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Evaluating the Energy Cost Benefit of a Biomass Fired Combined Heat and Power Plant

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Abstract

The feasibility of a proposed project is essentially determined by the economic savings accruing to the project in other to justify the huge capital investment to be made. This study investigated the economic potential of incorporating a back pressure steam turbine, steam generator and other auxiliary components into a process system in the Nigerian Institution of Oil Palm Research (NIFOR). Data from a proposed project with electricity generation capacity of 3.625MW reported in a research work was used. From the economic/financial analysis conducted in this study, it was observed that with an estimated capital investment of $2, 000,000, there would be a cash inflow of $388, 990.362 per annum. It was also observed that electricity demand by NIFOR from the National Grid would drop from 1443200kWh to 1051380.8kWh per month, consequently reducing the cost of electricity and savings to $488, 990.362 per annum. The internal rate of return is 36.42% while the simple payback period for which the project would payback itself is 5.14yrs after which the plant would continue to generate more revenue for the Institution. The Net Present Value (NPV) is also positive which ultimately indicates that the proposed project is essentially valuable based on the financial analysis and therefore should be adopted by the Nigerian Government and the private investors.

1. Introduction

Basically, the generation of several forms of useful energy such as heat and electricity can be referred to as combined heat and power (CHP), which of course, is in a single integrated system. According to Novakovic, [1], a combined heat and power plant applies heat energy emanating from the combustion of fuel to produce mechanical power for electricity generation. Equipment such as compressors, pumps and fans are utilised in combined heat and power system. In the Catalog of CHP Technologies [2], it was reported that heat energy from the process can be used to generate hot air, steam, hot water, and also chilled water for adsorption cooling process. Again, Novakovic [1] also reported that the efficiency of a conventional electricity production increases by the use of process waste heat through combined heat and power (CHP) technology. District heating systems can be achieved through waste heat, thus decreasing the need for electricity during heating applications. If biomass fuel, which is said to be carbon neutral, is used to fire a CHP power plant, the attendant issues associated with greenhouse gas emission could be a thing of the past. Scarlat et al., [3] also reported that higher efficiency can be achieved during the production processes of combined heat and power unlike it is in separate production of heat and power.

According to Yablecki et al.[4], CHP system is considerably accepted for small scale level. In Dong et al. [5], small and micro-scale biomass CHP systems was reviewed. Also, the research work discussed the technological options and scope for the application of biomass power systems at small-scale level. Yeblecki et al. [4] in his study also reported and proposed a model for power generation ranging between 250 kW and 5 MW. The report further stated that this can be achieved through effective biomass management and utilization at small-scale level. Pantaleo *et al.,* [7] presented a scenario where CHP plants fired by natural gas and solid waste biomass were used. They evaluated the thermo-economic benefit at small scale (100 kWe) level. Again, Pantaleo *et al.*[7] further assessed the trade-offs between: (a) lower energy conversion efficiency and higher investment cost of high biomass input rate. (b) higher primary energy savings and revenues from bio-electricity feed-in tariff (in case of high biomass input rate).

In Sipila et al., [8], a research study on small scale district heating and biomass CHP plant was carried out. Sipila et al., reported that CHP in Finland have the potential to generate 214MW of heat and 80MW of electricity with 6000 hours of annual peak load time. Essentially, the study established the profitability of investing in a small scale CHP plant fired by biofuel. From their result, when a biofuel-fired boiler is placed among the options for heat production, the economic feasibility scale remains relatively large for biofuel-fired CHP plants. Rezaur [9] presented a feasibility analysis on wood-biomass energy generation for off-grid community in Brochet. The feasibility analyses were carried out through the process of survey, interviews and document reviews. In other to assess the suitability of biomass energy generation, Rezaur [9] explored four different areas: (a) technology availability (b) cost attractiveness (c) the community's perspective, (d) resource assessment. From the result of the cost analysis presented, the study established that the current planned investment in diesel power facility is not economically viable but a biomass plant at Brochet would be more economically viable. Wood and Rowley [10] also carried out a research to determine the techno-economic prospect of a series of CHP plants fired by biomass energy in a community. Six systems comprising of different technologies were studied. Wood and Rowley obtained technical performance and cost data on the various biomass CHP systems and the actual demand data for a representative community housing scheme. Furthermore, the research work analysed a number of operational scenarios in other to determine the viability of specific systems and also developed an economic modelling tool. From the result presented by Wood and Rowley [10], CHP plants, fired by biomass energy, can demonstrate positive net present values without the need for capital subsidies within specified and realistic operating conditions. Oyegoke and Baba El-Yakubu [11] carried out a techno-feasibilty study on a bio-power plant in Nigeria which produced 130MWh of electricity from 50tons of biomass (sugarcane bagasse) and energy generation cost of 0.07 $/kWh. From this work, it was reported that the sum of $89million and $81 million as the capital and the operating cost for the bio-plant. This was used to assess of the profit that would made by the plant. From their result, Oyegoke and Baba El-Yakubu [11], established that the bio-plant would make a net profit of $26million, payback period of 3.5 years, and 29% return on investment as well as a net present worth of $191million. Angelo and Morrone [12] investigated the energetic performance and economic prospect of Organic Rankine Cycles (ORCs) for CHP generation. The researchers further analysed the trans-critical and subcritical cycles, with superheated and saturated conditions at the turbine inlet, the impact of internal regeneration on system behaviour were also studied. the results obtained established that biomass-fired ORC system appears an attractive option for single-family CHP applications. Onochie [13] investigated the potentials of raw oil palm residues (produced in large quantity) for energy utilisation in the Nigerian Institution for Oil Palm Research (NIFOR). In his study, two case scenarios (base & proposed) were compared. For the base case, no electricity was generated because it's only heat process system (as it were in NIFOR) while the proposed case, which was the CHP system, has the potential of generating a power output of about 2.95MW. However, in order to determine the economic implication and viability of the proposed case, Onochie and Aliu [14] further investigated the economic/financial analysis of the two cases scenarios carried out by Onochie [13]. The investigation showed that with a capital investment of $2, 000,000, NIFOR would demand less electricity from the National Grid (i.e. 1443200kWh to 1089200kWh), consequently reducing the cost of electricity from $61, 026.743 to $46, 057.6 thereby saving about $14, 969.143 per annum. However, from his findings, Onochie [13] suggested the need to pelletize the raw residues to increase its power generation capacity to further reduce the demand and cost of electricity from the National Grid.

As a way of further research, Onochie and Ighodaro [15] carried out a study to improve the work of Onochie [13] by using biomass pellets from oil palm residues as suggested by Onochie [13]. They showed in their study that producing and utilizing biomass pellets from oil palm residues would increase power generation capacity by 11% (that is from 2.95MW to 3.265MW). However, the work did not consider the need to investigate the economic/financial feasibility of the proposed project. This study is novel in the sense that there are very few specific references on the subject. Essentially, the study determines whether the CHP system proposed by Onochie and Ighodaro [15] would offer significant potential economic benefit to the process system in NIFOR.

2. Methodology

The method used here is similar to the work of Onochie and Aliu [15]. The data used for the analysis in this study are as follows:

i. Data from Onochie and Ighodaro [15] and;
ii. Data from Onochie and Aliu [14]

Figure 1 show the process system in NIFOR. Raw residues were used as fuel to fire the boiler while the steam obtained was used for the processing of the palm oil. Figure 2 show the schematic diagram of proposed CHP plant by Onochie and Ighodaro [15].

Table 2: Result of data obtained from economic analysis

Electricity demand per month	**Cost of grid electricity per month**	**Reduction in Electricity Demand**	**Savings from cost of grid electricity**
1443200kWh/month	$101.069/month	1089200kWh/month	$179, 629.724/yr.

Source: *Onochie and Aliu [14]*

2.1 Design specification for the CHP system

Major equipment incorporated by Onochie and Ighodaro [15] into the process system to become a CHP system includes a back-pressure steam turbine, steam turbine generator and a pump. The power

generated from analysis is 3.265MW as presented in Table 1, therefore, the specification for the back-pressure steam turbine and generator are presented in Table 3 and 4.

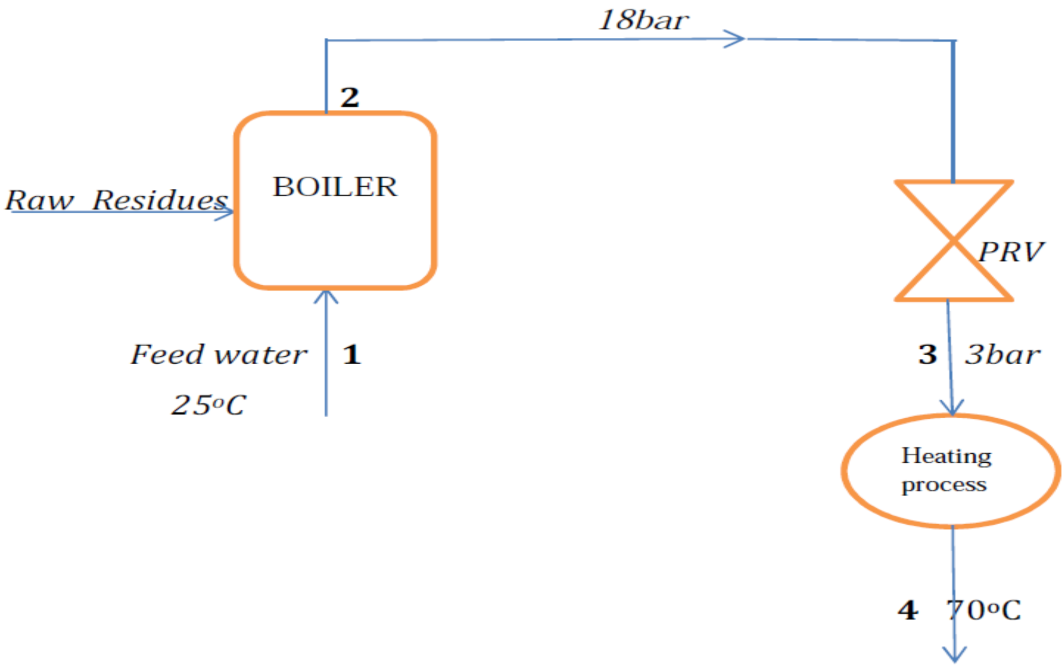

Figure 1: Schematic diagram (base case scenario) of process plant in NIFOR

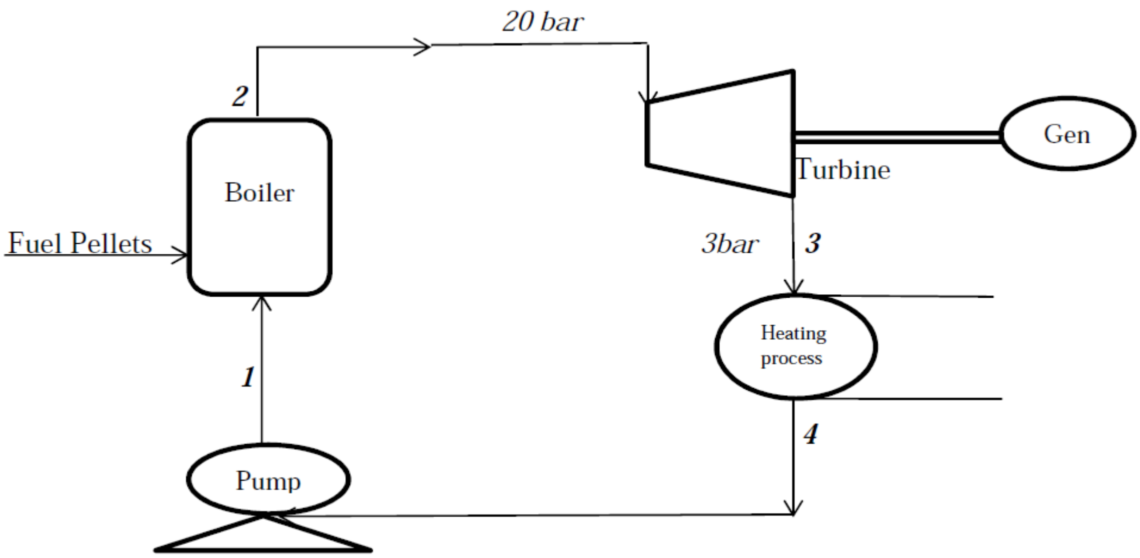

Figure 2: Schematic diagram of CHP plant (proposed case scenario)

Table 1 show the data reported in Onochie and Ighodaro [15] on power generation potential from the biomass fuel pellets developed from oil palm residues as proposed in Figure 2. Table 2 is the data reported in Onochie and Aliu [14] on savings from cost of Grid electricity.

Table 1: Result of data obtained from pellets as fuel

Parameters	Fuel Energy (kW)	Heat Supply (kW)	Power (MW)
Data	35373.78	30067.72	3.265

Source: *Onochie and Ighodaro [15]*

Table 3: Specification of back pressure steam turbine

Component	Capacity (MW)	Speed (rpm)	Pressure (MPa)
Back pressure steam turbine	6	6500	2.35

Source: *Wuxi Land Mechanical & Power Engineering Co. Ltd, China*

Table 4: Specification of steam turbine generator

Component	Power (MW)	Voltage (V)	Speed (rpm)
Steam turbine generator	4-6	230/110	1000/2500

Source: *Chongjing Green Energy Electric Steam Generator, China*

2.2 Electricity Demand and Cost Analysis

Information from the study area, NIFOR, states that the mill operates 8hrs/day in 15day/month. Hence, the electricity that would be generated if turbine is incorporated in the process plant is given as:

Electricity generated = Power × Operating hour/day × No of days/month (1)

Electricity generated = = 3265.16kW × 8hrs/day ×15days = 391819.2kWh/month

However, according to NERC Multi-Tariff System (2015), the cost of commercial price of electricity for the C1T class (three phase category) for the year 2017 is $0.104/kWh.

Thus, the cost of electricity generated/month is:

Cost of electricity generated/month = Commercial price × Electricity generated/month (2)

Cost of electricity generated/month = $0.104/kWh × 391819.2kWh

Cost of electricity generated/month = $40,749.1968

But NIFOR electricity demand is estimated to be 8.2MW for (22 working days) from the grid in kWh;

Electricity demand/month = 8.2 ×1000kW × 8hrs/day × 22day

Electricity demand/month = 1443200kWh

Hence, the cost of grid electricity/month is thus;

Cost of grid electricity/month = Cost of commercial price × Electricity demand/month

Cost of grid electricity/month = $0.104/kWh × 1443200kWh

Cost of grid electricity/month = $150, 092.8

Now, if the electricity generated is 391819.2kWh /month and the quantity needed and demanded for by NIFOR for its operation is 1443200kWh/month; therefore, new electricity demand from grid will be:

New Electricity Demand = Grid electricity – Electricity generated (3)

New Electricity Demand = 1443200 kWh – 391819.2kWh = 1051380.8kWh

This means that NIFOR would no longer be demanding as much as 1443200kwh of electricity, rather, they would demand 1051380.8kwh of electricity in a month.

Thus, the savings made would be;

Savings from cost of grid electricity = Base Case – Proposal Case (4)
Savings from cost of grid electricity = (1443200 × $0.104) – (1051380.8 × $0.104)
Savings from cost of grid electricity/month = $40, 749.197/month (i.e. $488, 990.362/yr.)
This amount is far greater than the savings ($179, 629.714/yr.) established in previous studies of Onochie and Aliu [14]. Figure 3 shows the comparative.

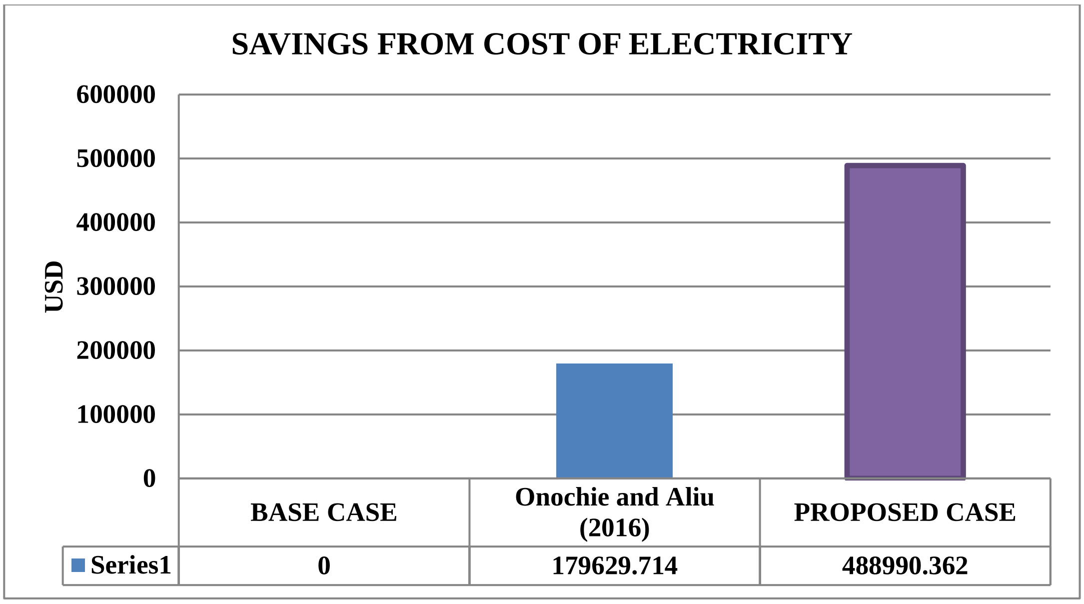

Figure 3: Savings from cost of electricity

2.3 Financial Analysis

This section deals with economic viability of the proposed case. The analysis here determines if the proposed project justifies the investments to be made.

Assumptions:

For the purpose of financial analysis, some assumptions were made.

i. Capital Investment = $2**,** 000,000
ii. Operation & Maintenance = 5% of Capital Investment = $100**,** 000
iii. Life cycle of the power plant = 25yrs

The cash inflow is determined by:
Cash inflow = Savings – operation/maintenance cost (5)
Cash inflow = $488, 990.362 – $100**,** 000 = $388, 990.362

The Bill of Engineering Material and Evaluation (BEME) for the component parts that would make up the CHP plant are shown in Table 5.

Table 5: Bill of Engineering Material and Evaluation (BEME) for the proposed CHP

COMPONENT	QUANTITY	UNIT COST ($)	TOTAL COST ($)
Steam turbine	1	800,000	800,000
Turbine generator	1	640, 300	640, 300
Feed Water Pump	1	160, 000	160, 000
Condenser	1	180, 000	180, 000
Installation/ Pipes/Fittings		204, 000	204, 000
Pelletizing Plant facility	1	15, 000	15, 000
TOTAL			**2, 000,000**

2.3.1 Simple pay-back

This is a technique that helps the investor to decide whether to invest or not, based on the recovery period. Therefore, the Simple pay - back period of the proposed project is:

Simple pay - back = Capital Investment / Cash inflow (6)

Simple pay - back = $2, 000,000 / $388, 990.362
Simple pay - back = 5.14yrs

2.3.2 Net Present Value

The Institute of Chartered Account of Nigeria ICAN emphasised that for any project to be economically viable, the net present value must be positive. In other words, if negative, the investor should back-off. The present value interest factor annuity discount (PVIFA) is:

$$PVIF = [1 - (1 + r)^{-n}] / r \quad (7)$$

Where,

n = no of years
r = percentage discount @ 10% and 60%

Table 6 presents the value interest factor annuity discount at 10%.

Table 6: Present value interest factor annuity discounted at 10%

YEAR	CASH INFLOW ($)	PVIFA @10%	PRESENT VALUE ($)
1-25	388, 990.362	9.08	3, 516,175.22

Thus, the Net present value at 10% discounts;

NPV = Present value – Capital Investment
NPV = $3, 516,175.22 – $2, 000,000 = $1, 516,175.22

2.3.3 Internal Rate of Return

This is the break-even point of capital as established by the Institute of Chartered Accountant of Nigeria (ICAN). Table 7 shows the present value interest factor annuity discounted at 60%.

Table 7: Present value interest factor annuity discounted at 60%

YEAR	CASH INFLOW ($)	PVIFA @ 60%	PRESENT VALUE ($)
1-25	388, 990.362	1.67	646, 697.43

Thus, the Net present value at 60%;

NPV = Present value – Capital Investment
NPV = $646, 697.43 – $2, 000,000
NPV = - $1, 353,302.57

Hence, the internal rate of return (IRR):
By interpolation,

At 10%	$1, 516,175.22
IRR	0
At 60%	- $1, 353,302.57

Thus,

IRR = 36.42%

3. Conclusion

The result from the savings of the cost of grid electricity shows that $488, 990.362/yr. can be saved if the proposed case is adopted by relevant authorities. Essentially, using the pellets as fuel would enable enough power generation thereby increasing the savings from cost of grid electricity. The savings is far beyond $179, 629.714/yr. established in Onochie and Aliu [4] as shown in Table 2. This is a significant difference of $309, 360.648/yr. The simple pay-back period for the CHP plant is the period for which the project would pay back itself after 5.14yrs of operation after which profit would continue to flow-in. The IRR is 36.42% and positive. According to the Institute of Chartered Account of Nigeria (ICAN), when the NPV of a project is positive, it ultimately indicates that the project is viable and should be adopted by the Government and the private investors.

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