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Research article

AN ECONOMIC ASSESSMENT OF BIOMASS GASIFICATION FOR RURAL ELECTRIFICATION IN NIGERIA

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Abstract

Considering the rising electricity supply shortages in Nigeria especially the rural areas, it is necessary to explore alternative means of electric power generation. In this context decentralised off grid power generation becomes significant. Since woody biomass is abundant in Nigeria, a wood fired biomass gasifier coupled with an internal combustion engine (ICE) system operating on dual fuel mode is an attractive option.

This paper thus presents the basic concepts and economic analysis of an 80 kWe commercial ready biomass downdraft gasification technology; using net present value (NPV) and Levelized cost of electricity (LCOE) methods. For an estimated investment cost of 4000 $/KW for the dual fuel gasifier based systems, the simulation results to a negative NPV value of $408, 830 and levelized generation cost of 0.5570 ($/kWh) which is three times more than the generation tariff price of electricity in Nigeria thus making the option financially unattractive. Sensitivity analysis indicated that change in the cost of major input parameters by up to ±80% do not bring about any appreciable reduction in the LGC but a 100% offset of the investment cost makes the NPV positive.

Key words: Biomass, Decentralised, Diesel, Economic, Gasification, wood

Acronyms

ACd	Ash content on dry basis
ACF_t	Annualised cash flow
BGPP	Biomass Gasification Power Plant
CF	Capacity factor
DCF	Discounted cash flow

Nomenclature

B	Biomass (kg)
C	Cost of fuel per Litre or kg ($)
D	Diesel (L)
E	Electricity Revenue in yr t ($)
F	Total Fuel consumed by engine

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ICE	Internal combustion engine	G_t	Electricity generated in yr t (kWh)
LCOE	Levelised cost of Electricity {$/kWh}	M	O&M cost ($)
LHVw	Lower Heating Value on wet basis	t	Year under consideration (yr)
MCw	Moisture content on wet basis	T	Company tax rate (%)
NERC	Nigerian Electricity Regulatory Commission	V	Total market value (Debt plus Equity), %
O&M	Operating and maintenance	W	Market value of Equity (%)
PV	Present Value	X	Market value of Debt (%)
SFC	Specific Fuel consumption		
WACC	Weighted average cost of capital		

1. Introduction

Access to a cheap, uninterruptible, and sustainable electricity supply is a precursor for attaining and sustaining socio economic development. In fact it is fundamental requirement for poverty reduction [1]. People without electricity access are constrained to a life of poverty. Nigerians especially the rural dwellers suffer some of the worst forms of electricity poverty in the world [2].

Presently, an average of 48% of Nigerian households (15.3 million) lack access to grid electricity as can be seen in Table 1 [2]; and for those connected to the national grid, supply is epileptic to say the least. Electricity demand has been on the increase geometrically [3] while installed electricity capacity has remained relatively stable over the last decade at 5.9 GW while annual electricity generation stands at between 2Gw to 3GW [3]. This is not enough to meet the current electricity demand forecasted at 10GW [4]. Nigerian rural areas suffer the most electricity deprivation [2].

Table 1: Distribution of households without electricity access in the different geo-political zones of Nigeria (in Percentage) [5]

South West	%	South South	%	South East	%	Nort West	%	North-Centeral	%	North East	%
Ekiti	15.2	Akwa Ibom	38.3	Abia	33.3	Jigawa	56.5	Benue	72.0	Adamawa	71.4
Lagos	0.3	Bayels	36.9	Anambara	38.3	Kaduna	42.4	Kogi	48.1	Bauchi	58.5
Ogun	20.4	Cross River	46.3	Ebonyi	68.1	Kano	56.2	Kwara	38.5	Borno	77.3
Ondo	41.9	Delta	46.3	Enugu	48.5	Katsina	59.7	Nasarawa	70.6	Gombe	55.4
Osun	33.9	Edo	15.2	Imo	12.6	Kebbi	54.4	Niger	56.5	Taraba	88.8
Oyo	38.8	Rivers	21.7			Sokoto	69.5	Plateau	71.3	Yobe	78.0
						Zamfara	77.1				
Average	**25**	**34.1**		**40.2**		**59.4**		**59.5**		**71.6**	

The Nigerian government has expansion plans to increase electricity generation assets to provide rising energy needs engendered by growing Nigerian economy. According to the policy document-The Nigeria Vision 2020 broad vision Program [1], ‘’the Nigerian Government targets to meet the electricity coverage/demand in all sectors of the Nigerian economy including the energy needs of households in rural and urban areas with safe, clean and convenient energy at an affordable cost’’. This entails rural electrification of the hundreds of small communities presently without electricity and far from the existing grid. To attain the vision, it must be done in a technically efficient, economically viable and environmentally sustainable manner using different energy sources, conventional and non-conventional, as well as new and emerging energy sources to ensure good mix and supply at all times with minimal disruption.

Ideally, Extension of electrical grid, where adequate capacity exists, is generally the favoured choice for supplying electricity to isolated areas because it allows for the provision of regular power minimises maintenance costs and maximises reliability and efficiency, compared with smaller stand-alone diesel generators [6]. However With the ongoing restructuring and privatization of the Nigerian electricity industry, it is obvious that for logistic and economic reasons especially under the privatized power sector, extending the grid to rural areas will not be attractive to independent private power investors. Such areas may remain un-electrified for the distant future except an alternative source of energy that is not grid dependent is explored.

Again, when grid extension is not economically feasible, electricity is supplied by decentralised diesel generators [6] However despite low initial investment requirements, the operation and maintenance requirements/expenditures of diesel generators are very high, thus making this technology option unsustainable in isolated rural communities where household income is low and skilled labour scarce.

Under these circumstances, renewable energy technologies, which are relatively easy to maintain, and do not require imported fuel inputs, represent an attractive and cost-effective source of electricity for rural areas where distances are large, populations are small, and demand for energy is low [6].

One of the great promises offered by the renewable energy technologies is their Potential to provide electricity in areas not served by national power grids. Fortunately, Nigeria is blessed with an abundant mix of renewable energy sources such as biomass, solar, wind and hydro-power as shown in Table 2.

Table 2: Estimated Reserves of Renewable Energy sources in Nigeria [1, 7]

Energy Source	Estimated Reserves
Large Hydropower	10,000 MW
Small Hydropower	734 MW
Fuel Wood	39.1 million tonnes/yr
Animal Waste	61 Million Tonnes per yr
Crop Residue	83 Million Tonnes per yr
Solar Radiation	3.5-7.0 KWh/m^2-day
Wind	2-4 m/s at 10m height
Municipal Solid Waste	4.075 million tonnes/yr

Among these options, biomass stands higher in the Nigerian context as the biomass is uniformly spread in the country and biomass based energy has a vital role in the rural life where agriculture is the principal activity [8]

Hydro-power potential of Nigeria is low due to the relative flatness of the country [1]. Wind power generation and its application in Nigeria have certain constraints due to lack of reliable wind speed data and seasonal variation of wind speed. The country has good prospects of utilising solar PV systems for electricity generation, but the high capital investment cost of solar PV is a big barrier for adopting such systems [9].

Nigeria can thus tap its abundant biomass resource for secure, reliable and affordable energy to expand electricity access and promote development.

Biomass is a widespread energy source in Nigeria and many biomass power generation options are mature, commercially available technologies (e.g. direct combustion in stoker boilers, low-percentage co-firing, anaerobic digestion, municipal solid waste incineration, landfill gas and combined heat and power [10].

It is currently the principal global contributor of renewable energy, and has considerable potential to expand in the production of electricity and bio-fuels for transport [10].

There can be many advantages to using biomass instead of fossil fuels for power generation, including lower greenhouse gas (GHG) emissions, energy cost savings, improved security of supply, waste management/reduction opportunities and local economic development opportunities [10]. Additionally, Power from Biomass has the potential to supply half of the total electricity demands in Nigeria especially in the rural areas. Biomass based power offers a highly affordable and viable alternative for bridging the electricity demand/supply gap with the overall benefit of accessibility and availability of electricity for lighting and small-scale industrial related activities, employment and income generation to the rural dwellers and ensuring diversity and security of supplies [10, 11]

Decentralized small-scale electricity production is currently a common practice in many countries of the world, especially where a well-established electricity grid is absent. Globally In 2010, the total capacity of installed biomass fuelled electricity plants was in the range of 54 GW to 62 GW [10] meaning biomass powered generation represented 1.2% of total world power generation capacity and provided around 1.4% to 1.5% of world electricity production [10].

The employment of biomass fuels is a proven option for decentralized small to medium scale electricity generation [12-14]. Nigeria is ideally suited for the development of small-scale biomass energy systems. This work therefore proposes sustainable biomass electricity generation model through Biomass gasification for rural electrification in Nigeria Northern states. This is done by investigating the Nigerian Biomass resource availability, feasible technologies, economic plant size, electricity generation cost, and sensitivity of basic factors of generation. Therefore, the study will not be comparing cost of biomass power and diesel since the low income in rural areas will mean the rural dwellers cannot afford the high cost of diesel based electricity. In particular, this research answers the question, "is **Decentralised Electricity Generation from biomass gasification viable in Nigeria rural areas?** The study estimates the electricity tariff through life-cycle cost of an off-grid electrification project using biomass gasification system and compares it with the tariff currently being charged for grid electricity in Nigeria over the same period.

2.0 Biomass Resource in Nigeria and Utilisation

Nigeria has an estimated population of over 158.3 million in 2010 and it covers a land area of 923,768 square km [15]. The total land available in Nigeria for agriculture and under vegetation is a measure of its biomass potential.

The Nigerian biomass energy resources is estimated to be 144 million tonnes/year [1] and consist mainly of wood, forage grasses and shrubs, animal wastes arising from forestry, agricultural, municipal and industrial activities as well as aquatic biomass.

The distribution of the biomass sources vary according to region with the highest quantity of woody biomass being generated from the rain forest in the south while the guinea savannah vegetation of the north central region generates more crop residues than the Sudan and Sahel savannah zones. Industrial effluent such as sugarcane molasses is located close to the processes with which they are associated. Municipal wastes are generated in the high-density urban areas. Table 3 shows the brake down of estimated biomass resources in Nigeria.

Table 3: Biomass Resources and Estimated Quantities in Nigeria [7]

Resource	Estimated Quantity (Million Tonnes)	Energy Value (000MJ)
Fuel Wood	39.1	531.0
Saw Dust	1.8	31.4
Agro-Waste	11.2	147.7
Municipal solid Waste (MSW)	4.1	-

Over the period 1989-2000, fuel wood and charcoal constituted between 32 and 40% of total primary energy consumption [7]. In year 2000, national demand was estimated to be 39 million tonnes of fuel wood. About 95% of the total fuel wood consumption was used in households for cooking and for cottage industrial activities, such as for processing cassava and oil seeds, which are closely related to household activities. A smaller proportion of the fuel wood and charcoal consumed was used in the services sector

According to the international renewable energy agency, in 2000 and 2009, the total primary energy supply in Nigeria was 3,760.4 PJ and 4,532.3 PJ respectively with biomass representing 83% and 85% of the total respectively as depicted in table4 [15]

Table 4: Total Primary Energy Supply in yrs 2000 and 2009 by Source [15]

Energy source	Primarry Energy Supply (yr. 2000)	Primarry Energy supply (yr. 2009)
Oil and oil Products	10%	9%
Natural Gas	6%	5%
Hydro	1%	0.4%
Biomass	83%	85%

3.0 Biomass to electricity conversion processes/technologies

Electricity can be gotten from Biomass in many ways. The conversion is typically done in two stages; the first stage converts biomass into intermediate fuel using either of biological processes (anaerobic digestion and fermentation), Chemical processes (Fischer-Tropsch and trans-etherification) or Thermal process (gasification, pyrolysis and combustion) [10]. In the second stage, there is a generation engine and the intermediate fuel of the first stage processes are then fed into a generation engine, which converts the intermediate products into electricity/energy.

Theoretically, various possible engines configurations or technology can be used in the second stage process above for the production of electricity/energy such as a combustion unit in combination with a steam turbine, a gas turbine, a Stirling motor, or even a fuel cell or a gasifier coupled to IC engine, steam or gas turbine. Fuel cells are still in an early stage of development and due to their very high cost seem to not be a viable option. Table 5 below shows the comparative technical evaluation of the options [11, 16]. In practice, IC piston engines are almost exclusively used to drive electric generators for the small-scale applications discussed here

Table5: Comparative evaluation of technical options for biomass conversion to electricity [11].

Technology	Efficiency (%)	Relative capital cost per KW	Merits	Limitations
1. Gasifier With generator coupled to IC engine (with producer gas)	15 - 22	1.0	Low cost and simple construction	High maintenance for engine, low fuel flexibility, Suitable for size up to 250 KW
2.Biomass boiler steam engine	<10	15 – 20	Robust design, fuel flexibility, low maintenance cost	Low efficiency, not suitable for installation in rural and remote areas
3.Biomass boiler steam turbine	15 – 24	1.1 – 1.3	Relative high efficiency, robust design, fuel flexibility.	Economically feasible for capacity of 5Mw or higher. Thus unsuitable for small to medium scalee application for rural villages
4.BIGCC with either steam or gas turbine	45 – 55	2.0 – 3.0	High efficiency	Complex design, under R&D
5.Biomethanation followed by ic engine (with menthane)	20 – 25	Under R&	Dlow maintenance cost due tto purer and cleaner gas, simple design, construction and operation	under R&D

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6.External combustion engines	20 – 30	1.2 – 2.0	High efficiency, biomass flexibility	Under R&D

Of the six technologies in table 5 above, two technologies; Gasifier with generator coupled with a dual fuel CI engine operating on producer gas/diesel and Biomass combustion through boiler steam turbine route are the only viable technologies for commercialization of electricity production from biomass [11,16]
Combustion through boiler steam turbine route is a proven, established conversion process and arguably the lowest cost option available today but it is less suitable for flexibly running energy systems because of its low efficiency and flexibility [17]. Additionally, it is economically feasible for capacity of 5Mw or higher [17] and thus unsuitable for small to medium scale application for rural villages that is the objective of this study.

The products of combustion may be passed to steam or hot water boilers. Steam generated may be passed to steam turbine or steam engine driven generators for the production of electricity [16]. Steam engines are robust for installation and operation in rural areas.

Biomass Integrated Gasification Combined Cycle with steam-injected gas turbine despite its expected high efficiency is still at infant stage of development and commercialisation [11].

Gasifier With generator coupled to IC engine represents the best area of focus for this study because the technology is mostly applied in small to medium sized systems [11, 16]. In addition, It is principally well suited for small power plants in the range of <10 kW to >100 kW where flexibility and off grid electricity is a top priority [18].

Biomass gasification technology is appropriate for distributed and decentralized generation in remote villages. There are several different gasification technologies in use or in development, but the small-scale power gasifiers use almost exclusively the downdraft fixed-bed technology [18]. A single biomass gasification unit (with either updraft or downdraft design) can generate up to 500 kW power, while a gasification station (with fluidized bed design) could have capacity of about 5 MW [11].

The following sections discuss briefly the technology the proposed 100 kWe biomass gasification power plant and its technical parameters. Extensive and detailed conversion technology descriptions can be found in literature [10].

3.1 A 100kW$_e$ BIOMASS GASSIFICATION POWER PLANT

Biomass Gasification is the partial oxidation of the biomass at elevated temperature in the presence of steam or low air/oxygen in a gasifier giving rise to the release of a gaseous product called producer gas or syngas. The Producer gas can be used as fuel in both Otto (gasoline) engines and diesel engines to generate electricity. These engines have to be adapted slightly to suit this fuel. While spark ignition (Otto) engines can run wholly on producer gas, diesel (CI) engines generally need co-fueling with conventional diesel fuel. Systems with diesel admixing seem to be more tolerant against fluctuation of the load and of the syngas quality and quantity [19].

A typical dua fuel biomass downdraft gasifier-based power generation system usually is comprised of a biomass gasifier, a gas cooling and cleaning unit, and a dual-fuel-diesel engine-electrical generator as shown in Fig1.

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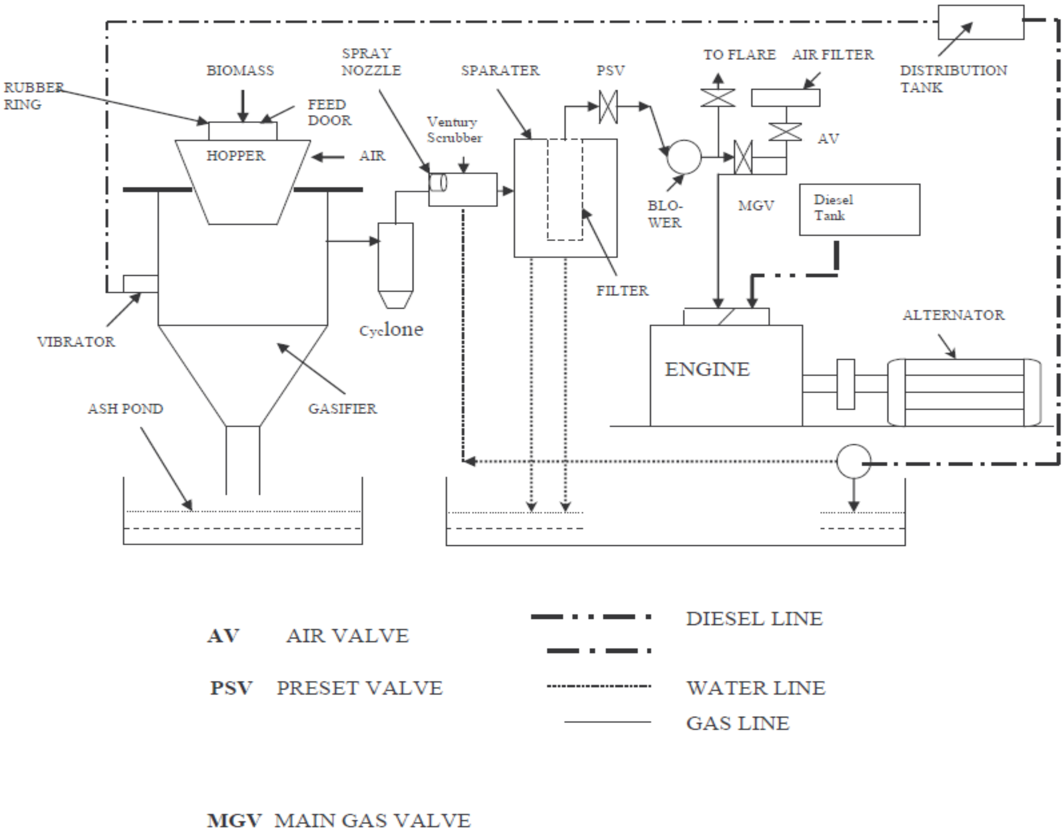

Figure 1: Typical biomass gasifier-based power generation system [19]

3.1.1 SYSTEM DESCRIPTION

The biomass is fed through the feed door and is dried in the hopper. The nozzle is the channel through which limited amount of air goes in. The gasifier is a chemical reactor where a variety of complex processes (physical and chemical) take place. In the gasifier, the biomass gets dried further, heated, pyrolysed, partially oxidised by the limited air and reduced as it flows through it [20] giving rise to the release of a gaseous product called producer gas or syngas. The Producer gas is then cleaned and cooled as it passes the cyclone and scrubber and delivered to the dual fuel engine as a clean gas through the main gas valve (MGV) while the diesel is supplied through the diesel tank. The rate of consumption of the producer gas and Diesel by the Engine varies depending on the mode of operation of the plant. Table 6 shows the detail of the performance parameters of the plant. The gas and diesel is combusted in the engine to produce electricity.

Table 6: Biomass gasifier coupled ICE parameters [11,21]

Parameter	Value
Plant capacity	100kW
Useful life period of components	
a. Engine generator set	20,000 h
b. Biomass gasifier	10,000 h
c. Civil works	20 years
Specific consumption of diesel in dual fuel engine	
a. At 50% rated capacity	0.11 L/kWh

b. At 75% rated capacity	0.10 L/kWh
c. At 100% rated capacity	0.11 L/kWh
Specific consumption of biomass (main fuel) in dual fuel engine	
a. At 50% rated capacity	1.32 kg /kWh
b. At 75% rated capacity	1.21 Kg/ kWh
c. At 100% rated capacity	1.10 Kg/ kWh
Other parameters	
Capacity utilization factor	*25%*
Load factor	*75%*
Auxiliary power consumed[a]	*10%*
Transmission loss	*10%*

A number of gasifier designs exist for use with biomass. The design can be a "fixed bed", "fluidised bed" or "entrained flow" configuration Depending on the mode of biomass–air (or oxygen) contact. The fluidized bed gasifiers is further sub categorised based on the mode of fluidization as; bubbling bed or circulating fluidized bed gasifiers. Entrained bed gasifiers proved unsuitable for biomass material as biomass could not easily ground to the particle size range of 100–400 μm as required for these gasifiers [11]

The syngas is a mixture of CO, H_2O, CO_2, char, tar and H_2, and can be burned after clean up in simple or combined-cycle gas turbines at higher efficiencies than the combustion of biomass to drive a steam turbine. [10]. It can also be reformed to produce fuels such as methanol or hydrogen

Specific fuel consumption of gasifier systems with internal combustion engines depends on the type of raw fuel and ranges between 1.1 – 1.5 kg/kWh for wood and between 1.8 and 3.6 kg/kWh for rice husk gasifiers [18].

Biomass gasification systems offer several advantages over direct combustion systems. Gasification technologies are commercially available and offer the advantages of feedstock flexibility and environmentally friendly technology for low-cost electricity production, compared to combustion systems. Gasification reduces corrosion compared to direct combustion because of the lower temperatures in the gases. Gasifiers can convert the energy content of a feedstock to hot combustible gases at 85% to 90% thermal efficiency. However, despite the commercial nature, only 373 MWth of installed large-scale capacity was in operation in 2010, with just two additional projects totaling 29 MWth planned for the period to 2016 [10]. Thus additional R&D and demonstration efforts in the areas of reduced complexity, cost, efficiency, improving fuel flexibility, removing particulates, alkali-metals and chlorine; and the removal of tars and ammonia [10] are required to be carried out to promote their widespread commercial use. Gasification also provides a route for small scale, decentralised bioelectricity production using gas engines

Gas clean-up

The syngas produced during biomass gasification contains a range of impurities whose percentage depends on the feedstock and the gasification process. When the syngas is used in a boiler or an internal combustion engine, the impurities are not a major problem but when the producer gas is to be used in turbines to achieve higher electric efficiencies, some form of syngas cleaning will be required to ensure the level of impurities in the syngas is reduced to acceptable levels.

It is to be noted that the removal of these impurities and contaminants comes at a cost increases in the capital (the gas clean-up equipment) and operating costs. Since the contaminants tolerance limits for each technology differs, the gas cleanup approach should be examined economically for each specific project. The accurate sizing and selection of feedstocks, gasifier and the generating technology can assist reduce the requirements for gas clean-up

A range of technologies exist to clean up syngas streams. Cyclones can get rid of up to 90% of big particles at realistic cost, but removing smaller particles will need high temperature ceramic or sintered metal filters, or the use of electrostatic precipitators [10].

3.2 FEEDSTOCK REQUIREMENTS

Feedstock requirements for a biomass power facility are dependent upon the capacity of the facility and, to a lesser extent, the efficiency of a specific technology. There are a variety of Biomass feedstocks and their quality or chemical composition varies depending on the plant species. The main characteristics that affect the quality of biomass feedstock are moisture content (MW), ash content (AC) and particle size, and density [10].

Table 7: Typical characteristics of different biomass fuel types being used for commercially for energy production [22]

Type	LHVw (KJ/kg)	MCw (%)	ACd (%)
Baggase	7,700 – 8,000	40 – 60	1.7 – 3.8
Cocoa Husks	13,000 – 16000	7 – 9	7 – 14
Coconut Shells	18,000	8	4
Coffee husks	16,000	10	0.6
Maize			
Cobs	13,000 – 15,000	10 – 20	2
Gin trash	14,000	9	12
Palm oil residue			
Fruit stems	5,000	63	5
Fibres	11,000	40	
Shells	15,000	15	
Debris	15,000	15	
Peat	9,000 – 15000	13 – 15	1 – 20
Rice husks	14,000	9	19
Straw	12,000	10	4.4
Wood	8,400 – 17,000	10 – 60	0.25 – 1.7
Charcoal	25,000 – 32,000	1 – 10	0.5 - 6

High moisture content impacts negatively on the energy content of biomass feedstock. It brings about increase in transportation costs and the fuel cost on an energy basis, as more wet material is required to be transported and provide the equivalent net energy content for combustion [10]. High moisture content can be reduced by natural drying or accelerated means. Other options include torrefaction, pelletising or briquetting, and conversion to charcoal. Table 7 shows the typical properties of biomass fuel types commonly used for commercial energy production [22]

Natural drying is cheap but requires long drying times. Artificial drying is more expensive but also more effective. In practice, artificial drying is often integrated with the gasification plant to ensure a feedstock of constant moisture content. Waste heat from the engine or exhaust can be used to dry the feedstock

Ash content is another important consideration as ash can form deposits or slaggs inside the combustion chamber and gasifier, called “slagging” and “fouling”, which can impede performance and raise costs of maintenance [10]. Grasses, bark and field crop residues typically have higher amounts of ash than wood. Slagging and fouling can be minimised by keeping the combustion temperature low enough to prevent the ash from fusing [10].

The size and density of the biomass feedstock is also important because they affect heating and drying rate during the process. Large particles heat up more slowly than smaller ones, resulting in larger particles producing more char and less tar [23].

TABLE 8: Biomass Power Generation Technologies and Feedstock Requirements

Biomass conversion technology	**Commonly used fuel types**	**Particle size requirements**	**moisture content requirements (wet basis)**	**average capacity range**
Stoker grate Boilers	Sawdust, non-stringy bark, shavings, end cuts, chips, hog fuel, bagasse, rice husks and other agricultural residues	6 – 50 mm	10 – 50%	4 to 300 MW many in 20 to 50 MW range
Fluidised Bed Combustor (BFB or CFB)	Bagasse, low alkali content fuels, mostly wood residues with high moisture content, other. no flour or stringy materials	< 50 mm	< 60%	Up to 300 MW (many at 20 to 25 MW)
Co-firing: pulverised coal boiler	Sawdust, non-stringy bark, shavings, flour, sander dust	< 6 mm	< 25%	Up to 1500 MW
Co-firing: stokers fluidised bed	Sawdust, non-stringy bark, shavings, flour, hog fuel, bagasse	< 72 mm	10 – 50%	Up to 300 MW
Fixed bed (updraft) Gasifier	Chipped wood or hog fuel, rice hulls, dried sewage sludge	6 – 100 mm	< 20%	5 to 90 MW_{th}, + up to 12 MWe
Downdraft, moving Bed Gasifier	Wood chips, pellets, wood scrapes, nut shells	< 50 mm	< 15%	~ 25–100 KW
Circulating Fluidised Bed, dual vessel, Gasifier	most wood and chipped agricultural residues but no flour or stringy materials	6 – 50 mm	15 – 50%	~ 5 – 10 MW
Anerobic Digesters	animal manures & bedding, food processing residues, mSW, other industry organic residues	NA	65% to 99.9% liquid depending on type (i.e. from 0.1 to 35% solids)	

The feed stock requirement for biomass power generation depends on the type of conversion technology in use. Some combustion technologies can accept a wide range of biomass feedstocks, others require much more homogenous feedstocks in order to operate. Stoker and CFB boilers can accept higher moisture content fuel than gasifiers. In anaerobic digestion, so many options are obtainable, including high solids-dry, high solids-wet or low solids-wet. In the case of a low solids-wet configuration, such as with manure slurry, the solids content can be 15% or less. Details of the feedstock requirements for the various biomasses to power technologies are summarised in table 8 below [10]

4.0 Economic viability

A power plant should generate a reliable supply of electricity at a possible minimum cost to the investor and consumer. The cost of generation is determined by so many factors principal among them is the investment or capital cost of biomass power projects which is made up of cost of; gasifier, engine generator, civil works, biomass preparation unit, electricity distribution network and electrical and piping connections to the site of gasifier installation.

Other factors which also influence the cost of power generation are (1) O&M cost (M) covering salaries and wages, overhauling equipment, repairs including spare parts, water, lubrication and miscellaneous expenses, (2) Fixed costs mainly Interests, depreciation (D), taxes (T), (3) Fuel costs (F) i.e unit price of biomass and supplementary fuel, i.e. diesel (4) capacity factors (CF), gasifier and generator useful life, and (5) KWh_{net} of electricity sent out per year (G). These factors may vary from country to country.

Though several options exist for checking the fiscal performance of an investment power project, the recommended indicators in the electricity industry for checking viability of decentralised electricity generation system namely the levelized generation cost (LGC) and the net present value *(*NPV) [24] is applied here.

4.1 Methodologies

Our costing analysis employs the DCF analysis approach to estimate the LCOE using BGPP and compares it with the cost of paying for grid-electricity [N30/kWh ($0.20/kWh) [4] over the same period assuming grid-electricity was available. The method is kept simple and transparent to aid revision by readers wishing to use different economic assumptions.

The simulation is carried out using a Microsoft Excel spreadsheet model that identifies the revenues necessary to recover invested capital, cover annual O&M expenses (M), and provide investor a return on their investment.

The LCOE is calculated by discounting the net cash flows of the project to the equivalent net present value costs at the first year the plant commenced operation and dividing the result by the yearly revenue of electricity sales over the project life time.

We present hereunder approaches and formulas applied in the excel model:

For a system whose annual electricity output (G_t) or savings remains constant over time, the equation for LCOE is [10,25-26]]

$$LCOE = \left(\frac{TLCC}{G_t}\right) UCRF \qquad \left[\frac{\$}{kWh}\right] \qquad (1)$$

Where

$$UCRF = \left[\frac{d(1+d)^N}{(1+d)^N - 1}\right] \qquad (2)$$

d is the inflation-adjusted discount rate reflecting the current money market, it is called nominal discount rate or the post tax WACC .

$$d = WACC = \frac{W \times R_e}{V} + \frac{X \times R_d}{V}\,(1-T)$$

An inflation-adjusted interest rate is obtained from the expression:

$$d = [(1 + d_r)(1 + e)] - 1 \qquad (5)$$

When the discount rate in the absence of inflation, (d_r), and e the inflation rate is known. If a real discount rate is used, cash flow is expressed in constant dollars while for a nominal discount rate, d; cash flow is expressed in current dollars [25].

TLCC would be obtained by discounting all the significant dollar costs over the life of the project to a **base** year using **present** value analysis. **Any** revenue generated from the resale of the investment **is** also discounted to the base year and subtracted from present value costs. i.e.

$$TLCC = I_{PV} + (1 - T)(F_{PV} + O\&M_{PV}) - T(D_{PV}) \qquad (3)$$

The PV subscript in the equation above means present value of the item involved.

The total investment cost (I) of a biomass energy conversion system is made up of cost of fuel conversion system or gasifier cost (C_G), cost Prime mover (C_{PM}), engineering and construction work costs (C_w) and cost of accessories and miscellaneous C_A and is estimated thus;

$$I = (C_G + C_{PM} + C_{CW} + C_A) \quad [\$]$$

This cost is annualized using the discount factor method as:

$$I_{PV} = \sum_{t=0}^{N} \frac{(C_G + C_{PM} + C_{CW} + C_A)}{(1+d)^t} \qquad (4)$$

The O&M costs (M) consist of labour charges, scheduled maintenance charges, routine component/equipment replacement cost

The operating and maintenance cost (M) expressed in terms of the fixed and variable O&M cost is:

$$M = FO \times KW_{rated} + VO \times KWh_{year} \qquad (5a)$$

M can also be calculated as fraction of the capital cost as follows [11]:

$$M = K_G C_G + K_C C_{PM} + K_{CW} C_{CW} + K_A C_A + 8760 \times CF \times MP_n W_r \qquad (5b)$$

Where FO is fixed O&M cost, VO is variable O&M cost and K represents the fraction of the capital cost of each item of biomass gasification power plant that is used for its operation and maintenance, MP_n is the number of manpower required *and* W_r is the Nigerian wage rate for manpower.

The cost of fuel (F) is determined by summing the cost of biomass used by the gasifier and the cost diesel used by the prime mover while factoring in their specific fuel consumption

$$F = 87600 \times CF \times KW_{rated}[C_D SFC_D + C_B SFC_B] \qquad (6)$$

Annual amount of electricity (G_t) sent out by the power plant in KWh net is given by

$$G_t = KW_{rated} \times 87600 \times CF \times \left(1 - \frac{G_{aux}}{100}\right) \times (1 - MLF) \qquad (7)$$

Where G_{aux} is the percentage power consumption by the auxiliaries, KW_{rated} is the rated or installed output and 87600 = 24 X 365 days per year and MLF is the marginal loss factor, to allow for the amount of electricity losses in transmission networks

Substituting equations 2, 3, & 4 into equation 1 reduces the LCOE equation to

$$LCOE = \frac{\sum_{t=1}^{N} \frac{I_t + (1-T)(F_t + M_t) - TD_t}{(1+d)^N}}{\sum_{t=1}^{N} \frac{G_t}{UCRF}} \qquad (11)$$

$$NPV = \sum_{t=1}^{N} \frac{ACF_t}{(1+d)^t} = \sum_{t=1}^{N} \frac{(1-T)(E_t - M_t - F_t) + TD_t - I_t}{(1+d)^t} \quad (12)$$

4.2 Key economic assumptions and parameters

Total capital cost or installed cost – The total investment cost of a biomass gasification conversion system with all the ancillaries in table 9 plus allowance for importation and freight charges is estimated by NERC as 4000 $/kwh [26]. Full installation cost will be based on this figure. Because Nigeria does not have any biomass power plant practical experience, and a lack of data, estimates of the percentage shares of the various cost components from a previous study as shown in table 9[10] is used.

Table 9: Biomass gasification Investment cost breakdown (2010 US $).

Item	Capital cost ($/kW)	Proportion of cost
Consultancy/Design	325.4	6%
Civil works	705.1	13%
Fuel handling/Prep	325.4	6%
Electrical/balance of plant	217.0	4%
Converter system(gasifier)	3362.9	62%
Prime Mover (Engine)	488.2	9%
Total	**4000**	**100%**

1USD = N150

Discount rate (d) - The discount rate used is the nominal post tax WACC of 17% as recommended by NERC [26]

Plant/equipment depreciation method – used straight line over 20 years

Whole Sales feed in price per kwh – assumed N30 ($0.20) per kwh based on a recommendation by NERC for Wholesale Feed-in-Tariff for Biomass Power Plant. Government subsidised rural consumer sales price ranges from N11 to N12A per kWh. So for rural consumption, sales price per kwh more than $0.07 per kWh will be considered too expensive for the rural dwellers while Sales price per kwh below $0.20 (holding all other variables constant) would not be economically feasible for an investor.

Fuel costs – Cost per delivered ton of biomass – assumed an average price of N3 per kg (USD 0.025/kg) based on estimate from an earlier study in 2003 [27] escalated to its supposed cost in 2010 USD using inflation rate of 3% and cost of diesel used is the prevailing market price of diesel in Nigeria which is N140 per litre (0.93 US $/L). Other economic parameters used are shown in table 10

Table 10: Economic parameters for the BGPP [26]

parameter	Value
Investment Cost[a]	4000 $/kW
Fixed O&M [a]	56 $/kW-yr
Variable O& M [a]	5.17 $/ MWh
Electricity tariff	0.17 $/kWh
Fuel Cost	

a.woody biomass	*0.024 $/kg*
b. Nigerian Diesel	*0.7190$/L*
Inflation rate (e)	8%
Fed Income tax (T)	32%
Risk free rate (R_f)	18%
Capital from Debt (D)	70%
Capital from equity (E)	30%
Nominal Cost of debt (R_d)	24%
Nominal return on equity (R_e)	29%
Nominal after tax WACC (d)	17%

Source:[gud re, NERC]
1USD = ₦150

4.3 Calculations and results

Using above methodology the result of the analysis shows that investment in Biomass gasification power plant will bring many economic dividends to the rural dwellers. However, from financial point of view, investing in biomass gasification systems for electricity generation in Nigerian remote villages is not profitable. A negative net present value of -US$ 408,830 is estimated indicating a huge financial loss; and a levelized generation cost of US$/kWh **0.557013** which represents approximately three times the tariff set by NERC. Other financial indicators tested do not support the investment. Figure 2 shows the composition of the total cost per generated electricity for the components of the BGPP for Nigerian conditions. It is clear that investment and fuel are the components with greater cost.

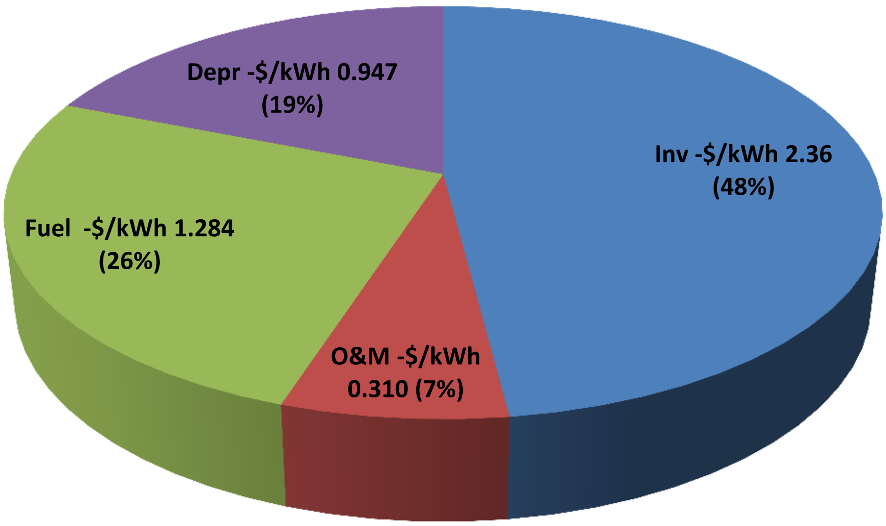

Figure 2: Share of the total life cycle cost (BGPP, load factor 75).

4.4 Sensitivity analysis

The values of the BGPP key variables such as capital cost, capacity factor , O&M cost, Fuel cost and discount rate used in the computation represent only a single point in a large parameter space. To further check the validity of the results as well as allow the user to generalize the effect of these factors, the economic analysis was conducted by varying the values of the key variables mentioned above by a factor of ±200%. Figure 3 Depicts How Changes In these Variables affects the LCOE. The baseline for this diagram is a LCOE of $0.5/kWh.

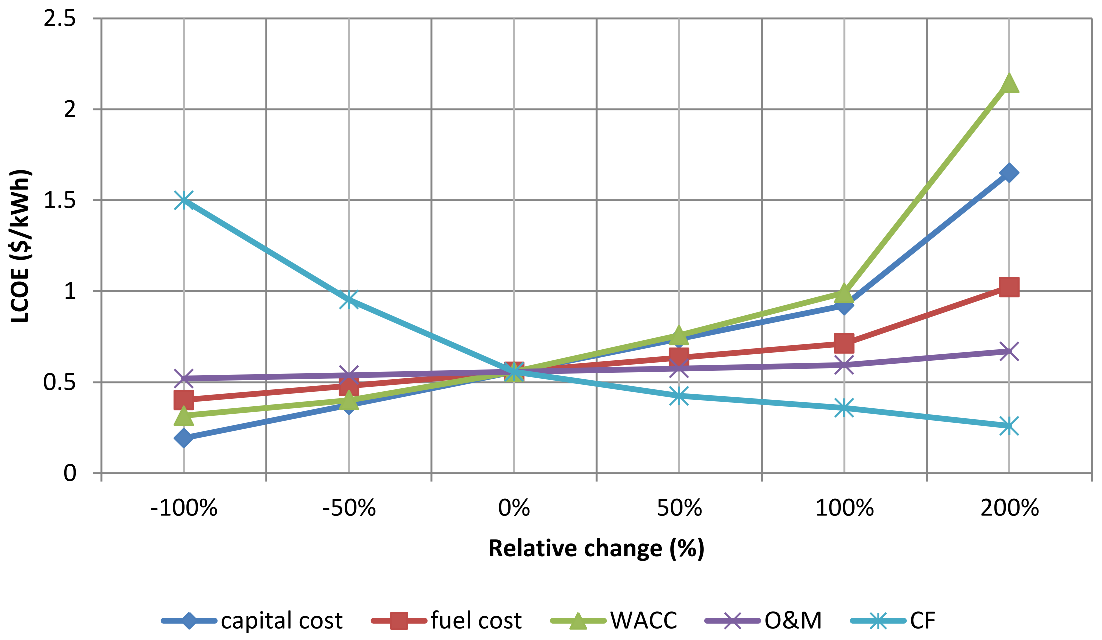

Figure3: Effect of changes of key variables to LCOE

5.0 Conclusion

In line with the Nigerian government's target of ensuring biomass contribute a sizeable percentage of the electricity generation mix in Nigeria by 2015, an economic analysis (EA) of a conventional biomass to electricity process was conducted, based on a commercial ready technology; biomass downdraft gasification, using External combustion (EC) engine operating on dual fuel (diesel/syngas).

The simulation results showed that the estimated Diesel/Biomass prices for the dual fuel gasifier based systems result in electricity selling prices higher than the tarrif price of electricity in Nigeria for the 2012-2017 multiyear tariff order as fixed by NERC.

The results obtained are consistent with most of the research conducted on the cost-effectiveness of biomass gasification systems, which find that even though biomass systems result in negative NPV values and high Levelized generation costs, they represent economic and the least-cost choice technology for electrifying rural areas where there is no extension of electricity grid. Diesel based electricity generating systems are the most cost effective option for a cluster of dwellings where the house hold income and per capita electricity demand are relatively high. Nevertheless, use of diesel does not only contribute to pollution, but since the rural dwellers cannot afford diesel since they are poor, any rise in energy demand may not be large enough to validate installing diesel generators.

The specific conclusions as also concluded by other authors [11 - 14] include the following:

1. Biomass gasification technology posses a huge potential as a decentralized power generation system in meeting the energy needs of the Nigerian rural dwellers like domestic lighting, running of irrigation pumps and small-scale commercial activities such as floor mill and other rural micro enterprises.

2. The main life cycle costs areas of BGPP are 1) the investment cost which is 48% of the total life cycle cost. 2) The fuel cost (cost of diesel and biomass) which is 26% of the TLCC. 3) Depreciation expenses which is 19% of the TLCC and 4) O&M cost which is 7% of the TLCC
3. The conventional BGPP process is not commercially competitive at this scale unless we use locally generated bio-diesel in place of expensive diesel

4. Sensitivity analysis indicated that:

a. Very low investment, O&M costs and Fuel costs are required to make the technology economically viable.

b. Reducing the capital costs through use of locally made Engine may significantly reduce the costs

c.. The plant capacity factor is a very important parameter. The plant needs to be operated close to rated capacity to derive the best in terms of efficiency and cost of power generation.

It is therefore recommended that :(1) An accurate estimate of the potential biomass resource base in Nigeria should be undertaken for implementation of a decentralised biomass gasification power plant (2) To ensure there is a steady supply of woody biomass for the project, a plot of land should be set aside and planted with trees to guarantee the source of raw material without a threat of deforestation (3)Government of Nigeria should grant financial incentives to any power investor interested in investing in renewable energy technologies especially Biomass power plant to encourage it adoption and development in Nigeria.

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