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Original Research Article

Comparative Techno-Economic Analysis of Biodiesel Production Routes using Soybean Soapstock and Cow Tallow as Viable Feedstocks

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ABSTRACT

The techno-economic analysis of biodiesel production from cow tallow (CT) and soybean soapstock (SBS) as feedstock was presented in this study. The production of biodiesel from SBS required esterification and transesterification reactions while CT only required transesterification for its biodiesel production. The yield for soybean soapstock biodiesel production was 99.9% with a net present value (NPV) of N109,482,384 ($251,684) and return on investment (ROI) of 38.47% over a 9 month period, while the CT biodiesel production afforded a 94% yield with N87,460,690 ($201,059) NPV, and 30.28% ROI over a 10 month period. The internal rate of return (IRR) of 88% for soybean soapstock biodiesel further highlighted its economic superiority when compared to that of cow tallow biodiesel at 80%. Though both processes recorded break-even points within the first year, SBS biodiesel production can be operated at a lower capacity (60%) to break-even when compared to CT biodiesel production at 80%. Analysis of the economic parameters of the processes required for the biodiesel production from CT and SBS showed that SBS is more economically viable when compared to CT. Profitability indices such as NPV, ROI and IRR values were all higher for biodiesel production from SBS due to its more efficient conversion. SBS though a more expensive feedstock requiring additional processes, can be regarded as the more cost-effective feedstock for biodiesel production.

1. INTRODUCTION

The negative impacts of conventional energy sources in most developing countries such as Nigeria cannot be over-emphasized, thus necessitating the search for alternative options that are clean, sustainable, cost effective and environmentally friendly (Elegbede et al., 2017). Biodiesel is a renewable, non-toxic, and biodegradable energy source, and therefore, a promising alternative to fossil diesel fuel. They can be produced from renewable biological feedstock such as vegetable oils, non-edible oils, animal fats, or waste oils (Al-Sakkari et al., 2017; Dhawane et al., 2019). Soybean soapstock, a non-edible oil is a lipid-rich by-product from soybean oil refining process and is a promising candidate for biodiesel production due to its low cost and availability (Wang et al., 2007). Cow tallow also a by-product from slaughter houses, can also be used in biodiesel production (Alajmi and Hairuddin et al., 2017).

In transesterification reactions, triglycerides in oils and fats react with alcohol to form biodiesel and glycerol with the alcohol required in excess to attain equilibrium in the reactions (Esonye et al., 2020; Esonye, 2022). Commercial biodiesel production requires a number of reactors and unit operations for its formation and purification with the use of reactive distillation helping to improve the productivity and purity of the biodiesel produced (Boon-anuwat et al., 2015). Alkaline homogeneous catalysts such as sodium and potassium hydroxide are used for the commercial production of biodiesel from feedstocks having concentrations of free fatty acids (FFA) below 2% such as in this case of cow tallow. However, the sole uses of these alkaline catalysts in feedstocks such as soybean soapstock with higher FFA concentrations are usually not viable.

Techno-economic analyses (TEA) are crucial in the early stages of development of processes to meet financial targets by using pilot scale information to design and analyze a theoretical scaled-up process. TEA achieves this through a combination of process and/or product design, simulation, and cash flow analysis to produce mass and energy balances as well as a variety of economic metrics that can be used to gauge the viability of a technology before it can be commercialized (Scown et al.,2021). A number of studies have demonstrated the techno economic assessment of biodiesel production using various processes and/or feedstocks.

Al-Sakkari et al. (2020) used economic factors such as return on investment (ROI), net present value (NPV), payback time and break-even point analysis to carry out comparative TEA on the use of waste cooking oils and virgin cooking oils for biodiesel production. However, a cash flow projection which gives a better idea of an investment’s rate of return was not conducted.

This study aims to present a comprehensive comparative techno economic study on biodiesel production from cow tallow and soybean soap stock feed stocks. The price estimate of the raw materials, equipment and biodiesel product were made in relation to the Nigerian market though the study could be applied globally as international procurement standards were taken into consideration. In addition to the profitability and break-even point analysis carried out in other works, detailed rate of return evaluations and cash flow projections were also made in this work.

2. METHODOLOGY

2.1. Cow Tallow Biodiesel Production

The process flow diagram (PFD) for biodiesel production from cow tallow is illustrated in Figure 1. The equipment set-up for the process where transesterification reaction with methanol in the presence of sodium hydroxide as catalyst and the separation of the biodiesel from the excess methanol/impurities was illustrated in the PFD. The biodiesel obtained was then analyzed using a gas chromatograph to ascertain the percentage of fatty acid methyl ester (biodiesel) and by extension its conversion from cow tallow feedstock. The fatty acid methyl ester (FAME) mole fraction obtained formed the basis for economic evaluation of the process. The process for biodiesel production from cow tallow as demonstrated in Figure 1 can be categorized into 3 major units. The first is the production unit where methyl ester (biodiesel) is produced from the reaction of waste cow tallow with methanol in the presence of NaOH catalyst. This was majorly carried out in the reactor. In the second unit (separation unit), the reactor effluent is fed to a gravity separator (decanter) to separate biodiesel (light layer) from glycerol (heavy layer). This separation is followed by the biodiesel purification where crude biodiesel is distilled and washed with hot water until its purity matches ASTM D6751 standards. In the production unit, biodiesel was produced using the optimum reaction parameters for cow tallow biodiesel production as highlighted by Mbah and Onukwuli (2021).

The equipment used in the production of biodiesel from cow tallow via transesterification include a mixer, a reactor, settling tanks, washing vessels, glycerol distillation columns and biodiesel distillation columns. The nature of operation of these equipment such as arrangement of impellers/baffles and other internal components, degree of mixing and physical properties of liquids influence the amount of energy required to achieve the needed degree of homogeneity in the transesterification process (Esonye, 2019).

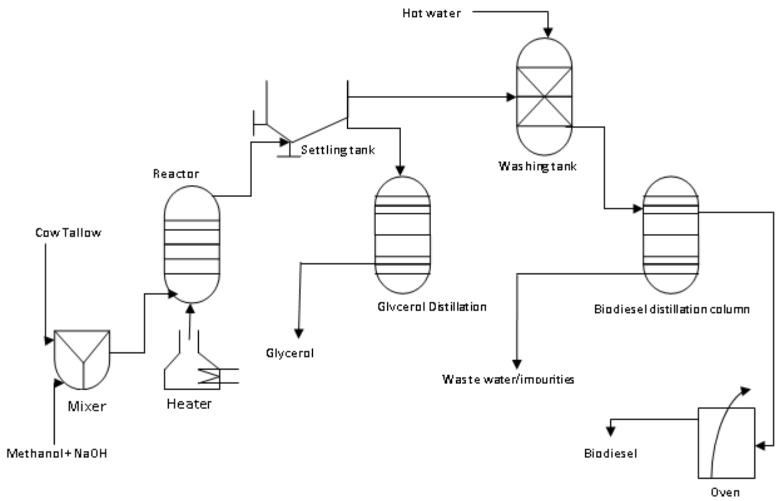

Figure 1: Flowchart for biodiesel production from cow tallow

2.2. Soybean Soapstock Biodiesel Production

The high free fatty acid (FFA) content of the oil requires both transesterification and esterification to reduce the FFA content to the acceptable levels (below 5-6). Esterification of soybean soapstock was carried out in a reactor using optimum operating conditions as reported in the work carried out by Mbah and Esonye (2021). The esterified oil was separated from the excess methanol/impurities in a settling tank as shown in Figure 2.

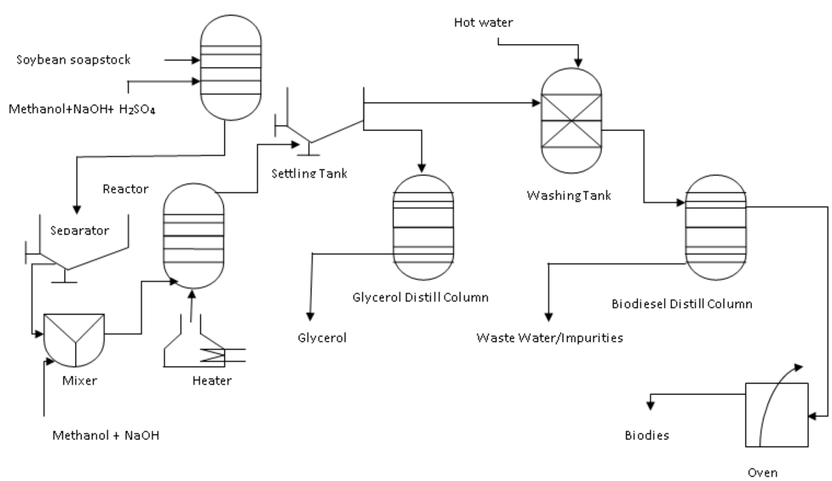

Figure 2: Flowchart for biodiesel production from soyabean soapstock

Biodiesel production from the esterified oil by transesterification, using methanol as solvent in the presence of NaOH as catalyst was carried out, and the biodiesel then separated from the excess methanol/impurities.

The major equipment used in the esterification/transesterification of soybean soapstock were; a mixer, 2 reactors, 2 settling tanks, a washing vessel, glycerol distillation columns and biodiesel distillation columns.

2.3. Cost Estimation

The economic study started with an estimation of the fixed cost, production cost, and the profit achieved for both processes. The economic feasibility of the two processes were evaluated with an average production rate of 250-280 litres/day of biodiesel. Cost estimation was conducted based on the cost for capital, equipment, raw materials, operation, utilities, and labor in accordance with the literature (Gebremariam and Marchetti, 2018) and the current market price in Nigeria. The method developed by Peters et al. (2003) was used for estimating the purchased cost of equipment (PCE). Economic analysis of biodiesel from cow tallow was performed by several steps, including, calculation of capital expenditures (CAPEX) and operating expenditures (OPEX), calculation of cash flows, profitability and breakeven point analysis. However, in order to analyze the economic value, several assumptions were made.

2.3.1. Assumptions

The price of biodiesel was taken from the international price of biodiesel at an average cost of $ 2.40/litre for biodiesel group B-5 as at 31st December, 2022 (MDA 2022). At the official exchange rate of ₦435 to 1 US dollar (as at September, 2022), the approximate cost comes down to ₦1000 ($2.30)/litre. A 300 L assumption of feedstock inventory was made considering the scale of equipment purchased, the available start-up capital and the available feedstock obtainable within the locality. A FAME (biodiesel) mole fraction of 0.82 and 0.94 were obtained from experiments in works carried out my Mbah et al. (2021), on cow tallow and soyabean soapstock respectively. The production indices and the mole fraction compositions of the feedstocks (cow tallow and soyabean soapstock) used in the production capacity estimation are shown in Tables 1, 2 and 3. From the FAME (biodiesel) composition column in Tables 2 and 3, production capacities of 66,000 L and 80,000 L were evaluated for the cow tallow and soybean soapstock biodiesel which formed a basis of equipment design. The economic parameters analyzed were gross profit, net present value (NPV), internal rate of return (IRR), return on investment (ROI) and payback period (PP) in order to determine and compare the level of profitability. These parameters were evaluated using Microsoft excel 2007.

Table 1: Summary of assumptions for cow tallow and soybean soapstock biodiesel production

Parameter	CTB	SBS
Production capacity (L/year)	66,000	80,000
Product price (L)	₦1000	₦1000 ($2.30)
Plant life (years)	5	5
Base year	2022	2022

CTB: cow tallow biodiesel, SBS: Soybean soapstock biodiesel

Table 2: Mole fraction/production capacity of cow tallow biodiesel (Mbah and Onukwiuli, 2021)

Component	Mg	Dg	Tg	FAME	Alcohol	Glycerol
Mole fraction	0.026	0.021	0.086	0.820	0.019	0.012
Daily production (L)	7.689	6.261	25.716	246.000	5.691	3.600
Yearly production (L)	2,307	1,878	7,715	73,800	1,707	1,080
Yearly production @ 90% efficiency (L)	2,076	1,690	6,943	66,420	1,537	972

Mg; monoglycerides, Dg; diglycerides, Tg: Triglycerides, FAME; Fatty acid methyl ester (biodiesel)

Table 3: Mole fraction/production capacity of soybean soapstock biodiesel (Mbah and Esonye, 2021)

Component	Mg	Dg	Tg	FAME	Alcohol	Glycerol
Mole fraction	0.002	0.009	0.017	0.941	0.003	0.017
Daily production (L)	0.645	2.775	5.040	282.330	0.942	5.241
Yearly production (L)	194	833	1,512	84,699	283	1,572
Yearly production @ 95% efficiency (L)	184	791	1,436	80,464	268	1,494

3. RESULTS AND DISCUSSION

3.1. Equipment Costing

Figures 1 and 2 shows the process flow diagram (PFD) for production of biodiesel from cow tallow and soyabean soapstock respectively. It can be observed that the difference in the composition of equipment in both processes is the additional equipment (reactor and separator) needed for esterification of soybean soapstock prior to the transesterification. The equipment used for both processes (cow tallow and soybean soapstock) and their costs are highlighted in Tables 4 and 5 respectively. It was observed that distillation columns and reactors constitute the bulk of the costs in both cases with distillation columns and reactors recording the bulk percentage of the equipment cost as shown in Tables 4 and 5. The total equipment cost for cow tallow biodiesel production was ₦20,000,000 ($45,977) while total equipment cost for the process using soybean soapstock was ₦21, 000,000 ($48,276).

Table 4: Equipment cost for cow tallow biodiesel production (Peters et al., 2003)

Equipment	Unit Cost (₦)	Cost (₦)	Percentage (%)
Reactor 2	6,775,000	6,775,000	33.87
Mixers (2)	466,500	933,000	4.66
Separators (1)	544,200	544,200	2.72
Heater	27,200	27,200	0.14
Distillation columns (2)	4,665,000	9,330,000	46.65
Washing Vessel	563,700	563,700	2.82
Oven	1,827,000	1,827,000	9.13
		20,000,100	100

Table 5: Equipment cost in biodiesel production from soyabean soapstock

Equipment	Unit Cost (₦)	Cost (₦)	Percentage (%)
Reactor 1	455,700	455,700	2.17
Reactor 2	6,775,000	6,775,000	32.26
Mixers (2)	466,500	933,000	4.44
Separators (2)	544,200	1,088,400	5.18
Heater	27,200	27,200	0.13
Distillation columns (2)	4,665,000	9,330,000	44.43
Washing Vessel	563,700	563,700	2.68
Oven	1,827,000	1,827,000	8.70
		21,000,000	100

3.2. Cost Evaluation

Total production cost was calculated based on the capital and operational expenditure for both processes and was found to be ₦31,440,000 ($72,276) for biodiesel production using cow tallow and ₦35,540,000 ($81,701) for biodiesel production using soybean soapstock. Tables 6 and 7 shows the estimated cost of production for biodiesel from cow tallow and soybean soapstock. Capital expenditures (CAPEX) were calculated to include cost of equipment, installation/instrumentation expenses, building/construction costs and working capital. Operating costs (OPEX) was calculated to include cost of raw materials, salary/wages, utilities and distribution/maintenance costs.

The operational expenditures were evaluated over a one-year period. The raw material costs were estimated with an assumption of 300 litres of cow tallow and soybean soapstock supplied to the plant per day. This assumption was made bearing in mind the capacity of the installed equipment and the availability of the raw material within the proximate locality. The quantity and cost of raw materials were used to estimate the total annual cost of the raw materials used as presented in Tables 6 and 7 for cow tallow and soybean soapstock respectively. The cost for the cow tallow which was ₦1,000,000 ($3,000) was considerably less than the cost of same quantity of soybean soapstock which was ₦2,300,000 ($5,287). This is because soybean soapstock has a higher alternative value (usually used in animal feed and soap production) and was thus more expensive to acquire. The annual salary/wages was estimated as ₦1,440,000 which is the annual salary for four (4) casual workers at a monthly salary of ₦30,000. The annual salary/wages for workers in both plants were the same as both processes only slightly differed in production routes.

Table 6: Estimated production cost for biodiesel production from cow tallow

Component	Cost (₦)	Percentage (%)
Capital expenditure		
Equipment	20000000	71
Installation/Instrumentation	2000000	7
Building/Construction	5000000	18
Working capital	1000000	4
	28000000	
Operational expenditure		
Raw materials	1000000	29
Salary/wages	1440000	42
Utilities	700000	20
Distribution/Maintenance	300000	9
	3440000	
Total Cost	31440000	

The utilities used in the production processes were basically water and electricity. The equipment required electricity for power while water was basic in both the production process and day to day running of the plants. The process using soybean soapstock required a higher utility cost (₦1,000,000) compared to that of cow tallow (₦700,000) due to the longer process route and extra equipment involved in production. Each unit of equipment is estimated to use an average of ₦250 worth of electricity per day at tariff rate of about ₦50 per kilowatt. With an average water bill of ₦100,000 per annum, the utility cost culminates to ₦700,000 and ₦1,000,000 for cow tallow and soybean soapstock biodiesel production processes. It can also be observed that cost of equipment and salary/wages constitute the majority of the capital and operational costs with 71% and 42% respectively for the CT process. The cost of equipment for cow tallow was though slightly lower than that for soybean soapstock as shown in Table 7 due to the additional equipment needed for the esterification reaction.

Table 7: Estimated production cost for biodiesel from soybean soapstock

Component	Cost (₦)	Percentage (%)
Capital expenditure		
Equipment	21000000	69
Installation/Instrumentation	3000000	10
Building/Construction	5000000	16
Working capital	1500000	5
	30500000	
Operational expenditure		
Raw materials	2300000	46
Salary/wages	1,440,000	29
Utilities	1000000	20
Distribution/Maintenance	300000	6
	5040000	
Total Cost	35540000	

This also resulted in an increase in the cost of utilities and working capital in biodiesel production using soybean soapstock. It can also be observed from Table 7 that the cost of raw materials for the process using soybean soapstock was higher than the cow tallow process. This was because the soybean feedstock was expensive (compared to cow tallow) due to its high alternative value. The soybean soapstock as the name implies can be used as raw material for soap production and sometimes for animal feed production. However, better alternatives in both cases have ensured that the demand for soybean soapstock will always be low with the price also consequently low. The cost of acquiring cow tallow however pales significantly with that of soybean soapstock because cow tallow has little or no alternative value and hence the smaller cost of acquisition.

3.3. Cash Flow Projection

The cash flow projection shows the cash that is anticipated to be generated or expended over a chosen period of time in the future. In other words, it shows how cash is expected to flow in and out of the processes. It is an important tool for cash flow management, letting one to know when expenditures are too high or when one might want to arrange short term investments to deal with a cash flow surplus. Cash flow projection gives a much better idea of how much capital investment a business idea needs. Tables 8 and 9 shows the annual sales and production costs over the five year period for the cow tallow and soybean soapstock respectively. There was a gradual increase in production cost and sales over the five year period with optimum sales and maximum production costs obtained at the fifth year as seen in Tables 8 and 9 below. This is however advisable as plants are usually started up at a percentage of their maximum capacity to properly study the equipment, process and procedures without putting too much pressure on staff and equipment. A maximum sale of ₦66,000,000 ($151,724)/year for cow tallow was obtained with the assumption of maximum biodiesel production capacity of 66,000 litres/year at a unit cost of ₦1000 per litre. A maximum sale of ₦80,000,000 ($183,908)/year was obtained from 80,000 litres/year at same unit price for soybean soapstock as shown in Tables 8 and 9 below. This notable difference in production capacity from both feedstock can be attributed to the higher biodiesel yield obtained from soybean soapstock when compared to the cow tallow feedstock. The total cost of production of cow tallow biodiesel over the 5 year period in view is ₦121,000,000($278,161) which represents 72% of the total sales at ₦166,800,000 ($383,448). This is higher than the percentage of cost (₦137,420,000) to sales (₦203,500,000) for biodiesel production from soybean soapstock which is at 67%. This lower cost to sales ratio for soybean soapstock biodiesel production when compared to that of cow tallow biodiesel production further confirms its higher profitability.

Table 8: Cash flow for biodiesel production using cow tallow

Year	Sales (₦)	Total Cost (₦)	Fixed cost(₦)	Variable cost (₦)
0	0	5,000,000	5,000,000	0
1	16500000	15100000	5,000,000	10,100,000
2	23100000	18120000	5,000,000	13,120,000
3	29700000	24160000	5,000,000	19,160,000
4	31500000	27180000	5,000,000	22,180,000
5	66000000	31440000	5,000,000	26,440,000
Total	166800000	121000000		

Table 9: Cash flow for biodiesel production using soybean soapstock

Year	Sales (₦)	Total Cost (₦)	Fixed cost(₦)	Variable cost (₦)
0	0	5,000,000	5,000,000	0
1	20000000	17300000	5,000,000	12,300,000
2	28000000	20760000	5,000,000	15,760,000
3	36000000	27680000	5,000,000	22,680,000
4	39500000	31140000	5,000,000	26,140,000
5	80000000	35540000	5,000,000	30,540,000
Total	203500000	137420000		

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3.4. Profitability Analysis

Profitability indicators were calculated to compare the economic feasibility of both processes: Net present value (NPV), annual gross profit (GP), annual net profit (NP), payback period, return on investment (ROI) and interest rate of return (IRR) were used in this work to evaluate and compare profitability of both processes. Assuming straight line depreciation and 10% discount factor, the above named indicators were evaluated. Table 10 shows the net present value (NPV), interest rate of return (IRR), annual gross profit (GP), annual net profit (NP), payback period and return on investment (ROI) of both processes. The equations for the calculation of net present value (NPV), gross profit (GP), payback period (PP), return on investment (ROI) and internal rate of return (IRR) are shown in Equations 1 – 5 presented as follows:

$$NPV = \sum_{t=1}^{T} \left\{ Ct/_{(1+r)^t} \right\} - Co \quad (1)$$

$$\text{Annual gross profit (GP)} = Total\ annual\ sales - Total\ annual\ costs \quad (2)$$

$$\text{Payback period (PP)} = \frac{\text{Total capital investment}}{\text{Annual average net cash f low}} \quad (3)$$

$$Return\ on\ investment\ (ROI) = \frac{\text{Annual profit}}{\text{Total investment cost}} * 100 \quad (4)$$

Solving for internal rate of return is an iterative process and was estimated using equation 5 below:

$$₦\,0 = \frac{\sum NCF}{(1+IRR)*t} \quad (5)$$

Where *Ct* is the net cash inflow during the period t, *Co* is the total initial investment costs,

r is the discount rate and *t* is the number of time periods, *NCF* is the net cash flow, and *IRR* is internal rate of return.

Economic analysis at 10% depreciation gave NPV as ₦87,460,690 ($201,059) and ₦109,482,304 ($251,683) which tells the current value of the CT and SBS plants respectively. A pay-back time of 10 months and 9 months for cow tallow biodiesel and soybean soapstock biodiesel respectively shows a faster pay-back period for SBS**.** The faster payback period obtainable from the soybean soapstock biodiesel production when compared to cow tallow biodiesel was as a result of the improved profitability indexes such as net/gross profits, internal rate of return (IRR) and return on investment (ROI). These two indices (ROI and IRR) slightly differs because while ROI shows total investment growth over a number of years, IRR shows the annual growth rate. Though IRR is generally ideal in analyzing capital budgeting projects, it can be misinterpreted if used outside appropriate scenarios. The higher net present value (NPV) after 5 years for the process using soybean soapstock indicates higher profitability when compared to the process using cow tallow as feedstock. Though the initial investments and cost of raw materials were higher for the soybean soapstock process, the high yield obtained resulted in the higher cash flow and thus higher profitability.

Table 10: Profitability indicators for cow tallow and soybean soapstock biodiesel

Probability indicator	Cow tallow biodiesel	Soybean soapstock biodiesel
Net present value (₦)	87,460,690	109,482,384
Internal rate of return (%)	80	88
Gross profit(₦)	45,800,000	66,080,000
Net profit (₦)	36,640,000	52,864,000
Payback period (years)	0.84	0.75
Return on investment (%)	30.28	38.47

3.5. Breakeven Analysis

The basic idea of breakeven point analysis is to plot the production expenses, sales, and revenues against the percentage of full production capacity in order to determine the point at which both production expenses and sales are equal, and hence the revenues are zero. This point is called the breakeven point. Expenses, sales, and revenues are first calculated at different percentages of full production capacity, i.e., 0 to 100%, and are plotted against the corresponding percentages to determine the zero revenue point, i.e., breakeven point. It should be noticed that the lower the break-even point, the more profitable and feasible the process will be.

Figure 4 demonstrates the breakeven point within the first year where the sales intercept with the cost. The sharp increase in sales after the 4th year was a result of a need to operate the plant at a fraction of its full capacity while Figure 5 shows the capacity (80%) and volume of sales (₦13,000,000) required to breakeven within the first year.

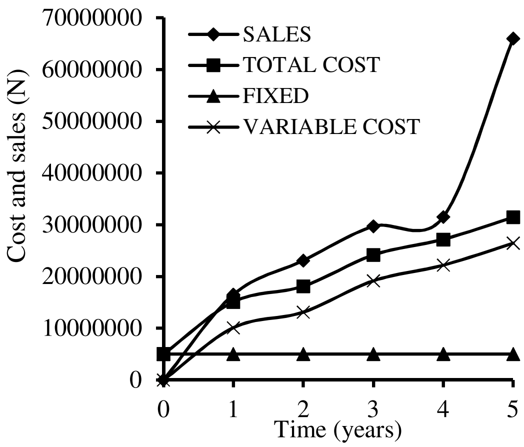

Figure 4: Plot of cost/sales against time for cow tallow biodiesel

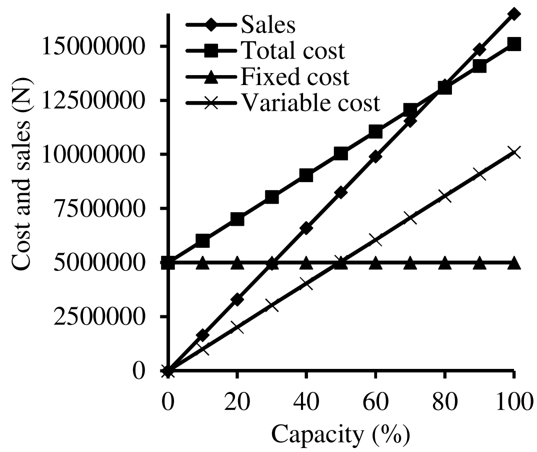

Figure 5: Plot of cost/sales against capacity for cow tallow biodiesel

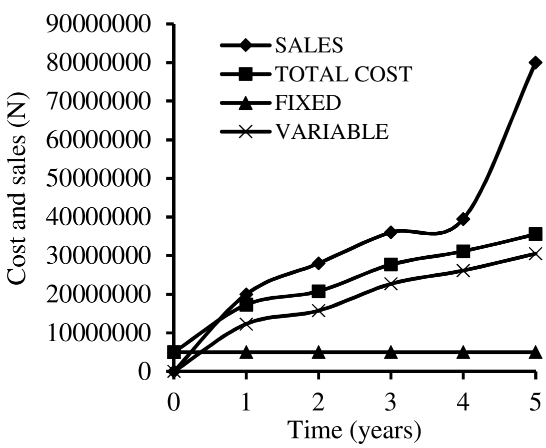

Figure 6: Plot of cost/sales against time for soyabean soapstock biodiesel

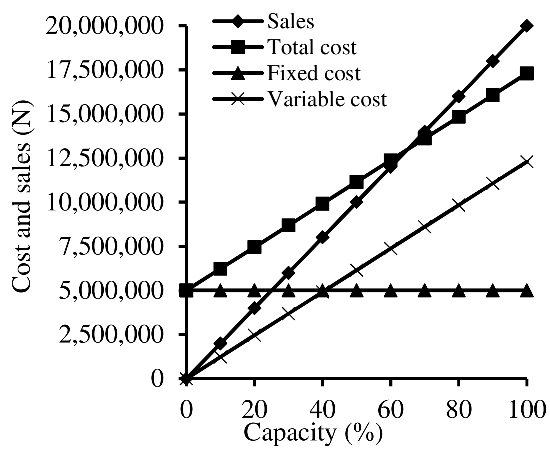

Figure 7: Plot of cost/sales against capacity for soybean soapstock biodiesel

It can be observed from Figure 6 and 7, the breakeven point for soybean soapstock biodiesel production, Figure 6 highlights that there was a breakeven within the first year while Figure 7 shows the capacity (60%) and volume of sales (about ₦13,500,000) required to breakeven within the first year. The lower production capacity required to breakeven in the first year when compared to the capacity in cow tallow production also signifies higher productivity in soybean soapstock biodiesel production.

The comparative probability and breakeven analysis from both processes has thus established biodiesel production using soybean soapstock as the more profitable method and thus recommended as the better feedstock for biodiesel production.

4. CONCLUSION

This comparative techno-economic study illustrated that the production of biodiesel using soybean soapstock feedstock has a relatively higher profit profile with a payback period of only 9 months at a production capacity of 60% when compared to 10 months needed to break-even for cow tallow biodiesel production at 80% production capacity. A return on investment of 38.47% for SBS biodiesel production was also high compared to CT biodiesel production with a ROI of 30.28%. These parameters among others such as net present value and Interest rate of return all point to higher profitability for SBS biodiesel production when compared to CT biodiesel production. It can thus be concluded from an economic perspective that soybean soapstock is the more economically viable feedstock for biodiesel production.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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