Economic evaluation of anaerobic digestion technology

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Abstract

This paper evaluates the viability of anaerobic digestion technology as a treatment process for organic waste with an intention of solving the landfill crisis as well as mitigation of greenhouse gases. The proposed technology consists of two digesters system using soaking as a pre-treatment method, and with recirculation of the process water and digested sludge. A financial model was developed to evaluate the economic feasibility of this technology as a renewable energy. Instead of the waste decomposing at local landfills, is converted into a source of energy while the by-products of the process are treated and used as fertilizers. This technology will require a capital investment of R 2, 2773,900 with a capacity to treat 730000 kg of waste annually. The annual production cost of R1, 269,138 was calculated. The proposed model has debt repayments of R 2,478,551. The total revenue from year 2 – 5 was R 2,360,800, R 2,930,158, R 3,457,314.6 and R 3,988,407.6, respectively. These AD facilities can produce up to 110960 kWh per annum of biogas fuel. The net present value of R3, 042,592, internal rate of return (IRR) of 33% and (BCR) of 1.96 shows that the technology is economically feasible.

Keywords: Anaerobic digestion, Energy recovery, Waste disposal

1. Introduction

Looking at the waste management hierarchy which include treatment and disposal of organic waste, energy recovery from waste, recycling and only disposing to landfill as a last alternative, requires that the external costs of different waste management options are valued in monetary terms using appropriate valuation methods, in order to ensure that they are properly understood

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and accounted for in decision making. This will allow all disposal options to be compared equally, on the basis of their overall costs to society per tonne of waste treated.

Worldwide, countries are embarking on investing in green technologies and jobs. For these reasons, governments have recognised the importance of anaerobic digestion, with many of them providing financial incentives for farmers to install anaerobic systems. This is because energy from anaerobic digestion is considered as biomass energy and, therefore, a form of renewable energy (Donoso-Bravo, et al., 2011).

This model aim to minimise capital investment and create green jobs for both skilled and unskilled individuals. In this paper, net costs were estimated based on the following considerations. Firstly, the plant was set to 5 year plant operating life with the cost of constructing the plant spread over 6 months, a depreciation schedule of 2 year was set. Furthermore, taxation rate was defaulted to 29% and the discounted cash flow rate was set at 8%. Lastly, the optimization function used is "Net Present Value".

2. Economic evaluation process

2.1 Production costs

Factors including durability and price were considered when selecting equipments. Quotations obtained from manufacturers were used to estimate all equipment costs. The AD model was designed based on a 5 years project life with daily operations of 8 hours. An estimate of the variable and fixed costs of generating the gas and the production flow sheet are in Table 1 which gives the raw material, labour requirements, and the capital cost estimate. In addition to raw material, labour requirements, and the capital cost estimate, factors such as depreciation, debt repayments, fixed and variable costs were also taken into account.

Table 1: Summary of production costs (Sinnott, 2005).

Description	Typical values
Variable costs	
Raw material	from flow-sheets
Utilities	from flow-sheets
Shipping and packaging	10% of the maintenance cost
Miscellaneous materials	usually negligible
	Sub-total A
Fixed costs	
Maintenance	5–10% of fixed capital
Operating labour	from manning estimates
Laboratory cost	20–23% of operating labour
Supervision	20% of operating labour
Plant overheads	50% of operating labour
Capital charges	10% of the fixed capital
Insurance	1% of the fixed capital
local taxes	2% of the fixed capital
Royalties	1% of the fixed capital
	Sub-total B
Sales expense	20–30% of the direct production cost
General overheads	
Research and development	
	Sub-total C
Annual production cost= A+B+C	
Production costs £/kg= Annul production cost/ annual production rate	

2.2 Cash flow

Cash flow method (**Figure 1**) was used to show the cash flow over the 5 year project life, where A – B shows the starting point of the plant including construction, investment required to design the plant as well as commissioning. Point B – C shows the heavy flow of capital to build the plant, and provide funds for start-up. Stage C – D illustrates the cash-flow curve turns up at C, as the process comes on stream and income is generated from sales. At this point, the net cash flow is positive. However, the cumulative amount remains negative until the investment is paid off at point D. Point D is referred as the break-even point which is commonly known as the pay-back time. Point D – E shows the cumulative cash flow is positive that is project is gaining a return on the investment. Point E – F represents the end of project life where the rate of cash flow may tend to fall off, due to increased operating costs and falling sale volume and price, and the slope of the curve changes. The point F gives the final cumulative net cash flow at the end of the project life.

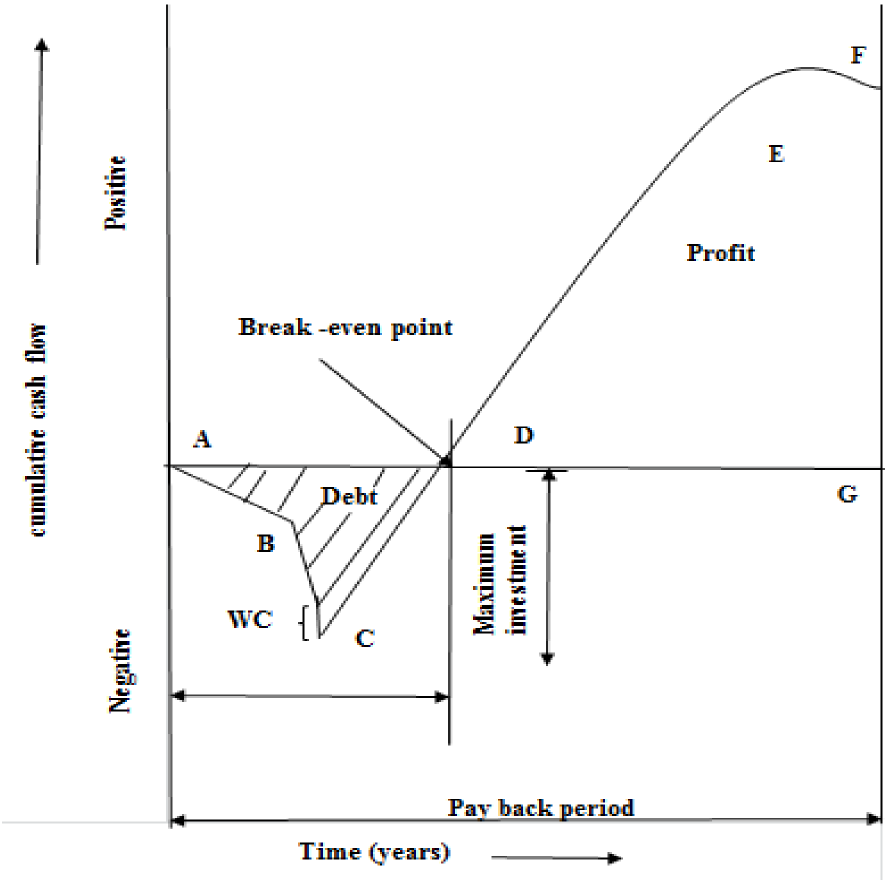

Figure 1: Typical cash flow diagram (Sinnott, 2005).

2.3 Profitability analysis

The profitability of the model was evaluated using the net present value (NPV), internal rate of return (IRR) and benefit cost ratio (BCR). The NPV substitutes the costs of capital at an interest rate for the discounted cash flow rate of return (Garrett, 1989). It is given by the estimated net future value in year n over the interest rate percentage (Equation 1). The positive value of the NPV will indicate profitability of this technology (SAICA, 2014; KPMG, 2014).

$$\mathrm{NPV} = \frac{\text{Estimated net future value (NFV) in "n" years}}{(1+\mathrm{r})^{\mathrm{n}}} \qquad (1)$$

Where r is the interest rate/100 and n is the number of years

$$\therefore \sum \mathrm{NPV} = \sum_{\mathrm{n}=1}^{\mathrm{n}=\mathrm{t}} \frac{\mathrm{NFV}}{(1+\mathrm{r})^{\mathrm{n}}} \qquad (2)$$

When comparing which project to invest in, IRR is often preferred over other investment criteria by financial officers (Brealey, et al., 2007). Internal rate of return is defined as the interest rate paid on the unpaid balance of a loan such that the payment schedule makes the unpaid loan balance equal to zero when the final payment is made (Newnan, et al., 2004). Conventional approach is to invest in only in projects with positive IRR. In this study, IRR were calculated using the equation 3.

$$\therefore \sum \mathrm{IRR} = \sum_{n=1}^{n=t} \frac{\mathrm{NFV}}{(1+r)^n} = 0 \tag{3}$$

Benefit cost ratio (BCR) is also one of the profitability tool that was used to assess the profitability of the model. It is normally expressed as discounted present values in monetary terms (Equation 4). For economic viability of process the ratio must always be greater than 1 and the higher the ratio the more chances for attraction of investors (Mian, 2010).

$$\mathrm{BCR} = \frac{\sum \text{Net benefit}}{\sum \text{Net cost}} \tag{4}$$

3. Result and discussion

The proposed economic evaluation model for AD technology consists of four preparation stages prior digestion. The preparation stages include: sorting of raw material achieved through hand sorting, screening of the undesired components, size reduction and soaking which was used as a pre-treatment method for the feedstock which takes place in the mixer. The raw materials are then pumped into the digester and the gas collected is then stored. To ensure accurate costing, the quotations supplied by the suppliers were used. For economic viability of this project, the NPV, BCR and IRR were considered.

3.1 Plant layout

In this section, an AD system was considered. Isometric projections of AD plant layout are presented in Figure 2 and Figure 3.

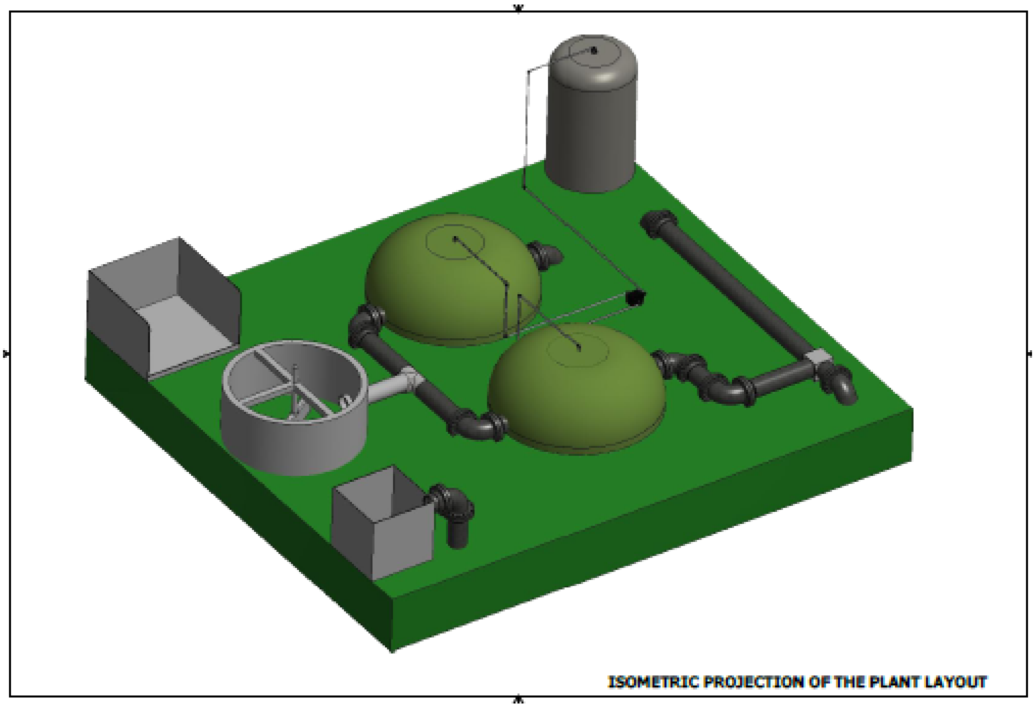

Figure 2: Isometric projection of the AD plant layout (drawn using Autodesk inventor, 2014)

The plant is composed of three interconnected sections: the mixer, digestion and scrubbing. With the aim of cost minimization for the AD technology by considering the plant operation parameters, feedstock pre-treatment strategies such as particle size reduction and soaking of feedstock prior digestion were employed to improve the methane yields. A site selection next to the landfill was considered with an intention of cutting costs for transportation of feedstock and taking into account the exhaustion of landfills, the demand for reduction of GHG and the carbon footprints. The technology offers a mixer to promote homogeneity of the feedstock. It is further accompanied by two batch reactors suitable to degrade 2000kg of organic matter.

The two anaerobic digesters will be aligned in parallel to each other with a working volume of 35m^3 each (Figure 4), to be located in Germiston, a town near the University of Johannesburg, with the intention of treating the organic waste collected in the surrounding area and the university. This technology has a total capacity of treating 62 000 kg/ month of organic waste that is approximately 730000 kg/year of waste. The generated methane will then be stored in a gasometer with a volume of 2500 m^3. The heat required by the digester to keep a correct operating temperature for bacteria ranges between 35 – 45 ˚C. In addition, the plants estimated to produce about 547 500 kg/year of compost which will be treated and used as fertilizers.

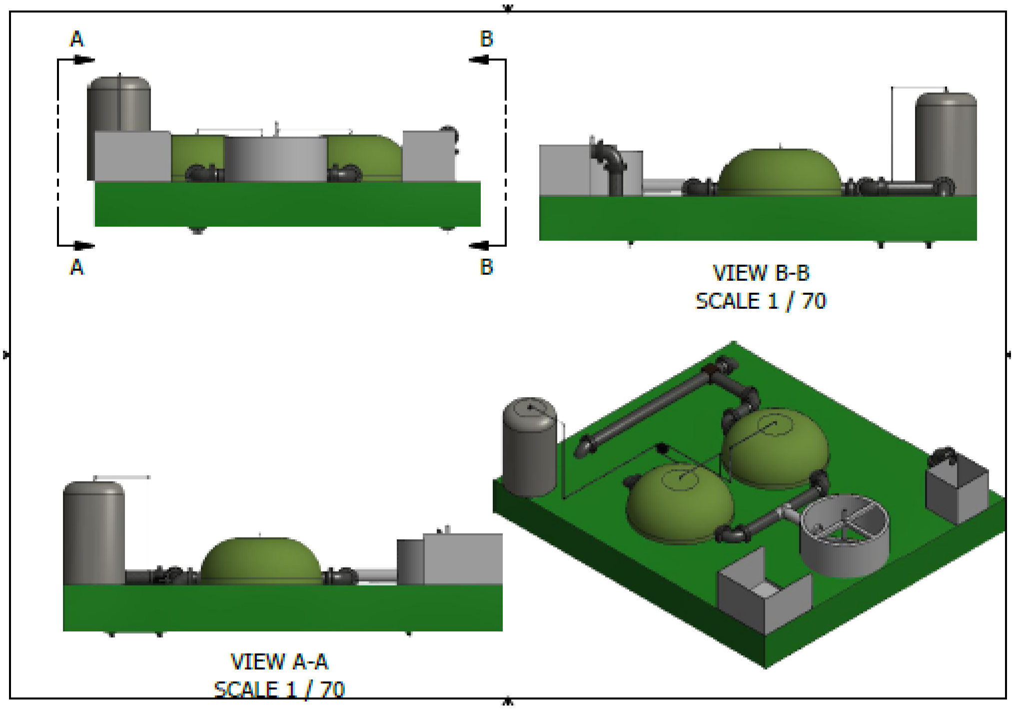

Figure 3: Side and top views of the proposed AD plant (drawn using Autodesk inventor, 2014).

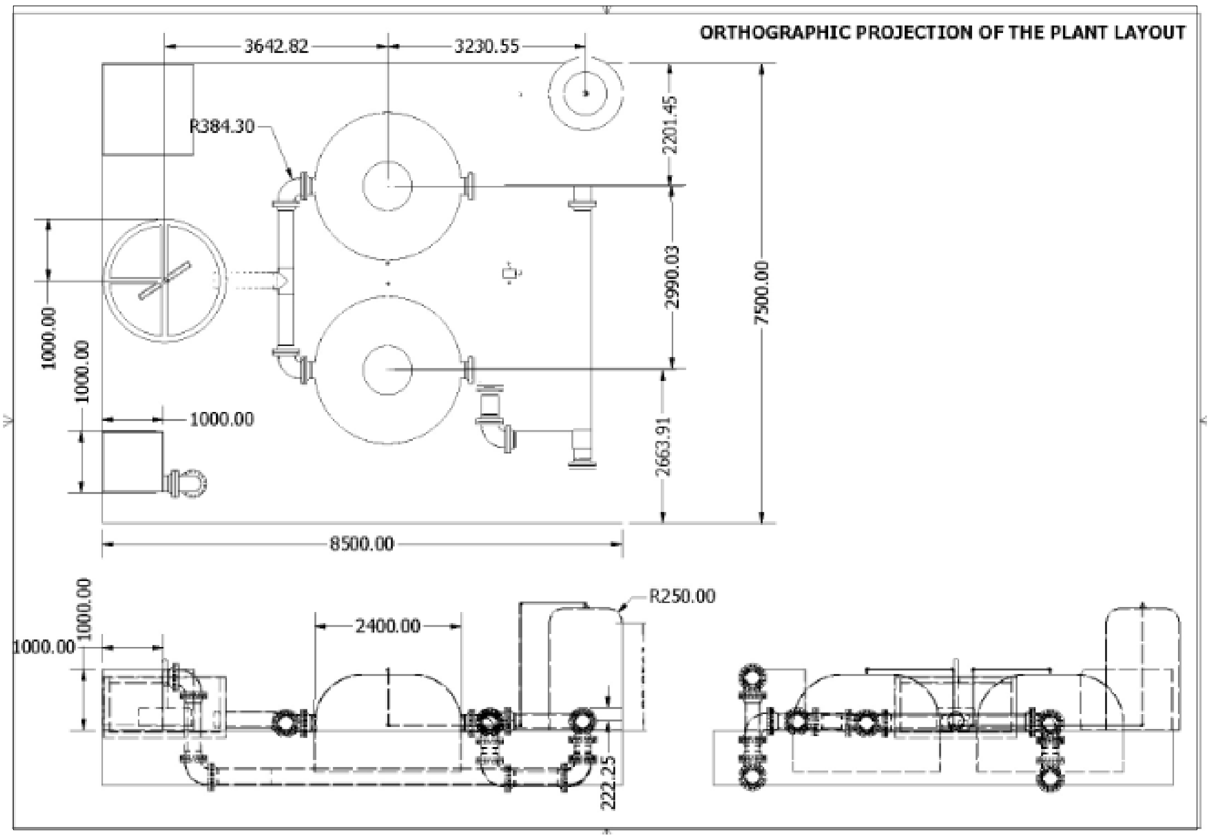

Figure 4: Orthographic projection of the AD plant layout (drawn using Autodesk inventor, 2014)

3.2 Mass balance

Material and energy balances were conducted to quantify utilities and products on a yearly basis. These were linked to the input unit costs in order to calculate the actual treatment cost per unit mass of waste taking into account factors such as depreciation, debt repayments, fixed and variable costs. Based on plant projections in section 3.1, the reactor have the capacity to accommodate 35 m^3 working volume with continuous feeding of 1000 kg/d per digester. This model allows a working schedule 8 hours per day for 30 days per month based on a 5 year project life. Table 2 shows the summary of materials balances for the process model. The information presented was used to quantify the costs for utilities and products. The average biogas production from both digesters is about 304 kWh/day, which is equivalent to approximately 110960 kWh/year (Table 3) of primary energy in the case of 8 hours operation per day and 2000 kg/day waste feeding for 7 days per week.

Table 2: Material balance for the model

	Mass balance	**Energy balance**	**Cost**	**Monthly costs**	**Annual costs**
Waste	1000 kg	51			
Water	1000 L	114.95	R 30	R 13,440	R 161,280
Electricity	0.325		R 21.28	R 9,536.8	R 114,441.6
Labour			R 13.39	R 6,000	R 72,000
Operating costs			R 64.68	R 28,976.8	R 347,721.6

Table 3: Daily, monthly and annual energy production rates

	Primary energy [kWh]
Daily	304
Monthly	9424
annual	110960

3.3 Summary of costing AD model

Raw materials used in this technology are biodegradable wastes such as animal manure, food waste, and garden waste. These materials are regarded as waste and are disposed to landfills; therefore, no raw material costs are involved. The pilot plant will be situated next to a landfill site, avoiding any direct transportation cost.

Detailed cost for AD model with a feeding capacity of 1000 kg/day of organic matter and 850 L of water per digester was conducted. The model costs were estimated using South African Rand at an exchange rate of US$1: R 10.30 (SARB, 2014) 0 with the corresponding funding with a total annual rate of 9 % per annum. The proposed annual rate was in accordance with those of Peters and Timmerhaus (1991) 0 who reported an interest rate of 9% or more for attraction of investors. Company tax rate and value added tax of 29% and 14%, respectively, were assumed (Table 4). The cost of R0.065/L for water was used (Anon., 2014). An electricity cost of R0.66 was used (rates, 2014).

Table 4: AD process model assumptions

Description	**Units**	**Value**
Annual Working Hours	Hrs/yr	5376
Plant Estimate Down Time	Hrs/yr	960
Plant Available Time	Hrs/yr	4416
Actual Plant Capacity	t/hr	960
Exchange Rate	R/$	10.30
Project Period	Yrs	5
Depreciation Period	Yrs	5
Capital Financing Period	Yrs	5
Margin on Investment	% per annum	3%
Dept	% Capital	1
Equity	% Capital	0
Bank Finance Fee	% on debt	2.00
Actual Annual Production	kW/yr	714760
Available Plant Capacity	kW/yr	720000
Actual Production	kW/day	1958.0
Input Cost		
Electricity Cost	R/KWh	0.66
Water Cost	R/L	0.065
Cost of sodium hydroxide	R/kg	
Electrical Power Consumption	KWh/hr	68.9
Water Consumption	L/day	500
Output Cost		
Sale of biogas	R/kg	R32.2
Sale of compost	R/kg	R65

The figures presented in this section are estimates based on desktop studies. All capital equipment was specified to the expected process duties, electrical and civil requirements. Cost calculations were conducted for an AD technology model with the capacity of treating 2000kg waste per day production capacity and with a total commissioning cost of R 401,076 (Table 5). These include the cost of two digesters (R 43,800), piping and valves (R 23,900), civils (R 47,000), transportation (R 30,089), wiring (R 56,500) and installation (R 105,859).

Table 5: AD plant commmissioning costs

Equipment	Qty	Unit Price	Total Price
Reactor	2	R 21,900	R 43,800
Piping and valves	Set	R 23,900	R 23,900
Structural work	Set	R 97,700	R 97,700
Civils	Set	R 43,400	R 43,400
Electricals and Instrumentation	Set	R 56,528	R 56,528
Transport and Logistics	1	R 25,889	R 25,889
Installation & commissioning	1	R 109,859	R 109,859
Total			**R 401,076**

The study also focused on the profitability of the technology over the given period of 5 years. The cost included fixed and variable costs of the process, taking into account 5% maintenance fee per annum as a percentage of capital investment. Management fee of 3% per annum of revenue generated was also considered. The total capital investment of the project was R2, 273,900. Again the fixed costs for this technology were estimated to be R792, 622 and the corresponding direct production costs of R1, 074,671. The annual production cost of R1, 269,138 was calculated (Table 7). The proposed model has debt repayments of R 2,478,551 calculated using 100% debt funding over a 5 year project life at 9% interest rate per annum.

On the 1st year of the project, R401,076 was used to commission the plant. At this stage, no revenue was observed as a result a negative cash flow was obtained. A break point is estimated after the first year of operation with two revenue streams. These streams include biogas and compost. The total revenue from year 2 – 5 was R 2,360,800, R 2,930,158, R 3,457,314.6 and R 3,988,407.6 (Table 6), respectively. The proposed model have the fixed capital investments of R 792, 622 with the running costs of R 28,976.0 per month resulting in annual running costs of R 347,721.60.

Table 6: AD revenue streams.

	Period (years)			
Revenue streams	**2**	**3**	**4**	**5**
Biogas (R/L)	R2128000	R2674419.20	R3165582.288	R3688179.78
Compost (R/kg)	R232800.10	R255738.80	R291732.32	R300227.78
Total revenue	**R 2360800**	**R 2930158**	**R 3457314.61**	**R 3988407.60**

Table 7: Summary of annual production of AD technology model.

Description	Costs
Capital Investment	
Total physical plant cost	R 1,363,658
Fixed capital cost	R 1,977,305
Working Capital	R 296,595.7
Total investment required	**R 2,273,900**
Fixed Costs	
Maintenance	R 79,092.19
Operating labour	R 201,600
Laboratory costs	R 30,240
Supervision	R 144,000
Plant overheads	R 80,640
Capital charges	R 197,730.50
Insurance	R 19,773.05
Local taxes	R 39,546.09
Sub total	**R 792,622**
Direct production costs	**R 1,074,671**
Variable costs	
Raw materials	R 0
Miscellaneous material	R 6,327.38
Utilities	R 275,721.60
Sub total	**R 282,049**
Sales expense	R 107,467.10
General overheads	R 57,000
Research and development	R 30,000
Sub total	**R 194,467**
Annual production cost	**R 1,269,138**

Taking into account the interest rate of 9%, the technology will break even after 1 year and 4 months (Figure 6) that is the payback period of 1 year and 4 months. At this point, the project is no making any profit or loss, that is all cost are recovered from sales values. At the end of the 5th year the, it will yield the net positive value of R 3,042,592. The project will yield an IRR of 33% which is higher than the cost of investment. The corresponding BCR of 1.96 was obtained which is acceptable since a higher ratio indicate good investment potential.

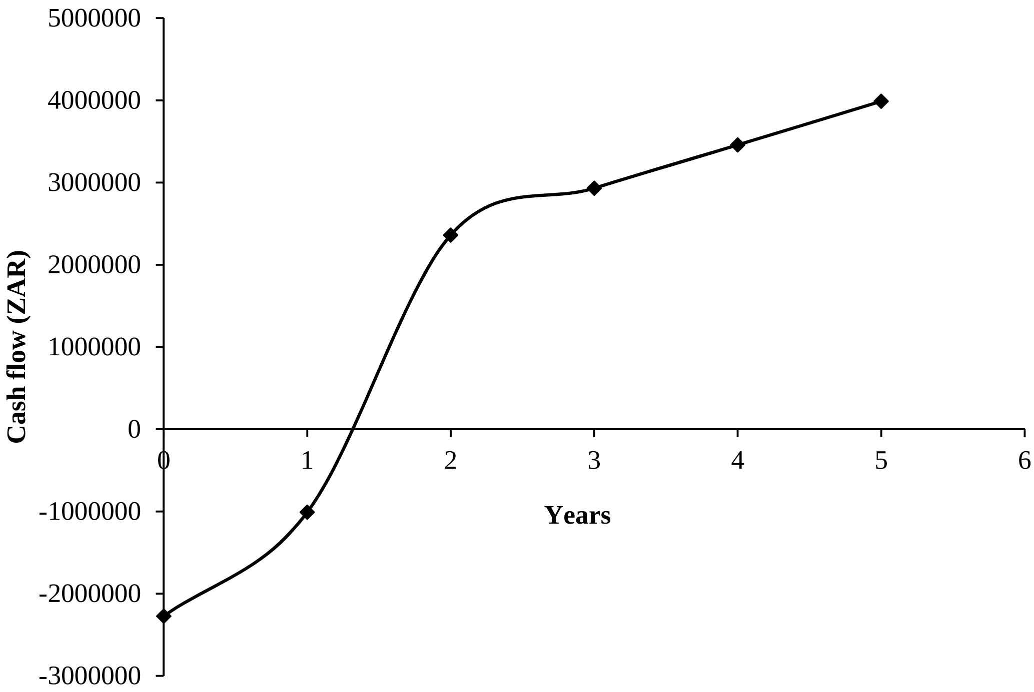

Figure 5: Cash flow diagram for Anaerobic Digestion technology.

4. Conclusion

In this paper an economic evaluation of an AD model was carried out on the basis of 8 hours per day operation based on a project life cycle of 5 years. The project takes 1 year and 8 months to recover initial project costs. Cash flow projections over 5 years indicate project viability as revenue is higher than total operating costs. This technology has a total capacity of treating 62 000 kg/month of organic waste that is approximately 7300000 kg/year of waste. The average biogas production from both digesters is about 18,000 Nm3/day, which is equivalent to approximately 1958 kW of primary energy. An interest rate of 9% was used. Company tax rate and value added tax of 29% and 14% respectively were proposed. A total commissioning cost of R401, 076 was calculated. The technology requires a total capital investment of R2, 273,900. Fixed costs for this technology were estimated to be R792, 622 and the corresponding direct production costs of R1, 074,671. The annual production costs of R1, 269,138 were calculated. The proposed model has debt repayments of R 2,478,551. The total revenue from year 2 – 5 was R2, 360,800, R2, 930,158, R3, 457,314.6 and R3, 988,407.6, respectively. Based on the total revenue cost, the proposed AD technology was found to be feasible for converting waste into energy. Again, this study has a considerable better economic and environmental performance. Future research is necessary to evaluate relative economic and environmental performance using a greater system boundary through experimental testing. These results suggest that conversion of organic waste to energy systems are preferred versus landfill disposal in terms of cost, energy, and greenhouse gas emissions. Additionally, development of guidelines on installation, use, and maintenance of these renewable energy systems are recommended to promote these technologies

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