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Investigation of the Feasibility of Transforming Sorghum Bagasse into Bioethanol Fuel in Nigeria: A Techno-Economic Analysis

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Abstract

The Nigerian government needs to reduce its over-dependence on the oil and gas economy as the benefit derived from these resources have gradually begun to suffer from several uncertainties. Nigeria is blessed with a vast green resource; therefore, there is a need to create an avenue of establishing a strong link between the downstream petroleum industry and agricultural activities. The Nigerian government has indicated a commitment to biofuels production from local feedstock, emphasising bioethanol and biodiesel with the projected annual local market possibility of 5.04 billion and 900 million litres, respectively. Therefore, the study is focused on investigating the economic feasibility of establishing a bioethanol plant that would process sorghum bagasse into a bioethanol fuel to complement the use of petrol. The sensitivity of tax rate (TR), the currency exchange rate (CER), bagasse price (BP) and government subsidy (GS) were also investigated. Results obtained for the profitability analysis of the project showcased the benefit the project tends to offer. The potential sensitive variables that have a strong potential of influencing the project's financial benefit were identified. The best return on investment was found to be obtainable at 20 % subsidy (minimum), 0% tax rate (waiver), 150 NGN/$ (lowest), and 10 NGN/kg (maximum). The NPW sensitivity to the parameters indicated currency exchange rate (CER) (with a maximum variation of 22%) to be the most significant of all ther parameters. Findings from the study reveal that the currency exchange rate has a significant impact on the return on the project investment. Which showcases why the government needed to develop a positive economic strategy that would appreciate and sustain local currency's value to attract investors in Nigeria.

1. Introduction

The over-reliance of Nigeria's economy on the oil & gas sector was becoming a subject of concern with the rising global warming effect of greenhouse gas (GHG) release from fossil fuel [1] coupled with the frequency changes reported for crude oil sales. It would be necessary for developing nations like Nigeria to give better attention to the economy and energy diversification by embracing green energy use. One of the essential tools in combating vehicular pollution is bioethanol being a cleaner fuel, environmentally friendly and sustainable [1]–[3]. This bioethanol can be produced via either sugar, cellulose, or starch-based materials. Nigeria produces a large quantity of the material in our farms annually, in line with the Nigeria Bureau of Statistics report for 2012 to 2019 [4], [5]. Being a country has long been struggling to manage its solid wastes, including the agricultural wastes often littered on the street during harvest to the season. However, these causes the polluting of our land, endangering the health of the public via exposure to landfill gas migration and disease vectors [6].

Notable among other reasons to look beyond the oil and gas and delve into an alternate source of energy production is the environmental threats posed by fossil fuels which are associated with the emissions of GHG (majorly CO_2), which are associated with climate change and other disastrous effects on the earth and its habitats [7]–[10]. According to Galadima et al. [11], about 75% of the Carbon dioxide made by humans is from burning fossil fuels. The authors also reported that Nigeria contributes the most considerable portion of this emission in Sub-Saharan Africa. Nigeria is also known as the second world’s biggest gas flare.

In the past century, Oil and Gas remain one of the significant sources of global energy. Since the discovery of crude oil in the Delta region in the mid-1950s, it has gradually taken over the core of Nigeria’s economy and gained ground as the primary source of energy and revenue to the country, side-lining other sectors in the process [12]. Oil and gas currently account for approximately 90% of the country’s total government revenues and foreign exchange benefits. Currently, these commodities account for over 90% of both foreign exchange benefits and total government revenues. Total and continuous reliance on this crude oil only spells doom for Nigeria’s economy, especially considering the recent global crash in the price of crude oil, which has negatively affected the Nigerian people's economic strength. Also, the current reserves of 36.22 billion barrels and 181 trillion cubic feet of oil and gas could only last for the next 35 to 40 years. This only implies that the days of the consistent flow of oil and gas are numbered, which could be attributed to the rapid increase in population and increased energy consumption rate, among other factors [13]–[15].

A survey of the literature indicated that many studies had studied the processes involved in the successful conversion of these wastes into bioethanol fuel, experimentally and computationally. Although, most of the studies have mainly focused on experimental studies of this process with less attention to the investigation of the technology economic feasibility study [16]–[34]. Some of the literature considering the economic feasibility investigation includes Christiana and Eric [35] that identified that bioethanol production from cassava would only be feasible in Nigeria provided the plant is sited next to the plant. Another study by Oyegoke et al. [32] established the economic potential of transforming sugarcane into bioethanol in Nigeria, indicating the need for government to introduce the subsidy and low tax rate to the production of bioethanol. Some of the other previous research are bioethanol production from molasses [36], combined sugarcane-bagasse-juice [37], [38], cassava cellulosic wastes [39], hazelnut husk [40], sorghum bagasse [41], and many other works.

With the rising waste generated and the government's inadequate attention to managing these wastes, mostly solid ones, this study seeks to investigate and establish the economic feasibility of viable process technology to produce bioethanol from sorghum bagasse in Nigeria using a process simulation approach. This study includes project profitability analysis and sensitivity analysis of the essential variables. The findings from the study showcased the economic benefits of embracing and promoting the use of green (or cleaner or sustainable) technology to produce fuels, especially in low-income nations like Nigeria. It would also go a long way to attract the interest of the government and private investors towards investing in such a project.

2. Methodology

2.1 Study Framework

The approach employed in this study is diagrammatically displayed in Figure 1. It was indicated that the studies began with the process of plant simulation. The resulting output from the process simulation was used to initiate the techno-economic analysis of the process. However, the report on the process modelling and simulation of the production processes has been reported in our previous studies [24], which entails the unhighlighted component of the block flow diagram, which focused on modelling and simulation of the plant, including equipment sizing and costing.

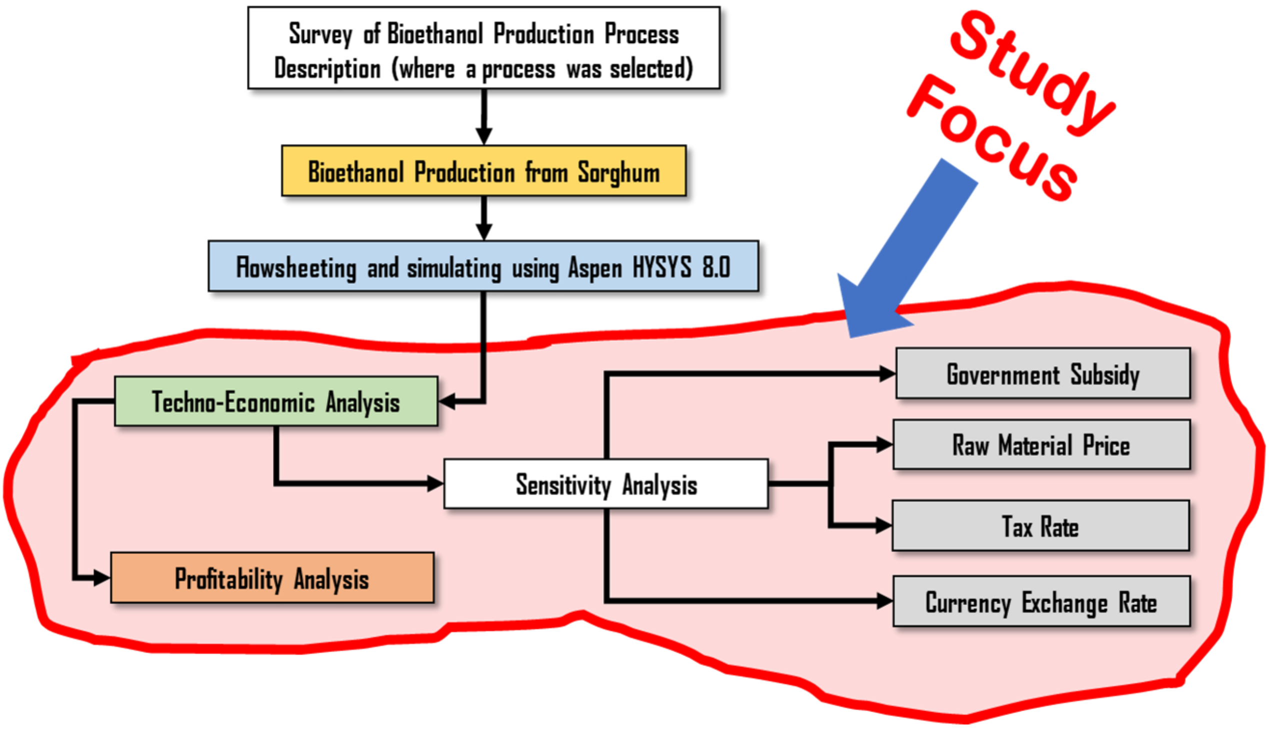

Figure 1: Research Approach Framework

So, the present study would focus on the execution of the highlighted section, which was not addressed in the previous study. Moreover, these advances the previous studies by providing the project's economic feasibility and provision of the sensitive factor that the project profitability largely depends on.

2.2 Process Description and Process Flow Diagram

Bioethanol production begins with a crushed and pre-treated sweet sorghum stalk feed whose compositions are presented in our previous studies in Ajayi et al. [28].

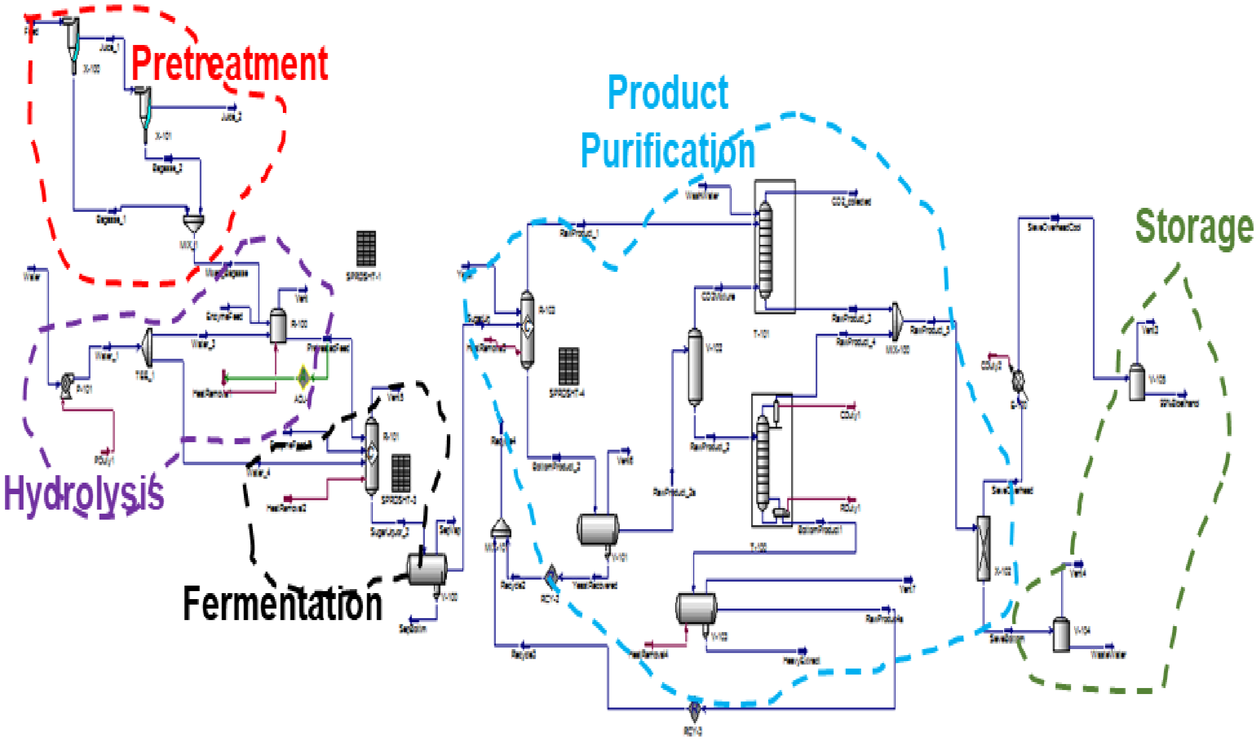

Figure 2: PFD for Bioethanol Production from Sorghum Bagasse

The feed in the modelled plant was extracted to remove juice from the sorghum stalk. The resulting product of extraction composed of sucrose, hemicellulose and cellulose were hydrolyzed in different reactors. After hydrolysis, the fermentable sugars were fermented. The raw bioethanol produced was then purified. The process flow diagrams shown in Figure 2 were modelled and simulated using the Aspen HYSYS simulator, whose report is presented in detail in the Ajayi et al. [42] report.

2.3 Techno-economic Analysis

The material and energy analysis results of the modelled and simulated process technologies were used to determine the size and cost process of the equipment. The resulting total cost of purchasing equipment for the different respective technologies was determined using the procedure in subsection 2.4.3. Furthermore, total capital investment and manufacturing cost were evaluated using the approach in subsections 2.4.4 and 2.4.5, respectively. After which, all various technologies were subjected to profitability analysis using decision criteria for investment as in section 2.5 using the project parameters and assumptions presented in Table 4 to assess their respective economic worth or value.

Project Parameters & Assumptions: In assessing the techno-economic feasibility study of the processes, the following project parameters and assumptions presented in Table 2 were employed in the different profitability analyses.

The material resource needed for effective and efficient production, equipment specification for cost basis, and bioethanol production quantity was determined from the Ajay et al. [37] report (as presented in Table 3) on material and energy balance obtained from the process simulation.

Table 1: Project Parameters & Assumptions

Descriptions	***Values***
Working time (h)	24
Working days (days)	335
Raw material NGN/kg) [43], [44]	26
Discount rate (%)	10
Proposed product(petrol) price ($/L)	152
Exchange rate (NGN/$)	199 (2016), 365 (2020), 385 (2021)
Tax rate (%) // Interest rate (%)	20 // 10
Economic project life (Yr)	25
Depreciation method [45], [46]	Straight line
Depreciation period (Yr)	10
Unit price of electricity (NGN/kWh)	43.38
Cost of yeast ($/kg)	0.10
Cost of enzymes ($/kg)	0.51

Table 2. Plant Parameters from the simulation [41]

Descriptions	***Values***
Total purchase cost of equipment ($)	9,439,700.78 in 2021 (8,960,000 in 2020)
Sorghum bagasse quantity (kg)	167,500,000.00
Bioethanol production (L)	59,778,931.90
Yeast quantity (kg)	23,201,061.50
Enzymes quantity (kg)	22,953,530.00
Feed flowrate (kg/h)	50,000.00

Table 3: Sources of data for total capital investment estimation

Capital Investment Components	*Manufacturing Cost Components*
Direct Plant Cost	*Direct Production Cost (DPC)*
Purchased cost of equipment [45]–[48]	Raw Material (RM) [43], [44]
Equipment installation cost[46]	*Operating Labour (OL)*
Piping installation cost[46]	Direct Supervisory & Clerical Labour (DS) [45]
Electricity installation cost[46]	Utilities Cost (UT) e.g. Cooling water, Electricity, Waste management, etc. [45]–[47], [49]
Instrumentation and control[46]	Maintenance & Repair (MR) [45]
Building and services [46]	Operating Supplies (OS) [45]
Excavation and site preparation[46]	Laboratory Charges (LC) [45]
Auxiliaries/service facilities[46]	Patents & Royalties (PR) [45]
Land survey & cost [46]	*Fixed Manufacturing Cost (FMC)*
Indirect Plant Cost	Depreciation [45]
Field & construction expense [46]	Taxes [45]
Engineering & supervision[46]	Plant Overhead (PO) Information [46]
Other Plant Cost	*General Expenses (GE)*
Contractor's fee, overhead and profit[46]	Administration Cost [45]
Contingency [46]	Distribution & Selling Cost [45]
Working Capital [46]	Research and Development Cost [45]

Plant Equipment Costing: Using Marshall and Swiss cost correlation and indices with Equation 1[45], [46] with the aid of Microsoft Excel 2013, each unit equipment cost was estimated as C_i while the resulting cost was escalated respectively using Equation 2 to evaluate an updated cost of each unit equipment as C_x.

$$C_i = C_o * S^n \tag{1}$$

$$C_x = C_i * (MS_x / MS_n) \tag{2}$$

Where C_i = Cost as at i year, C_o = Bare Cost at i year, C_x = Escalated cost as at x year, S = Size of equipment, n = Cost Index, MS = Marshall & Swiss Cost Index at n and x year

Total Capital Investment Estimation: The estimation of the capital investment was carried out using the data collected from the sources shown in Table 4. Using Factorial Method and Purchased Equipment Cost [46] with the aid of MATLAB program code reported in our previous studies [28]. The total purchased cost of equipment computed for the set of the equipment model in our previous study [41] was adopted in this analysis using relevant literature presented in Table 4.

Cost of Manufacturing Estimation: The estimation for the cost of manufacturing was done using relevant data sourced from the references presented in Table 4 for each item. Using factorial method [45] and case-study-based cost data for raw material, operating labour, and utilities cost with a MATLAB program, the manufacturing cost was estimated from the direct production, fixed manufacturing and general expenses.

2.4 Project Profitability

The proposed projects (plants) were analyzed for profitability and feasibility using the following investment criteria for evaluation:

Return on investment (ROI): The Return on Investment (ROI) was calculated as the benefit (or return) of an investment is divided by the cost of the investment. It was determined using Equation 3 [35]–[37], [40], [48], [50]–[53].

$$\mathrm{ROI} = \mathrm{NP}/\mathrm{TCI} * 100\% \quad (3)$$

Net present worth (NPW): Investopedia (2015) defined Net Present Worth as the difference between the present value of cash inflows and the present value of cash outflows. This was calculated using Equation 4 [35]–[37], [40], [48], [50]–[53].

$$\mathrm{NPW} = \sum[(B_n - C_t)/(1+r)^t] \quad (4)$$

Payback period (PBP): The time taken to recoup the capital invested in a project was calculated using Equation 5 with reference to Richard *et al.* [45].

$$\mathrm{PBP} = 1 + n - \sum(NCF)/\sum(PCF) \quad (5)$$

Internal Rate of Return (IRR): It accounts for the discount rate at which the present value of all the future cash flow equals the initial investment or, in other words, the rate at which an investment break [35]–[37], [40], [48], [50]–[53]. It was calculated with the aid of the Microsoft Excel 2013 command.

2.5 Sensitivity Analysis

In this analysis, some uncertainties were incorporated by varying the key parameters of the projects while observing their corresponded decisions considering a project life of 25 years. Using the parameters presented in Table 6, the effects of the change in sorghum bagasse price, currency exchange rate, tax rate and government subsidy on the feasibility of establishing a profitable bioethanol fuel production plant in Nigeria.

Table 4: List of factors to be examined and their levels.

Factors	*Unit*	*Low*	*Mid*	*High*
Tax rate	% per year	10	20	30
Subsidy removal	% per year	0	20	40
Currency exchange rate	NGN/$	150	170	400
Sorghum bagasse price	NGN per kg	15	27	30

Using One-factor-at-time (OFAT) design of experiment approach, the sensitivity of different factors listed above were analyzed with Table 6 displaying various variation levels, from which the effects of different factors on response variables such as Cost of manufacturing or producing a litre (CP), Selling Price per litre (SP), net present worth (NPW), Internal rate of return (IRR), Payback-period (PBP) and Benefits/cost ratio (B/C) for bioethanol production in Nigeria were examined. Moreover, analysis of variance was used to evaluate the significance of the impact on the project economic viability.

3 Results and Discussion

3.1 Total Capital Investment Estimation

The estimation of the Total Capital Investment is presented in Table A1, where the distribution of the cost components that made up the total capital investment was presented. The study estimated the total capital investment to be $ 53 million (to produce 59.8 million annual litres). The capital demand for the production of 1 litre of bioethanol was found to be 0.89 $/L which was found to be much higher that which was reported for the use of maize cob [31], sugarcane bagasse [29], and molasses [26] as 0.13, 0.34 and 0.10 $/L, respectively.

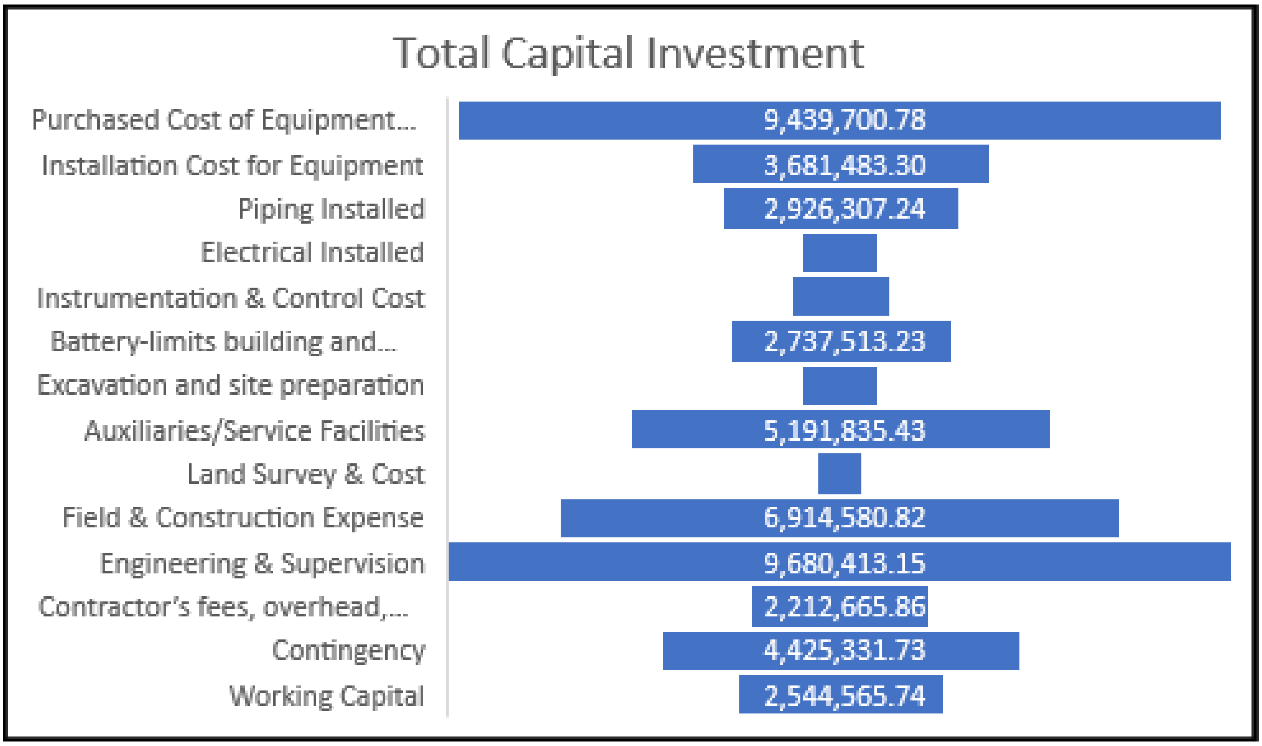

Figure 3: Components of Total Capital Cost for the Production

However, with the use of Figure 3, the cost of equipment and engineering & supervision cost was identified to have contributed mainly (35%) to the total capital investment (TCI), which qualifies it for being the component with the largest share while further findings indicated that land survey & cost was found to have contributed least (1%) to the TCI.

3.2 Operating Cost Estimation

The results obtained for the cost of Raw Material, Operating Labor, Direct Supervisory & Clerical Labor, Utilities Cost, Maintenance & Repair, Operating Supplies, Laboratory Charges, Patents & Royalties, Direct Production Cost, Depreciation, Local taxes, Insurances, Plant Overhead, Fixed Manufacturing Cost, Administration Cost, Distribution & Selling Cost, General Expenses, Research and Development Cost in the estimation of the operating cost estimation is presented in Table A2.

Findings from the operating cost of the project studied unveil that the total cost of manufacturing was $ 92 million (that is, to produce 59.8 million annual litres) based on the analytical approach used in the calculation, which resulted to yielding a cost of manufacturing a litre of bioethanol to be 1.56 $/L which was found to be higher to what was reported for the use of molasses [26] sugarcane bagasse [29], [30], and maize cob [31] as 0.60, 0.61, and 0.56 $/L in bioethanol production.

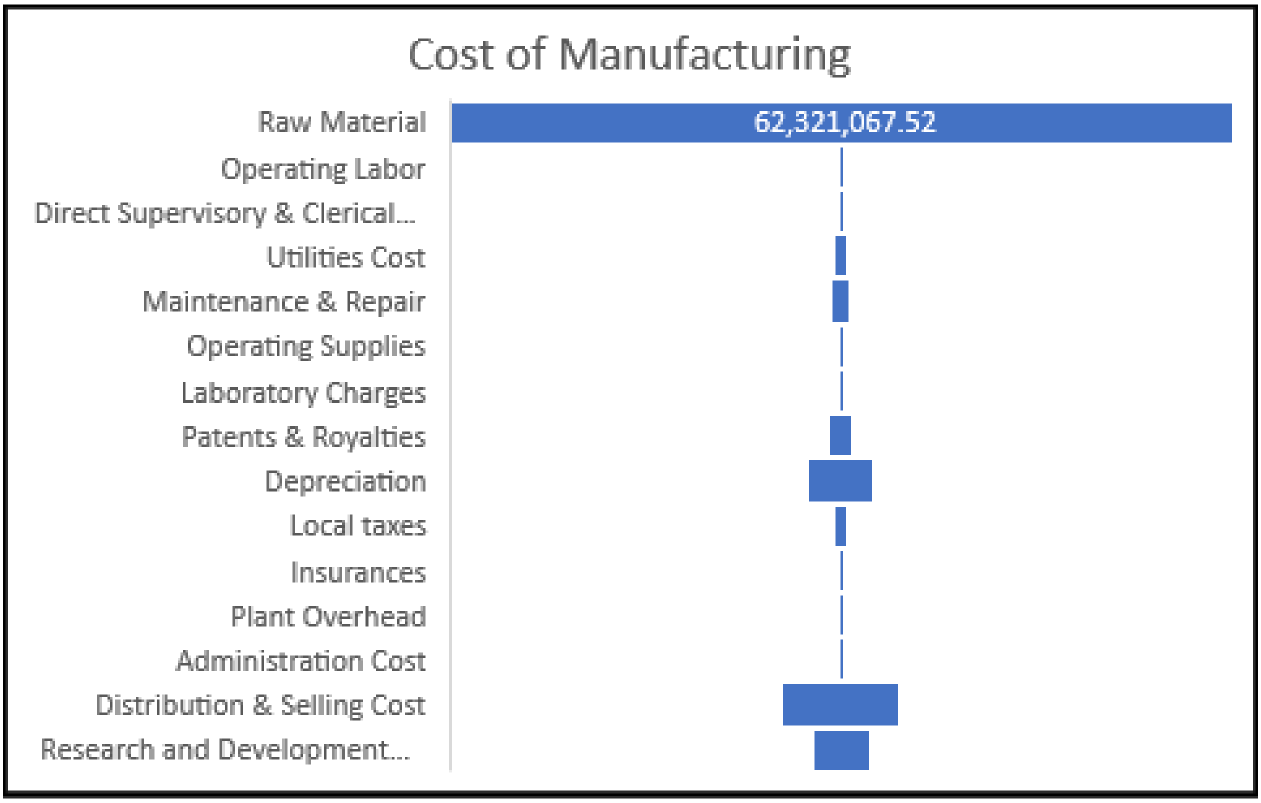

Figure 4: Components of Total Operating Cost for the Production

Furthermore, the raw material cost was found to have contributed 67% to the total manufacturing cost (COM). At the same time, the operating labour, direct supervisory, operating supplies, and other parameters account for 33 % of the COM.

3.2.1 **Profitability Analysis**

Based on the attempt made to evaluate the profitability prospect of the plant for a life span of 25 years, the results collected for the evaluation of the project viability is presented in Table 5 with the use of relevant investment criteria like revenue, net profit, payback period, net present worth, return on investment and the benefit/cost ratio.

Table 5: Results for Project Profitability Analysis for Project Life of 25 years

Descriptions	*Symbols*	*Amount*
Product Quantity (L)	nV	143,469,436.60
Production Cost per Liter ($/L)	CPv	0.64
Selling Price ($/L)	SPv	0.39
Subsidy (%)	Sub	0.00
Revenue ($)	R	58,987,867.45
Gross Income ($)	GI	-33,388,158.04
Tax Rate (%)	TR	0.20
Net Profit ($)	NP	-26,710,526.43
Discounted Payback period (yr)	PBP	NA
Discounted Net Present Worth ($)	NPW	-212,152,747.90
Return on Investment (%)	ROI	-49.99
Discounted Benefit/Cost (-)	B/C	0.00

However, findings from this report indicated a 50% loss on investment (-ROI) coupled with negative net profit, which implies a loss. The project profitability analysis indicated that the substitution of petrol with bioethanol fuel confirms that it would not be economically feasible, based on the benchmark (using similar selling price of PMS in Nigeria, recent Dollar-Naira exchange rate, and zero subsidies) employed in the study.

3.3 Sensitivity Analysis

As a measure to best guide both investors and government in the decision making regarding the promotion of green technology and biofuels, for example, bioethanol necessitated the need to investigate the sensitivity of selected economic parameters/factors to understand how it influences the loss obtained for the profitability analysis and to provide direction of how to alleviate the loss to promote investors towards investing in the green project like this one. The selected parameters used for the sensitivity analysis include raw materials, tax rate cost, labour wages paid, and government subsidy impact. The results are presented here.

Sensitivity Analysis for Government Subsidy and Tax Rate: The potential change in subsidy removal was considered. The result of its sensitivity analysis is presented in Figure 5-6, where Figure 5 presents the effect of changing the subject. The introduction of a subsidy on bioethanol sales influences all parameters (NP, NPW, and ROI). The tax rate change results in a significant NP, NPW, and ROI change.

Sensitivity Analysis for Change in Currency Exchange Rate and Raw Material Cost: The potential change in subsidy removal was considered. The result of its sensitivity analysis is presented in Figures 7-8.The change in the exchange rate influences changes in all the parameters (NP, NPW, and ROI). The rise in raw material cost resulted in a change in capital cost (CPv), NP, NPW, and ROI.

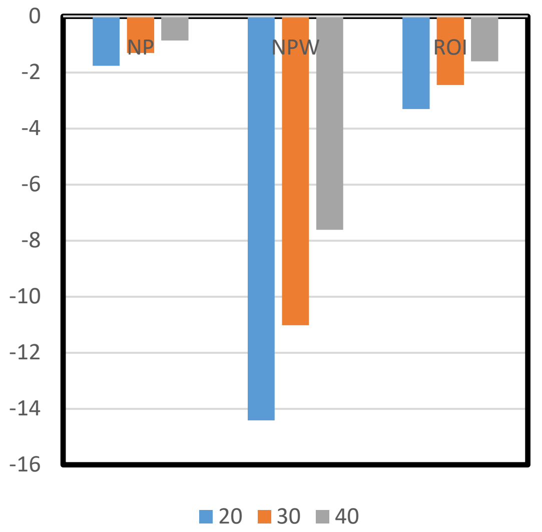

Figure 5: Sensitivity of Government Subsidy (%)

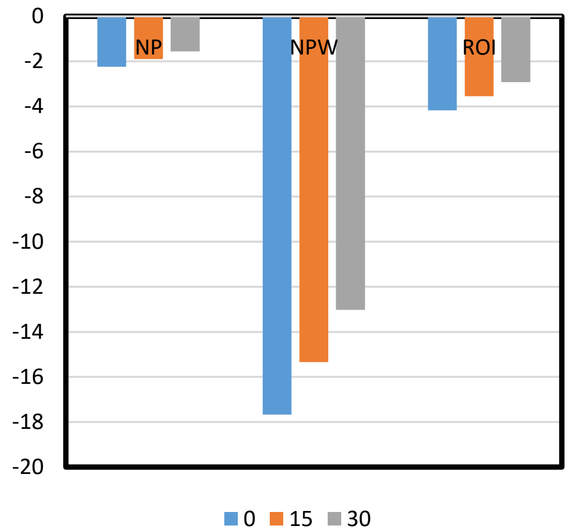

Figure 6: Sensitivity of Government Tax Rate (%)

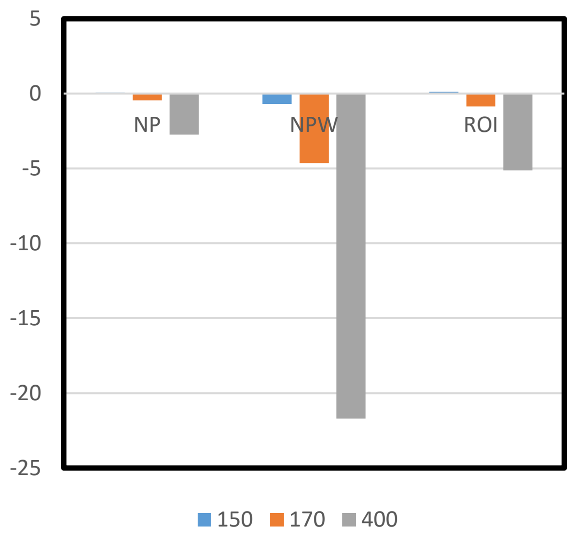

Figure 7: Sensitivity of Dollar-Naira Exchange Rate (NGN/$)

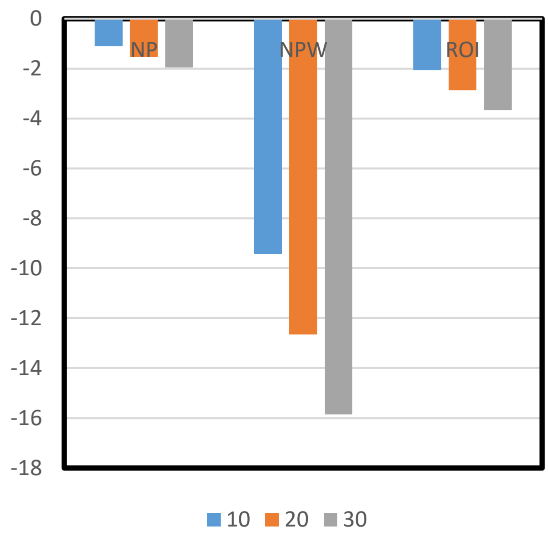

Figure 8: Sensitivity of Bagasse Price (NGN/kg)

4.0. Conclusion

A techno-economic analysis (TEA) to produce bioethanol from sorghum bagasse was successfully carried out using the Factorial method to estimate capital cost and investment criteria, including net present worth, return on investment, and net profit with the aid of the MATLAB program. The accounting for profitability and sensitivity analysis (SE) for selected parameters, including raw material cost, government subsidy, currency exchange rate and tax rate, were also investigated. The results obtained from the TEA confirm that using "bioethanol from sorghum bagasse" to replace the use of petrol would not be economically feasible in Nigeria due to the negative return on investment obtained as -49.9% and negative gross income of 33 million dollars. The infeasibility of the process was traced primarily due to the impact of the high exchange rate, and subsidy introduction slightly showed an impact. At the same time, other parameters (tax rate and bagasse/raw material cost) studied showed no significant impact, based on the results obtained for SE. Therefore, the government needed to make feasible policies that would strengthen and keep the Naira exchange rate more stable (especially Dollar-Naira) haven know that feasibility of the project significantly depends on the stability of the exchange rate. And the government are also encouraged to provide subsidies for promoting bioethanol production in developing nations like Nigeria.

Conflict of Interest

The authors declare no conflict of interest.

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Appendix

Table A1: Results for Plant Total Capital Investment

Descriptions	*Symbol*	*Amount ($)*
Purchased Cost of Equipment Delivered	PCE	9,439,700.78
Installation Cost for Equipment	**	3,681,483.30
Piping Installed	**	2,926,307.24
Electrical Installed	**	943,970.08
Instrumentation & Control Cost	**	1,227,161.10
Battery-limits building and service	**	2,737,513.23
Excavation and site preparation	**	943,970.08
Auxiliaries/Service Facilities	**	5,191,835.43

Land Survey & Cost	**	566,382.05
Field & Construction Expense	**	6,914,580.82
Engineering & Supervision	**	9,680,413.15
Contractor's fees, overhead, profit	**	2,212,665.86
Contingency	**	4,425,331.73
Total fixed-capital investment	FCI	50,891,314.85
Working Capital	WC	2,544,565.74
Total Capital Investment	TCI	53,435,880.59
Capital per Liter	-	0.89

Table A2: Operating Cost Estimation Results

Descriptions	*Symbol*	*Amount*
Raw Material	RM	62,321,067.52
Operating Labor	OL	46,466.54
Direct Supervisory & Clerical Labor	DS	5,575.99
Utilities Cost	UT	1,078,421.10
Maintenance & Repair	MR	1,526,739.45
Operating Supplies	OS	198,476.13
Laboratory Charges	LC	5,575.99
Patents & Royalties	PR	1,847,520.51
Direct Production Cost	DPC	*67,029,843.21*
Depreciation	DP	5,089,131.48
Local taxes	LT	1,017,826.30
Insurances	IS	101,782.63
Plant Overhead	PO	27,879.93
Fixed Manufacturing Cost	FC	*6,236,620.34*
Administration Cost	AC	466,246.41
Distribution & Selling Cost	DC	9,237,602.55
Research and Development Cost	RD	4,618,801.27
General Expenses	GE	*14,322,650.24*
Cost of Manufacturing	COM	*92,376,025.49*
Cost per Liter	-	*1.56*