Design and Feasibility Study of a 5MW Bio-Power Plant in Nigeria

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Abstract- This work established the techno-feasibility of building a bio-power plant in Nigeria using 50 ton sugarcane bagasse to produced 130 MWh at a capital cost of $ 89 million, an operating cost of $ 81 million and an energy generation cost of 0.07 $/kWh. A biomass-fired combined heat and power technology (CHP) was adopted for the conversion of sugarcane bagasse to electricity. In the analysis of the bio-power plant, the heating value, energy generation and power supply duration were estimated and were used to determine the equipment cost. Both total capital investment and cost of operation were determined and used for the assessment of the plant profitability. These were done with the aid of a Matlab and Microsoft Excel 2013. The establishment of this plant was found to have net profit of $ 26 million, net present worth of $ 191 million, discounted payback period of 3.5 years, and return on investment of 29%. These show that the investment will be economically viable if established in Nigeria based on the project parameters adopted. This will help in alleviating the problems of power supply in the country. Also, this will link agriculture to energy industries which will also boost the investment in the agriculture and engender rural community development.

Keywords Economic Feasibility, Bio-power Plant, Bagasse, Bioenergy, Renewable Energy.

1. Introduction

1.1. Background of study

Biomass, being a renewable resource, is a natural choice for the power industry and is good for the environment. The use of biomass has potential of linking agricultural and energy industries. This engenders rural development and alleviate poverty in developing countries. Recent reports indicate that the use of bio-power is widely spread across about 62 countries of the world. From Diji *et al* [1], it was reported that USA was rated as the major producer (26 % of world production), followed by Germany (15 %), Brazil and Japan (both 7 %). Nigeria being a country that majorly depends on hydropower has been known for years to be facing several challenges in its energy sector. Some of these challenges are lack of constant power supply, low voltage of power supplied, and high cost of electricity. This has contributed in growth of many manufacturing and textiles industries in Nigeria and other African countries.

Hence, this study will tend to device a means of addressing the challenge through the conversion of agricultural waste to electricity otherwise known as bio-power production.

1.2. Biomass and Nigeria Biomass Resources

Biomass as the basic feedstock for bio-power production was defined as a term used to describe all plant derived materials in a given area especially when considered as an energy source [2] Many previous research works has shown that biomass can be used to generate energy by direct combustion or by conversion of the plant materials to either a liquid or a gaseous fuel.

These biomass resources includes agricultural crops, wood, charcoal, grasses and shrubs, residues and wastes (agricultural, forestry, municipal and industrial), and aquatic biomass. Report from Obioh and Fagbenle [6] shows that Nigeria has a total biomass potential consisting of animal and agricultural waste, and wood residues.

Furthermore, Agba *et al* [7] research revealed that bio-energy reserves and/or potential of Nigeria stood at: Fuel wood of 13 million hectares, animal waste of 61 million tonnes per year and crop residues of 83 million tonnes.

Hence, the report of Obioh and Fagbenle [6] and Agba *et al* [7] confirmed that Nigeria has enough biomass resource that will be needed to meet the needs of a bio-power plant establishment and will be able to complement the existing hydro-power plant. Therefore, the aim of this work is to analyses the design and economic feasibility of establishing bio-power plant in Nigeria. This will be a useful information for potential investors in this sub-energy sector of the economy.

1.3. Nigeria Agricultural Land Area and Use

According to The World Factbook [27], Nigeria with a population of about 186 million and a growth rate of 2.44 % has a total land area of 923, 768 km^2 (comprising 910, 768 km^2 of land and 13,000 km^2 of water). Out of this total, approximately 37.3 % is arable, 7.4 % is under permanent crop, 33.3 % is under permanent pasture, 9.5 % is under forest and woodland and approximately 0.3 % (2,930 km^2) is under irrigation. Fig. 1 shows land use estimates in Nigeria. Agba *et al* [7], Abiodun [8] and Osaghie [9] reported that this indicator shows that there is high potential for the production of agricultural produce which are bioenergy/biofuel feedstock.

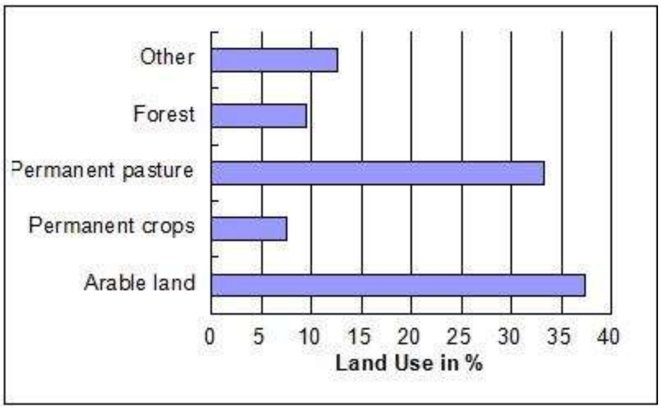

Fig. 1: Land use estimate in Nigeria.

From the perspective of available land and wide range of biomass resources, Nigeria has significant potential to produce bioenergy and even become an international supplier. Elijah [11] reported that bioenergy feedstock is not only abundant in Nigeria, it is also widely distributed.

1.4. Energy Consumption and Supply in Nigeria

The study of Nigeria energy consumption and or supply conducted by EIA [12] shows that oil has 13 %, natural gas has 6 %, hydropower has 1 % and biomass has 80 % as shown in Fig. 2. This high share represents the use of biomass to meet off-grid heating and cooking needs, mainly in rural areas. It's important to note that estimates of traditional biomass consumption are imprecise because biomass sources are not typically traded in easily observable commercial markets.

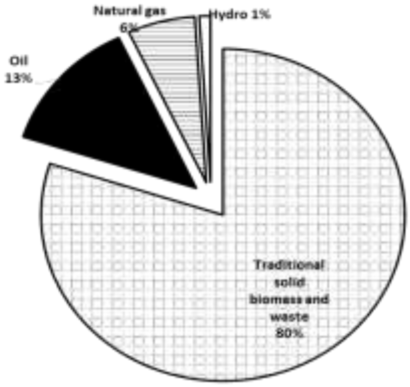

Fig. 2: Total primary energy consumption or supply in Nigeria [12].

It was also noted that biomass provides 14 % of the world’s energy resources or about 28 million barrels of oil equivalent per day (Mboe/day) and is the most important source of energy in developing countries.

The electrification rate in Nigeria is estimated at 41 % leaving approximately 100 million people in Nigeria without access to electricity [13].

1.5. Bioenergy – Energy from Biomass

Bioenergy is a form of renewable energy; it denotes the use of organic material (biomass) as a source of energy for power generation and direct source heat applications in all energy sectors including domestic, commercial and industrial purposes as well as the production of liquid fuels for transport.

Biomass releases carbon dioxide (CO_2) and small amounts of other greenhouse gases when it is converted into another form of energy. However CO_2 is absorbed during the regrowth of the restored vegetation through photosynthesis process.

A conventional combustion process converts solid biomass through direct burning to release energy in the form of heat which can be used to generate electricity and heat. Chemical conversion processes breaks down the biomass into fuels, in the form of biogas or liquid biofuels, which are then used for electricity generation and transport. Generally it can be accomplished through biological, thermal and chemical processes. There are four major ways in which biomass is converted into usable energy sources. These are fermentation to produce bioethanol, burning to produce heat/electricity, bacterial decay to produce biogas, and conversion to electricity.

Moreover, report from IEA [14] shows that Nigeria is the 3rd world largest user of bioenergy with 3582 PJ and bioenergy has a share of about 80 % of the total primary energy consumed in Nigeria. Although, Nigeria is not enlisted among the countries that generates electricity from bioenergy and uses biofuels. Therefore, in order to make our environment friendly and sustainable for human habitations, both government and private sector has to invest in bioenergy for the generation of electricity in Nigeria.

1.6. Bio-power

Bio-power (or biomass power) is electricity produced from biomass fuels. Biomass-fired plants have been explored, both in developed and developing countries. There are also several biomass-fired and co-fired plants across Europe and America [15]. Biomass-based power systems are unique among non-hydro renewable power sources because of their wide range of applicability to a diverse set of needs. Biomass systems can be used for village-power applications in a 10–250 kW scale, for larger scale municipal electricity and heating applications, for industrial application, in agricultural applications such as electricity and steam generation in the sugar cane industry, and for utility-scale electricity generation in the 100 MW scale. Biomass-based systems are the only non-hydro-renewable source of electricity that can be used for base-load electricity generation.

1.7. Different Technologies of Producing Bio-power

There are basically two modes of utilizing biomass for electricity production. The first is by a dedicated use of biomass, while the second is by co – firing biomass with an existing fossil fuels plant. And this co-firing can be done by direct, indirect or paralleling means as show in Fig. 3.

Fig. 3: Different Biomass Co-firing Configurations [15].

The technology for the primary direct use of biomass for electricity production is direct combustion, gasification, pyrolysis and biochemical degradation.

Combined heat and power (CHP), also known as a co-generation, is the simultaneous production of electricity and heat from one source of energy. CHP systems can achieve higher overall efficiencies than the separate production of electricity and heat when the heat produced is used by industry and/or district heating systems (Fig. 4). Biomass-fired CHP systems can provide heat or steam for use in industry (e.g. the pulp and paper, steel, or processing industries) or for use for space and water heating in buildings, directly or through a district heating network [15].

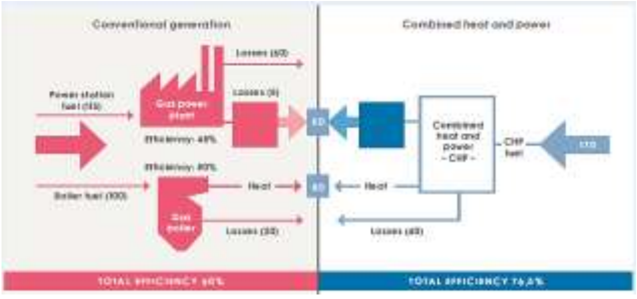

Fig. 4: An Example of Efficiency Gains from CHP [15].

The viability of biomass CHP plants is usually governed by the price of electricity and the availability and cost of the biomass feedstock. Although many sources of biomass are available for co-generation, the greatest potential lies in the sugar cane and wood processing industries, as the feedstock is readily available at low cost and the process heat needs are onsite [15, 16].

2. Research Approach

This research adopts the use of biomass-fired combined heat and power (CHP) technology for the conversion of sugarcane bagasse to electricity. This was due to its high overall efficiency reported by John [17] as 70 % which was recorded as the highest compared to other available technologies. John [17] also reported that biomass CHP was advantageous due to its low capital cost, low operating and maintenance cost and high efficiency of power generation. Direct combustion system was chosen for the biomass firing.

In Diji [3], it was reported that direct-combustion system (43%) was the most efficient, followed by gasification (40%) and the least effective technology was pyrolysis (31%) for energy conversion from biomass to electricity. The sketch for the bagasse bio-power plant is shown in Fig. 5.

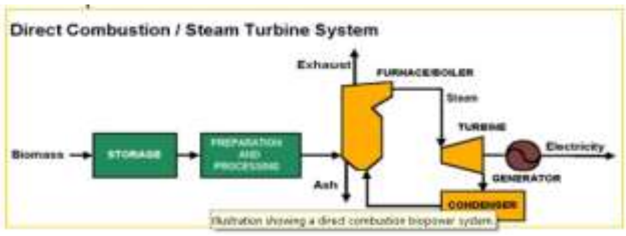

Fig. 5: Direct Combustion system [3].

The choice of the plant capacity was made based on the average available amount of bagasse in Kaduna State from the report of NASS [18]. This is important because it will minimize the investment risk which will maximize return.

This research analyzed the feasibility of establishing a biopower plant with the aid of a Matlab and Microsoft Excel 2013 spreadsheet .

2.1. Analysis of the Bio-power Plant

Here, the estimated value of the heating value, energy generation and duration of the power supply were determined first after which the total equipment cost were then determine using unit capital cost from a reference source together with the chosen plant capacity. Both the total capital investment and plant cost of operation were evaluated after which the profitability analysis of the plant was carried out using decision criteria for investment with the aid of Matlab programming and the use of the project parameters and assumptions presented below in order to assess its worth.

```
%PARAMETER
disp('DESIGN & INVESTMENT PARAMETER')
d = 355; %days/year for operation
w = 18500; %amount of minimum wage in NGN/month
x = 199; %dollar conversion factor in NGN/$
S = 0; %subsidy on electricity
TR = 0.20; %tax rate
Pr = 0.37; %profit rate
p = 25; %economic or project life in years
r = 0.10; %discount rate using straight line discounting method
%Current electricity unit price: 0.102 $/kWh or 20.26 NGN/kWh (KEDCO)
%Salvage value: 20.00 % (Sinnott, 2008)
%Depreciation method:   Straight Line  (Richardson et al.(2012))
%Depreciation period:   10 years
CF = 0.94; %capacity factor (Mott, 2011 and IRENA, 2012)
PC = 5*10^3; %plant capacity in kW
FM = 0.45; %fuel moisture
HHV = 17.0*10^6; %heavy heating value (HHV) in J/kg range 15.6-19.4
LHV = 16.0*10^6; %lower heating value (LHV) in J/kg range 15.0-17.9
OJ = 10; %no of plant operation jobs (John, 2008)
CT = 1.5; %construction time in years (John, 2008)
s = 20/x; %feedstock/fuel cost(sugarcane) in NGN/kg
UCC = 2540; %unit capital cost in $/kW (John, 2008)
WG = 18500; %minimum wages in NGN/month
FD = 50000; %kg/h
```

2.1.1. Estimation of Heating Value, Energy Generation and Daily Supply Duration

Using the average quantity of sugarcane available on daily basis (50 tonnes), with a moisture content of 0.45 for the bagasse; the daily heat available from the sugarcane bagasse was estimated using equation from Diji [3] where heating value is determined as the product of (1 - moisture), heavy heating value (HHV) and feed rate (FD):

```
   HA = (1-FM)*HHV*FD/10^9 %GJ
%Since the power to be generated is PC (MW) the duration of daily supply (DR)
%will be: DR in hour = heating value (kJ)/power generated (kW)/3600
   h = HA*10^6/PC/3600 %in hours
%Daily energy generation
   EC = PC*h %in kWh
%Annual power generation
   PG = CF*PC*h*d %in kW
%Annual Energy generation
   EG = CF*EC*h*d %in kWh
```

2.1.2. Total Capital Cost (TCI) Estimation

The capital investment was estimated using the data collected from the report of John [17] about the different cost of equipment for different power capacities. The total equipment cost (PCE in $) was estimated using the product of unit capacity cost (UCC in $/kW) and plant capacity (PC in kW) while the inflation factor was computed as follows using the ratio of the present and previous worth of dollar:

```
%Equipment costing using, PCE = UCC * plant capacity
PCEo = UCC*PC %purchased cost of equipment (John, 2008)
PCE = PCEo*199/160 %PCE due to inflation in dollar
```

Table 1: Sources of Data for TCI Estimation

Items	**Source of data**
Direct Plant Cost (DPC) Purchased cost of equipment, Equipment installation, Piping installation, Electricity installation, Instrumentation and control, Building and services, Excavation and site preparation, Auxiliaries/service facilities, Land survey & cost	[19] and [26]
Indirect Plant Cost (IPC) Field & construction expense, Engineering & supervision.	[19] and [26]
Other Plant Cost (OPC) Contractor's fee, overhead and profit, Contingency, Working Capital (WC).	[19] and [26]

Factor method was adopted in determining the value of the fixed, working and total capital with reference to different source reported on Table 1 and the Matlab programme stated below:

```
%DIRECT PLANT COST
   f(1) = 1.00*PCE; % Purchased Cost of Equipment Delivered (PCE)
   f(2) = 0.39*PCE; % Installation Cost for Equipment
   f(3) = 0.31*PCE; % Piping Installed
   f(4) = 0.10*PCE; % Electrical Installed
   f(5) = 0.13*PCE; % Instrumentation & Control Cost
   f(6) = 0.29*PCE; % Battery-limits building and service
   f(7) = 0.10*PCE; % Excavation and site preparation
   f(8) = 0.55*PCE; % Auxiliaries/Service Facilities
   f(9) = 0.06*PCE; LD = f(9); % Land Survey & Cost
%Total direct plant cost (DPC)
      f(10) = sum(f(1:9));  DPC = f(10);

%INDIRECT PLANT COST
   f(11) = 0.25*DPC; % Field & Construction Expense
```

```
   f(12) = 0.35*DPC; % Engineering & Supervision
%Total Indirect Plant Cost (IPC)
   f(13) = sum(f(11:12));  IPC = f(13);
%Total Direct & Indirect Plant Cost (DIPC)
   f(14) = DPC+IPC;  TPC = f(14);
%OTHER PLANT COST
   f(15) = 0.05*TPC; % Contractor's fees, overhead, profit
   f(16) = 0.10*TPC; % Contingency
%Total fixed-capital investment
   f(17) = TPC+f(15)+f(16);  FCI = f(17)
%Working Capital
  f(18) = 0.05*FCI;  WC=f(18)
%Total Capital Investment for this project was estimated to be TCI
   TCI = FCI+f(18) % Total Capital Investment
```

2.1.3. Cost of Operation (COP) Estimation

This estimation for the cost of operation of bio-power plant was done with the used of relevant data sourced from the references presented in Table 2 for each items with the aid of a Matlab programme stated below:

```
   tol=0.0001;    km=1000;    COPo=58*EC/1000; %in $/MWh
   err=0.02;    k=0;
while err>tol & k<km
      COP=COPo;

%DIRECT MANUFACTURING COST (DMC)
%Feedstock (FS) i.e. Sugarcane cost
   %FS = quantity * unit price * hr * days
   FS = FD*(s/x)*h*d; %Annual feedstock/fuel cost in $
%Operating Labor (OL)
   %OL = no of operators * unit wage * months
   OL = OJ*(w/x)*12; % Annual Operating Labour Cost in $
%Direct Supervisory & Clerical Labor (DS)
   DS = 0.12*OL; %with reference to Richard et al.(2012)
%Utilities Cost (UT)
   UT = 0.12*OL; %with reference to Richard et al.(2012)
%Maintenance & Repair (MR)
   MR = 0.02*FCI;%with reference to Richard et al.(2012)
%Operating Supplies (OS)
   OS = 0.10*MR;%with reference to Richard et al.(2012)
%Laboratory Charges (LC)
   LC = 0.12*OL; %with reference to Richard et al.(2012)
%Patents & Royalties (PR)
   PR = 0.02*COP; %with reference to Richard et al.(2012)
%Direct Manufacturing Cost
   DMC=FS+OL+DS+UT+MR+OS+LC+PR;
%FIXED MANUFACTURING COST (FMC)
%with reference to Richard et al.(2012)
%Depreciation
   m(14) = 0.1*FCI; DP = m(14);
%Local taxes
   m(15) = 0.02*FCI; LT = m(15);
%Insurances
   m(16) = 0.002*FCI; IS = m(16);
%Plant Overhead (PO)
   m(18)=0.5*(OL); PO=m(18);  %With Reference to Sinnotti (2005)
%Fixed Manufacturing Cost
   m(5) = sum(m(14:18)); FMC = m(5);
%GENERAL EXPENSES(GE)
%Administration cost
   m(20)=0.177*OL+0.009*FCI; AC=m(20);
%Distribution & Selling Cost
   m(21)=0.10*COP; DC=m(21);
%Research and Development Cost
   m(22)=0.05*COP; RD=m(22);
%General Expenses
   GE=sum(m(20:22));
   COPF=0.28*FCI+2.73*OL+1.23*(UT+FS);
   err=max(abs((COPF-COP)/COPF));
   k=k+1;
   COPo = COPF;
end
%Cost of Operation with discount
   COP=COPo
%Cost of Operation without discount
   COPd=0.18*FCI+2.73*OL+1.23*(UT+FS);
```

Table 2: Sources of Data for the COP Estimation

Items	**Source of data**
Direct Production Cost (DPC) Raw Material, Operating Labor, Direct Supervisory & Clerical Labor, Utilities Cost, Maintenance & Repair, Operating Supplies, Laboratory Charges, Patents & Royalties	[10], [18], [19], [22] and [26]
Fixed Manufacturing Cost (FMC) Depreciation, Local taxes, Insurances, Plant Overhead	[19] and [26]
General Expenses (GE) Administration Cost, Distribution & Selling Cost, Research and Development Cost	[19] and [26]

2.1.4. Power Generation Cost

Using the cost of plant operation, power generated and energy produced, the cost power generated was estimated while the cost of selling a unit of energy was taken to be 0.102 $/kWh (20.26 NGN/kWh) as stated in the Matlab programme below:

```
%POWER GENERATION COST
%Power generation cost in $/kW
   PGC = COP/PG
   PGCn = COP/PG*x %in NGN/kW
%Energy generation cost in $/kWh
   EGC = COP/EG
   EGCn = COP/EG*x %in NGN/kWh
%Unit selling price for electricity in $/kWh
   SPv=0.102 %(1+Pr)*EGC*(1-S)
```

SPvn=SPv*x %in NGN/kWh

2.2. Analysis of Project Profitability

The proposed projects were analysed for profitability and feasibility using the following investment criteria for evaluation:

2.2.1. Payback period (PBP)

The time taken to recoup the capital invested in a project was calculated using Matlab command (PBP = interp1q(CNDCF, y,(LD+WC)) - 2; DPBP = interp1q (CDCF , y, ((LD+WC)/(1+r)^p)) - 2;) to determine the period required, after start-up, to recover the fixed capital invested, FCI for the projects with reference to Richard *et al* [19]. The value of PBP and DPBP were deduced using non-discounted and discounted cash flow respectively.

2.2.2. Net present worth (NPW)

The net cash flow from the start of the investment to the end of the useful life time of the project with a defined discount rate in a specific time (that is, present time) was calculated using Equation (1).

$$NPW = \sum[(Bn-Ct)/(1+r)^t] \quad (1)$$

2.2.3. Return on investment (ROI)

The amount of return on an investment relative to investment's cost was calculated using Equation (2).

$$ROI = NP/TCI * 100\% \quad (2)$$

2.3. Sensitivity Analysis of the Bio-Power Plant

In this analysis, some uncertainties were incorporated by varying the key parameters of the projects while observing their corresponded decisions. Using the parameters presented in Table 3, the effects of the following factors on the decision criteria for investment or the proposed project profitability were examined:

(a) Effects of variation in fuel heavy value and choice of plant capacity,

(b) Effects of change in fuel rate and cost ,

(c) Effects of change in tax rate and electricity unit price.

Table 3: List of Factors examined and their Levels

Factors	Unit	Low	Mid	High
Heavy Heating Value	MJ/kg	15	17	19
Plant Capacity	MW	5	10	15
Feed Rate	Ton/h	25	50	75
Fuel/Sugarcane Cost	NGN/kg	10	20	30
Electricity Unit Price	$/Liter	10	15	20
Government Tax	%	10	20	30

The sensitivity of different factors listed above were analysed using one-factor-at-time (OFAT) design of experiment approach with Table 3 displaying various variation levels, from which the effects of different factors on response variables such as cost of operation (COP), energy generation cost per kWh (SPv), net present worth (NPW), payback-period (PBP) and return on investment (ROI) for bio-power generation in Nigeria were examined.

3. Results and Discussions

Here, the results collected are presented and discussed below:

3.1. Energy Generation Assessment

Table 4: Results of Energy Generation

Variable	Amount
Fuel Rate, s (ton/h)	50.00
Heating Value, HA (MJ/kg)	467.50
Supply Duration, H (hr)	25.97
Daily Energy Produced, EC (MWh/day)	130.00
Daily Power Produced, PC (MW/day)	4.70
Annual Power Generated, PG (GW/yr)	43.30
Annual Energy Generated, EG (GWh/yr)	1,130.00

The assessment of energy generated of the 5 MW bio-power plant with capacity factor 0.94 or (94 %) IRENA [15] reported on Table 4 shows that 50 tonnes with heating value of 467.50 MJ/kg would be able to produced 4.7 MW or 130 MWh per day. Based on the project parameters, the annual generation will be 43.3 GW or 1,130 GWh. This was in agreement with that which was report of Clean Energy Council [21] for power generation from bagasse. These results confirm that it would be able to power an area whose daily energy demand is not greater than 130 MWh per day.

3.2. Profitability Assessment of the Plant

Fig. 6: Cash Flow Diagram Analysis
(**Note:** NDCF means Non-discounted cash flow, CNDCF means Cumulative non-discounted cash flow, CDCF means Cumulative discounted cash flow).

In Table 5, it was reported that at the fuel cost 20.00 NGN per kg, the total plant capital and operating cost was $ 89.4 million and $ 80.9 million respectively. It was also deduced that the cost of power and energy generation was 1.87 $/kW (or 371.35 NGN/kW) and 0.07 $/kWh (or 14.30 NGN/kW) respectively.

At 20 NGN/kWh, the fixed price of electricity unit, the analysis of the plant profitability with reference to Fig. 6 confirms that the net profit (NP) would be as high as $ 25.8 million, the discounted payback period (DPBP) would be as low as 3.45 years, the net present worth (NPW) would be as high as $ 191 million, while the return on investment would be 28.9 %.

Table 5: Results of Profitability Assessment

Variable	**Amount**
Fuel Cost, FD (NGN/kg)	20.00
Capital Cost, TCI (M$)	89.40
Operating Cost, COP (M$/yr)	80.90
Power Generation Cost, PGC ($/kW)	1.87
PGC in (NGN/kW)	371.35
Energy Generation Cost, EGC ($/kWh)	0.07
EGC in (NGN/kWh)	14.30
Electricity Unit Cost, SPv ($/kWh)	0.11
SPv in (NGN/kWh)	20.00
Net Profit, NP (M$/yr)	25.80
Payback Period, DPBP (yr)	3.46
Net Present Worth, NPW (M$/yr)	191.00
Return on Investment, ROI (%)	28.85

This assessment confirms that the investment would be economically viable. This was due to the fact that its DPBP was low, and NPW was positive.

3.3. Effects of Variation in Fuel Heavy Heaving Value and Choice of Plant Capacity

From results reported in Table 6 displaying the effects of change in heating value that as its changes from 15 to 17 and 17 to 19 MJ/kg, it was observed that the duration power supply rises from 23 to 29 hour, COP rise from $ 74 to $ 87.6 million, the quantity of both power generated and energy produced rises as well while the TCI remain constant. This was because the amount or quantity of electric power to be produced depends largely on the heating value of the feedstock or fuel. This means the lower the heating value the lower the generated power quantity. In the case cost of generation, a fall from 0.08 to 0.06 $/kWh was observed, this was due to the high amount of energy generated using lesser cost of fuel.

Moreover, it was deduced that as this changes hold in the heating value of the fuel, the economic parameters such as NP, NPW, and ROI was observed to be rising while a fall was observed in the case of DPBP. This confirms that heating value of the fuel play an important role in the decision making of the plant.

Considering the effect or sensitivity of the changes in the plant equipment capacity as presented on Table 6, it was deduced that as the capacity rises from 5 to 10 MW and from 10 to 15 MW with a constant fuel rate, cost and heating value at 20 NGN/kWh fixed electricity unit price, both the daily power and energy generated was observed to be constant, the power supply duration falls from 26.0 to 8.6 hours, the annual power generated remained unchanged while the energy generated annually falls from 1,130 to 375 GWh/yr. This was due to the constant fuel feeding rate and the fall observed in the daily supply duration.

It was also observed as that the capital, operating and generating cost rose from $ 89.4 to $ 268 million, $ 80.9 to $ 90.6 million and 0.07 $/kWh (14.30 NGN/kWh) to 0.24 $/kWh (48.04 NGN/kWh) respectively. This rise observed was inferred to be as a result of the increasing change in the plant capacity as constant fuel feeding rate with falling power supply duration.

Table 6: Results of Heavy Heating Value (HHV) and Plant Capacity (PC) Sensitivity

Variables\Cases	**HHV (MJ/kg)**			**PC (MW)**		
	15	**17**	**19**	**5**	**10**	**15**
HA (GJ)	412.50	467.50	522.50	467.50	467.50	467.50
H (hr)	22.92	25.97	29.03	25.97	12.99	8.66
EC (MWh/day)	115.00	130.00	145.00	130.00	130.00	130.00
PG (GW/yr)	38.20	43.30	48.40	43.30	43.30	43.30
EG (GWh/yr)	876.00	1,130.00	1,410.00	1,130.00	563.00	375.00
TCI (M$)	89.40	89.40	89.40	89.40	179.00	268.00
COP (M$/yr)	74.20	80.90	87.60	80.90	76.20	90.60
PGC ($/kW)	1.94	1.87	1.81	1.87	1.76	2.09
PGCn (NGN/kW)	385.96	371.35	359.80	371.35	349.99	415.87
EGC ($/kWh)	0.08	0.07	0.06	0.07	0.14	0.24
EGCn (NGN/kWh)	16.84	14.30	12.40	14.30	26.95	48.04

SPv ($/kWh)	0.10	0.10	0.10	0.10	0.10	0.10
SPvn (NGN/kWh)	20.00	20.00	20.00	20.00	20.00	20.00
NP (M$/yr)	11.10	25.80	43.00	25.80	-15.70	-42.3
DPBP (Yr)	7.05	3.46	2.17	3.46	NaN	NaN
NPW (M$/yr)	70.20	191.00	333.00	191.00	-173.00	-414.00
ROI (%)	12.44	28.85	48.07	28.85	-8.79	-15.76

Note: *NaN means not-a-number or infinity

Moreover, from results collected on Table 6, the plant was found to be unprofitable as the plant rose from 5 MW to 10 MW and from 10 MW to 15 MW at fixed fuel feeding rate (50 ton/h), fuel cost (20 NGN/kg) and electricity unit cost (20 NGN/kWh). This was because the DPBP become infinity (NaN which mean Not-a-Number or uncountable), NPW becomes negative (that is from $ 191 to - $ 414 million), and ROI becomes negative as well (that is from 28.9 % to – 15.8 %).

3.4. Effects of Change in Fuel Rate and Cost

The study of Table 7, it was deduced that as the fuel cost (that is, sugarcane) price rises by 100 % from 10 to 20 and 50 % rise from 20 to 30 NGN/kg, it was observed that heating value (HA), power supply period, power/energy generated, total capital investment (TCI) remain unaffected while cost of operation (COP) keep rising from $ 52.4 to $ 109 million.

Meanwhile, the changes caused the net profit (NP) to fall from $ 48 to $ 3 million, discounted payback period (DPBP) to increase from 1.94 to 21.6 years, net present worth (NPW) to falls from $ 379 to $ 3.21 million, and return on investment (ROI) to falls from 54.4 % to 3.4 %. These deductions revealed that, the fall in the economic benefit of this project was due to the rising cost of fuel and plant operation which has made the cost of energy generation expensive at the fixed electricity unit price (stated by the regulating body).

The deductions from the results displayed on Table 7 for the effects of the fuel feed rate rising from 25 to 50 ton/h and from 50 to 75 ton/h were:

One that the heating value raises from 233.75 GJ to 701.25 GJ, the power supply duration rises from 12.99 to 38.96 hr which was as a result of the increment in the heating value of the fuel fed.

A rise in daily energy supply, annual power and energy generation was observed as the fuel feed rate rises. While the capital cost remain constant ($ 89.4 million), the cost of operation rose from the $ 38.1 to $ 152.0 million, this was due to the increasing duration of power supply/production recorded.

Table 7: Results of Feed/Fuel rate and Fuel Cost Sensitivity

Variable\Cases	**Feed rate (ton/h)**			**Fuel Cost/Sugarcane (NGN/kg)**		
	25	**50**	**75**	**10**	**20**	**30**
HA (GJ)	233.75	467.50	701.25	467.50	467.50	467.50
H (hr)	12.99	25.97	38.96	25.97	25.9722	25.9722
EC (MWh/day)	64.90	130.00	195.00	130.00	130.00	130.00
PG (GW/yr)	21.70	43.30	65.00	43.30	43.30	43.30
EG (GWh/yr)	2,810.00	1,130.00	2,530.00	1,130.00	1,130.00	1,130.00
TCI (M$)	89.40	89.40	89.40	89.40	89.40	89.40
COP (M$/yr)	38.10	80.90	152.00	52.40	80.90	109.00
PGC ($/kW)	1.76	1.87	2.34	1.21	1.87	2.52
PGCn (NGN/kW)	350.14	371.35	465.65	240.49	371.35	502.20
EGC ($/kWh)	0.14	0.07	0.06	0.05	0.07	0.10
EGCn (NGN/kWh)	26.96	14.30	11.95	9.26	14.30	19.34
SPv ($/kWh)	0.10	0.10	0.10	0.10	0.10	0.10
SPvn (NGN/kWh)	20.00	20.00	20.00	20.00	20.00	20.00
NP (M$/yr)	-7.88	25.80	81.90	48.60	25.80	3.00
DPBP (Yr)	NaN	3.46	1.19	1.94	3.46	21.60
NPW (M$/yr)	-86.60	191.00	654.00	379.00	191.00	3.21
ROI (%)	-8.81	28.85	91.63	54.35	28.85	3.36

Note: *NaN means not-a-number or infinity

These changes resulted in the fall of the cost of energy generated from 0.14 $/kWh (26.96 NGN/kWh) to 0.06 $/kWh (11.95 NGN/kWh) which thereby brought about rise in the net profit from - $ 7.88 to $ 81.9 million, NPW from - $ 86.6 to $ 654 million and ROI from – 8.81 % to 91.63 %. While in contrast, a fall was reported for DPBP from infinity (NaN) to 1.19 year.

This confirms that the rising effect of fuel feed rate will further makes the investment become more profitable unlike the rise effect of fuel cost which rather cause more losses to the investment than benefits.

3.5. Effects of Change in Tax Rate and Electricity Unit Price

With reference to results on Table 8, it was deduced that the changes in tax rate and electricity unit cost does not affect heating value (HA), power supply duration (H), energy or power generation (EG or PG), total capital investment (TCI), cost of operation (COP) and generation cost at a fixed unit price of electricity. The variables mentioned earlier were constant while tax rate and electricity unit price were changing because the government tax and fixed electricity unit price does not affect production stage. Instead its only affect the process of trading that is, the process of buying and selling energy generated in the plant.

Table 8: Results of Electricity Unit and Tax Sensitivity

Variable\Cases	**Electricity Unit Price (NGN/kWh)**			**Tax (%)**		
	10	**15**	**20**	**10**	**20**	**30**
HA (GJ)	467.50	467.50	467.50	467.50	467.50	467.50
H (hr)	25.97	25.97	25.97	25.97	25.97	25.97
EC (MWh/day)	130.00	130.00	130.00	130.00	130.00	130.00
PG (GW/yr)	43.3	43.3	43.3	43.3	43.3	43.3
EG (GWh/yr)	1,130.00	1,130.00	1,130.00	1,130.00	1,130.00	1,130.00
TCI (M$)	89.40	89.40	89.40	89.40	89.40	89.40
COP (M$/yr)	80.90	80.90	80.9	80.9	80.9	80.9
PGC ($/kW)	1.87	1.87	1.87	1.87	1.87	1.87
PGCn (NGN/kW)	371.35	371.35	371.35	371.35	371.35	371.35
EGC ($/kWh)	0.07	0.07	0.07	0.07	0.07	0.07
EGCn (NGN/kWh)	14.30	14.30	14.30	14.30	14.30	14.30
SPv ($/kWh)	0.05	0.08	0.10	0.10	0.10	0.10
SPvn (NGN/kWh)	10.00	15.00	20.00	20.00	20.00	20.00
NP (M$/yr)	-1.94	3.18	25.80	29.00	25.80	22.60
DPBP (Yr)	NaN	20.43	3.46	3.11	3.46	3.88
NPW (M$/yr)	-182.05	4.63	191.00	220.00	191.00	162.00
ROI (%)	-21.75	3.55	28.85	32.46	28.85	25.25

Note: *NaN means not-a-number or infinity

Moreover, this rise in tax rate reduces the net annual profit, net present worth, return on investment and internal rate of return but increases the period of payback. These factors were affected because they are either directly or indirectly dependent on tax rate. This confirms also that rise in the unit of tax rate will always not favour this investment viability while fall in the tax rate will favour it.

The rise in the electricity unit price resulted in a rise in the net annual profit from - $1.94 to $ 25.8 million, net present worth from - $ 182 to $ 191 million and return on investment from – 21.75 % to 28.85 % while DPBP shortens from infinity (NaN) to 3.46 years. These factors were affected because they are either directly or indirectly dependent on electricity unit price. These deductions inferred that a rise in electricity unit price will be always favor while fall in the price will not favour the bio-power plant investment based on project conditions.

4. Conclusions

Based on the deductions made from this research, it was confirmed that 5 MW bio-power plant using 50 ton/h of fuel at the cost of 20 NGN/kW will produce 130 MWh of energy per day from its plant operation.

The profitability assessment confirms that it would be economically viable due to its good net profit (25.80 M$/yr), positive net present worth (191.00 M$/yr), high returns on investment (28.85 %) and shorter payback period (3.46 yr).

Moreover, the sensitivity analysis reveals that a fuel with heavy heating value and low cost will favour the investment viability. It also reveals that rise in plant capacity will always demand additional fuel input in order to make the investment viable. Further analysis confirms that change in unit price of electricity will significantly affect the investment viability while government tax would not significantly affect the profitability of the investment of the power plant.

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