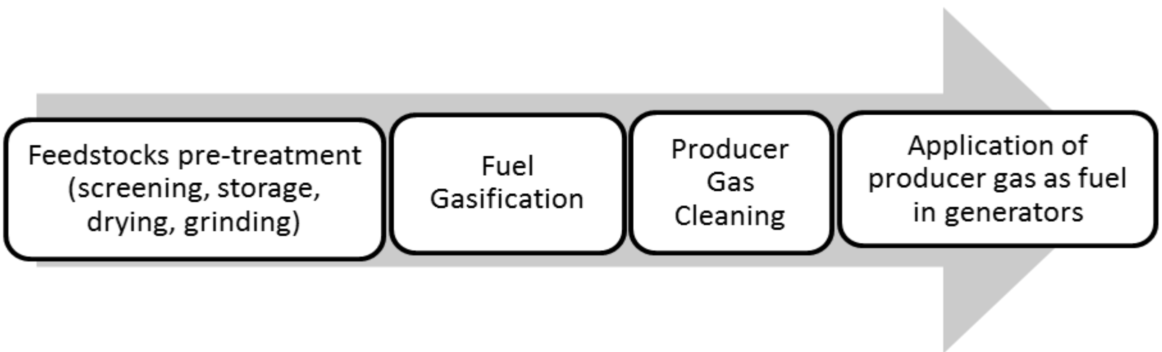


Fig (1): Gasification Processes for Electricity Generation

There are several conditions to be met in selecting appropriate gasification feedstock. The first criterion is the significant availability of biomass resources. Secondly, low humid materials as feedstock (the dryness of the feedstock can be obtained through seasoning or exploitation of power plant heat). Then the size and shape of the feedstocks are also important in order to ensure uniform and consistent feed into the gasifier resulting in consistent and efficient gasification (Bocci et al. 2014). However, the last criterion can increase the operating cost of the whole process. The chemical composition of this feedstock is another factor to be highlighted. The most suitable feedstock for BGT is wood (because of low ash content), maize cobs, coconut shells and rice husks (Bocci et al. 2014; Asadullah 2014). The major economic obstacle of BGT are the ash and tar contents of the resources; meaning the more the ash content, the more gas cleaning exercises, hence increasing operating cost (Bocci et al. 2014). The utilisation of these feedstocks in the gasification process in small gasifier and ICE to generating unit of electricity will require between 1.1 – 1.5 kg/kwh (wood), 0.7 – 1.3 kg/kwh (charcoal) and 1.8 – 3.6 kg/kwh (rice husk) (Mahapatra & Dasappa 2012).

The BGT system sometimes requires a gas cleaning unit mainly because of PG characteristics as highlighted below. The PG used in generating electricity has limitations on the level of impurities concentration to be accepted by the power plant (Asadullah 2014). The wet scrubbing gas cleaning system is the preferred option for ICE generator because the PG must be cool at injection to the engine. While the hot gas filtration gas cleaning system is the best for turbine system (Bridgwater et al. 2002).

The electricity generation from small scale gasification plants is exclusively via Internal Combustion Engines (ICE), but can be burned in combined-cycle gas turbines with better efficiency than the steam turbine driving from biomass combustion (IRENA 2012), and micro Gas Turbines/Fuel Cell (Bocci et al. 2014). This process is mostly for converting wood, wooden and agricultural residues into a gas mixture ready for combustion (Evans et. al. 2010; Demirbas 2001), see figure (1) above for details. For satisfactory ICE operation, the acceptable particle and tar concentration in PG must respectively be < 50 mg/Nm^3 and 100 mg/Nm^3 (Bocci et al. 2014). ICE has matured, fully commercialized and with enough operational experience gain across the world but with limited capacity (< 1 MW) (Bridgwater 1995). BGT electricity costs depend mainly on biomass cost (Mahapatra & Dasappa 2012; Ganesh & Banerjee 2001).

METHODOLOGY

Assessing and optimising the economic competitiveness of BGT in providing sustainable electricity in Nigeria's rural areas is the basis of this study. To achieve this, a Whole life costing (WLC) approach has been used because it systematically sums up the whole cost and revenue related to the asset, from the commencement stage through the operation to the end of the asset. This will allow determining the unit cost of electricity from an energy source. In addition, it can optimize cost of ownership and running of physical assets by representing their present worth value. Furthermore, WLC helps in making the right decisions at the beginning or during the operation of the asset.

The WLC framework proposed by Mahapatra and Dasappa (2012) has been adapted and modified for use in the current study. The reason for selecting this WLC framework is because it is suitable for evaluating biomass energy source. The carbon trading incentive in the framework is not applicable in the Nigerian power sector at the moment, as such it is being replaced with the Feed-in-Tariff (FIT) incentive strategy in the country and details are as shown in table (2) below. Salvage value and inflation are not considered in this study for ease of calculation. The WLC framework is given by:

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

- Where $C_F = (S_C \times f_{con} \times h \times f_C)$, $C_M = (S_C \times f \times M_C)$, $FIT = (L \times h \times n \times I)$

The details of the nomenclature are as follows: C_G is capital cost of gasifier, C_E is capital cost of engine, C_F is annual fuel cost, C_M is annual maintenance cost, S_C is gasifier rating (kg), f_{con} is fuel consumption (kg/h), f_C is unit fuel cost, M_C is maintenance cost of the system, P is present worth factor, d is discount rate, n life of the project, n_1 life of each component, C_R component replacement cost, FIT is annual feed-in-tariff benefit, I is incentive benefit, h annual operation hours, L is load (kW).

The parameters used for the WLC exercise are as shown in table (1-2). The WLC in this study aims to evaluate and optimise the NPV/kWh of generating electricity using BGT for Nigeria's rural areas. A summary of data collected and analysed are presented in table (3) and figure 2- 3.

Biomass Gasification Technology PGE(US$/kW)	=	2,489 - 1280
Fuel Consumption/Kw (Kg/h)	=	1.4
Fuel cost (N/kg)	=	5.71
Gasifier Lifespan (yr)	=	15year
Engine Life (yr)	=	7.5 year
Annual maintenance cost (N/kW)	=	4.84

Table (1): The parameters utilised

	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

Table (2): Proposed Renewable Energy FIT Model in Nigeria (Whole Contract Prices N/kwh) (National Electricity Regulatory Commission 2013)

The cost of BGT components were sourced from the manufacturers directly. This is because the literatures reported wide varying figures. The wide difference didn't change with this research work despite sourcing the prices from manufactures. This problem may not be unconnected with the fact that the technology is still an emerging one; also location factors (more expensive in Europe and America but cheaper in India) as highlighted by Breeze (2014) and O'Connor (2011). Ganesh and Banerjee (2001) confirmed that "gasifiers cost in India is much lower than those elsewhere". The cost prices of BGT components, their accessories and installation figures are presented in table (3). Hence, the prices obtained are classified under high, medium and low rates following the above problem.

The costs are presented in US$ for universal understanding, even though the prices are obtained in India Rupee (INR). At the moment a US$ is exchange for INR 62 and Nigeria Naira (N) is 200. The discount rate used is 13% and the figure has been obtained from Central Bank of Nigeria. The figure used for annual maintenance cost has been adopted from the studies of Mahapatrra and Dasappa (2012) and Banerjee (2006).

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**

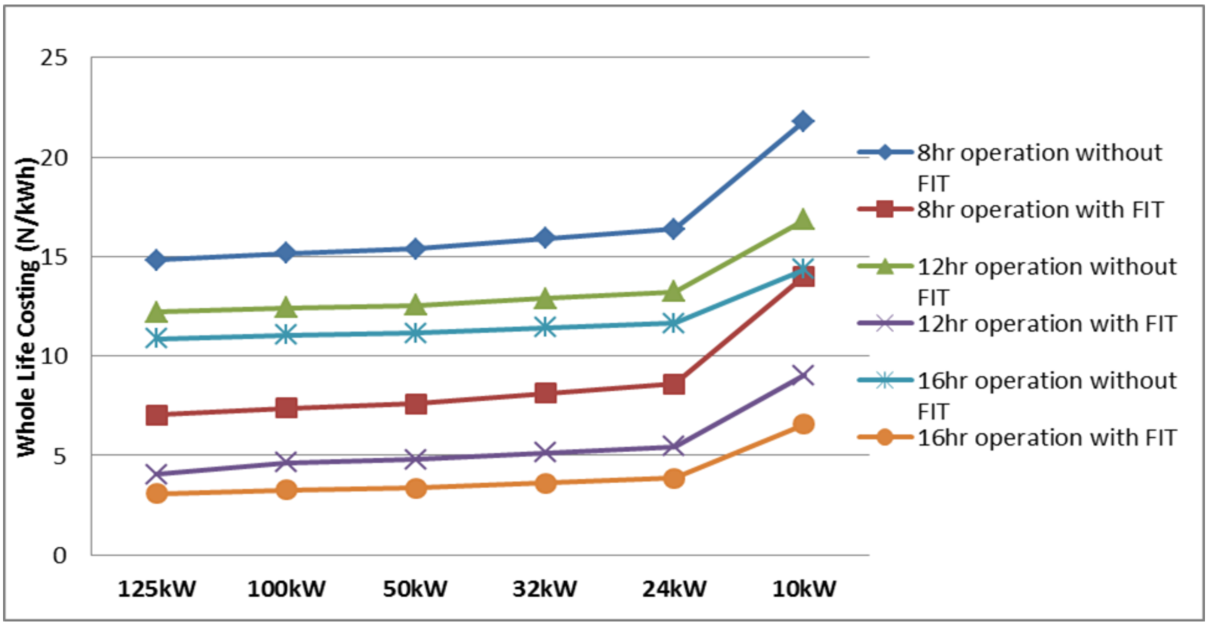
‘Note: DD=Downdraft; PGE= Producer Gas Engine

Table (3): The Cost (‘000)/kW of BGT in Nigeria’s Rural Areas

Fuel wood has been used for this study because of its strategic benefit as highlighted above and the cost price has been obtained from the field survey. A Mitsubishi Canter truck with loading capacity: 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 market with approximately 105kg/unit and each unit is sold at US$3.00. Hence, the unit cost of the wooden fuel is N571/ton. This principle has been adopted for other fuel sources, such as corn stover US$3.85/ton and rice husk US$1.90/ton. The low-price of wooden biomass may be connected to the fact that it is an already established market. The biomass fuel consumption figure utilised reflects averages reported in the literature and as obtained from manufacturers.

Analysis and Discussion

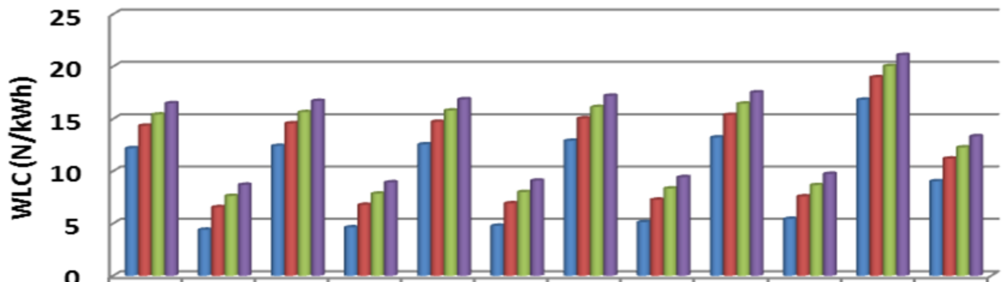
This study considered different capacities of BGT as shown in table (3) above. The unit cost/kW from table (3) above are as follows: *high rate US$2,252-US$3,604, medium rate US$1,289-US$2,489 and low rate US$594-US$1,594.* The high difference noticed is in agreement with IRENA (2012), Nouni et al. (2007), and O'Connor (2011). The economy of scale noticed in the exercise, is indicative that the higher the BGT capacity the lower the cost/kW. In fact the cost reduction between the higher capacity and lower capacity under each of the three rates - higher, medium and low - represent 38%, 49% and 63% respectively.



Rated Capacity (Note -medium rate in table 3 has been adopted)

Figure (2): WLC of electricity from BGT

From figure (2), 6 different system capacities and 3 different operation hours have been considered in this study. The WLC of generating unit of electricity from BGT using 12 operation hours without FIT incentive, the NPV/kWh varies from US$0.06-US$0.084 for capacities between 125Kw – 10kW. Using the same variables as above but with FIT incentive, the NPV/kWh ranges from US$0.02 -US$0.045. The lowest and highest NPV/kWh is 16 hour operation with FIT and 8 hour operation without FIT respectively. The findings also reflect that increase in operational hours and increase in system capacity decrease the unit price of generating electricity using BGT. Hence, the overall NPV/kWh of generating electricity from this study is from US$0.015-US$0.11, with only 8 operation hours at 10kW capacity that exceeds the current unit price of electricity in Nigeria, which is averagely US$ 0.083 using a fossil fuel source. This is in agreement with Mahapatra and Dasappa (2012) and Nouni et al. (2007) that biomass source is cost competitive with fossil fuel sources in generating electricity particularly in developing countries but in disagreement with Evans et al. (2010).



	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

Note: FPC = Fuel Price Change, WIN=With Incentive, NI=No Incentive

Reference: FPC 0% means current fuel price (N 5.71), Daily operation hour: 12hr

Figure (3): Sensitivity analysis (optimising) of WLC of electricity in relation with system capacity, fuel price increase, FIT Incentives, cost of generating electricity

Considering competing alternative uses of the biomass resources in the event of adoption of BGT, there is a likelihood of fuel price changes. The current NPV/kWh of generating electricity without incentive varies from US$ 0.061 – US$ 0.084 for capacities between 125kW -10kw. However, if the prices of the fuel change by 50%, 75% and 100% the cost/kWh of generating electricity from BGT will increase between (US$ 0.072 –US$0.095)-13%, (US$0.08-US$0.10)-20% and (US$0.08 –US$0.11)-27% respectively. This is in agreement with Ganesh and Banerjee (2001) and Mahapatra and Dasappa (2012).

CONCLUSION AND WAY FORWARD

Nigerian rural communities are facing severe electricity shortage as result of the following: investment pattern and limitation, economy of gridline network, insecurity (vandalism) of energy infrastructure, transmission and distribution losses (technical and non-technical) and climate change effect. BGT has been recognised to be the way forward for the current electricity problem, through application of downdraft gasifiers and 100% producer gas engine using wooden fuel. The cost/kW of BGT is as follows: high rate US$2,252-US$3,604, medium rate US$1,289-US$2,489 and low rate US$594-US$1,594. The difference noticed is connected to the fact that BGT is an emerging technology. While the NPV/kWh of generating electricity 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 incentive strategy is from US$0.015-US$0.11. The only scenario that exceeds the current unit price of electricity generation in Nigeria from fossil fuel source, which is on average

US$0.083, is 8 hour operation without FIT incentive at 10kw. In the event of BGT adoption in the country rural areas and the fuel prices increase by 50%, 75% and 100%, the average increase in NPV/kWh will be 13%, 20% and 27% respectively. For successful BGT utilisation, the study recommends that National Energy Policy should be sign into law with a view to guarantee private sector participation, encourage decentralised energy generation and sustainable energy plantation in the country.

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