Feasibility of using Biogas digesters as a Palm Oil Mill Effluent (POME) Management Tool in a Developing Country: A Ghanaian Case Study

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ABSTRACT

This study investigates the economic feasibility of using biogas digesters for Palm Oil Mill Effluent (POME) management by artisanal palm oil millers in Ghana. A 20 m^3 and 40 m^3 digesters were piloted in two (2) regions in Ghana and data on parameters such as total cost of an operational system, gas production per day, operation cost, and possible selling price for the biogas and liquid produced taken. These system operating parameters coupled with exchange and interest rates were used to compute the Net Present Value (NPV) and Payback Period (PBP) to examine the profitability (NPV >0) of running the system as a business. The base case scenario showed profitability as the NPV was $ 457,881 for the 20 m^2 and $ 922,062 for the 40 m^3 systems. The PBP of the 20 m^3 and 40 m^3 were 0.08 years and 0.06 years respectively. The systems were still profitable even with ± 5 % variation in all the system operational parameters. The analysis showed the suitability of using this technology for small scale processors in the management of POME to stop environmental degradation. The analysis also shows the sustainability of the technology in a developing country context.

Keywords: Net Present Value (NPV); Palm oil mill effluent (POME); Biogas; Economic feasibility; Profitability analysis: Bio-digester

Introduction

The oil palm value chain is one of the most important commodity value chains in Ghana. In terms of food security, it represents a significant source of the country's fats and oils for the populace (Osei-Amponsah et al., 2012). There is also a plethora of derivative products such as wine, pharmaceutics, clothing, roofing materials and baskets that are available as a result of this value chain (Akhbari et al., 2019). The production and marketing of these derivative commodities along the value chain, makes the oil palm crop one of the most important economic crops in Ghana. As a result of this fact, attempts are being made by both government and non-governmental organizations to grow this industry.

The cumulative effect of these programmes/ interventions is increased production, processing and commerce within the oil palm value chain. The sustainability of these gains is however dependent on the ability of various actors in the value chain to scale their production while minimizing the environmental impact of their activities. Consequently, Non-governmental organisations such as Solidaridad West Africa actively incorporate environmental sustainability measures into all its support to stakeholders. For instance, a significant feature of the Best Management Practices (BMP) training to farmers involves the efficient application of organic and/or inorganic fertilizer to minimize its impact on the environment. Such sustainability measures ensure that farm production is sustainably increased with minimal environmental impact. On the processing side of the oil palm value chain, a significant environmental hazard that needs mitigation is the Palm Oil Mill Effluent (POME). This is a by-product of the processing operation which,

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although a valuable resource, becomes an environmental hazard if not properly handled. For every tonne of fresh fruit bunches processed, about 0.7 – 1 m^3 of POME is produced. Thus, a small 2 tonnes/hour mill will produce about 1.4 – 2 m^3 for every hour of operation. This volume multiplied by the usual long hours of operation of the mills brings into sharp focus the scale of the POME problem mills have to deal with.

Most small scale or artisanal millers simply spill the untreated POME unto land. A few mills have trenches that lead to dug-outs where the POME goes to. These dugouts are simply covered with earth when full. These disposal methods cause serious damage to the environment. The continuous draining of the POME unto the bare floor makes the processing centres highly insanitary as the POME mixes with the soil to create a soggy dark bacteria filled soil-POME mix. The part of the POME that seeps into the soil ends up killing soil microorganisms as the POME is released hot (60 - 80^o C) and acidic (pH 3.3 – 4.6)(Corley & Tinker, 2003). A significant portion of the POME also drains unto nearby lands making it waterlogged. Mills that are close to water bodies also end up polluting them with POME. This perilous picture of land and water pollution is representative of most artisanal or small-scale mills in Ghana.

Globally, biogas digesters are one of the most prevalent tools for treating POME in the oil palm industry(Tan & Lim, 2019; Tan et al., 2021)the motivation and support from mills still reported low in Malaysia. This paper aims to discuss the benefits and drawbacks of POME utilisation in the palm oil supply chain based on environmental, social and economic concerns to review the favourability of POME elimination. A zero effluent approach is introduced based on POME evaporation technique, undiluted clarification practice and water recycling strategy as an alternative for conventional POME management approaches. An integrated palm oil complex concept is proposed which includes new palm oil processing approach that eliminates POME and provides industrial symbiosis possibilities within palm oil upstream and downstream sectors to promote sustainability of palm oil industry with balanced economic and environmental advantages. A comparative study between POME utilisation (Case 1 and 2. They allow mills to adequately treat POME to reduce the Biological Oxygen Demand (BOD) as anything beyond 5000 mg/l will have deleterious effect on the soil (Rankine & Fairhurst, 1999). The use of biogas digesters also allows the capture and an environmentally safe repurposing (combustible fuel for cookers, electric generators, light bulbs, steamers, etc.) of methane (CH_4) a greenhouse gas which is twenty one (21) times more lethal to the ozone layer than carbon dioxide (CO_2).

The Ghanaian ecosystem is not completely alien to the use of biogas digesters. There is literature reporting several biogas digesters being used for several purposes since the 1960's. The biogas digesters were mostly institutional (treatment of waste for schools, hospitals, abattoirs, etc.), communal and household systems (Bensah & Brew-Hammond, 2010). The main purpose of the biogas digester systems in Ghana has been the generation of biogas for cooking and electricity production and not the treatment of organic waste to address the sanitation issues or the use of the treated waste as organic fertilizer (Ahiataku-Togobo, 2016). This was because biogas was seen as a means of reducing Ghana's reliance on wood fuel which constituted 72 % of the nation's primary energy supply (Arthur et al., 2011). Most of the biogas digesters however failed shortly after the projects that deployed them ended. Several reasons have been adduced for the consistent failure of biogas project across the years. Some are non-availability of organic waste, breakdown of system component, absence of maintenance services, lack of operational knowledge and bad user experience (Bensah & Brew-Hammond, 2010). It is also worth noting that most of the identified causes of the failure have economic underpinnings. This is because there would not be any issues of not being able to replace faulty system components if the system generated enough residual income to replace such components. Such residual income would also allow the managers to afford all required routine maintenance activities, procure alternative organic waste streams if original stream is compromised, organize refresher courses for operators to enhance service delivery and improve user experience.

The underlying economic underpinnings of the causes of failure makes it imperative that one conducts an economic analysis of specific biogas systems to ensure that they are sustainable.

Although the general biogas literature is replete with economic feasibility studies of these systems, those analysis may not be directly applicable to the developing country setting where even institutional systems are relatively small and the nature of organic waste differs (Gebrezgabher et al., 2010; Lok et al., 2020; Meyer et al., 2021; Vo et al., 2018; Zhang & Xu, 2020)management and policy scenarios were investigated. Economic evaluations of all scenarios, except no subsidy scenario, show positive NPV. The highest NPV and IRR values are observed under reverse osmosis (RO. There have been efforts to study the economic feasibility of some biogas projects in Ghana. Kemausuor et al., (2016) studied the socio-economic feasibility of a 300 m^3 biogas system in a rural community in Ghana. The study found a Net Present Value (NPV) of $ 22,000 with a 16 years Payback Period (PBP) at a 10 % discount rate. Their proposed system however only works if there is a subsidy as only 5 % of the surveyed households were willing to pay the estimated base tariff of $ 30/ m^3 for the biogas produced. Mohamed et al. (2017) also investigated the feasibility of integrating a biogas digester into a waste treatment plant in Ghana. The simulations showed a profitable NPV at a discount rate of 23 % and a PBP of 5 years. Cudjoe et al. (2021) net present value, investment payback period, levelized cost of energy, and internal rate of return methods. A sensitivity analysis based on two scenarios (optimistic and pessimistic also modelled the economic feasibility of using biogas from food waste to generate electricity in two large cities (Accra and Kumasi) in Ghana. The study found that the project was only economically feasible when the discount rate did not exceed 20 % in both cities.

The utility of the results of the reported feasibility studies in Ghana are however highly sensitive to the plant and machinery cost, type of waste and the discount rates. It is therefore important that one performs an economic feasibility analysis whenever one intends to use a different type of waste (POME) and machinery as in this study's particular context. This study therefore reports on the economically feasible use of a 20 m^3 and 40 m^3 biogas digester for the treatment of POME in the Eastern and Central regions of Ghana.

Materials and Methods

Two balloon type biogas digesters were constructed at two artisanal mills in Kade (Eastern Region) and Fosu (Central Region). The two sites were chosen so as to capture the predominant technologies used in oil palm processing. This is important as the quality of POME is dependent on processing technology used in the artisanal process thus any economic analysis must take this into account. Aside being in the largest artisanal palm oil processing regions in Ghana, these locations were also chosen because they had all the main technologies and processes prevalent at most artisanal mills. The POME produced there was therefore expected to be representative of the majority of artisanal mills due to the similarities in the processing technologies and operations.

Study Area Description

Mill A (Kade)

The mill at Kade is a tolling centre where farmers bring their Fresh Fruit Bunches (FFB) to be processed for a fee. This mill mostly spills the POME into an uncemented channel that drains the POME into nearby land. A 40 m^3 biogas digester was constructed to hold and treat the POME. The digestate of this system will serve as liquid fertilizer for the numerous oil palm nurseries in the area. At the time of the study, a nursery farmer was willing to buy the digestate at GHS 5 per 25 litre gallon (i.e. $ 0.0425 per litre assuming GHS 1 = $ 0.17).

Mill B (Fosu)

The mill at Fosu was also a tolling site owned and managed by a cooperative of about 15 women. The small nature of their operation allows the processors to carry the POME and dispose it in some bushes behind the mill. These bushes however form part of the bank of a small stream that flows near the processing center. There is therefore the likelihood of POME being washed into the stream when it rains. This, as amply explained earlier, is bad for the environment. Based on the volume of production, a 20 m^3 biogas digester was set up at this site.

Economic assessment

The economic analysis was conducted using the Discounted Cash flow (DCF) method (Ahmad et al., 2020; Lee et al., 2021; Okolie et al., 2021)the cellulose and hemicellulose fractions of lignocellulosic biomass are catalytically converted to γ-valerolactone (GVL. This involved an analysis of capital cost of the 20 m^3 and 40 m^3 system, respective operation costs and revenue streams from the operation. Economic indicators of profitability such as Net Present Value (NPV) and Payback Period (PBP) were computed.

The cost of the installed biogas digesters (Table 1) were given by the supplier of the system (Webber Energy Ghana) and this cost included the cost of the biogas digesters as well as all civil works necessary for the operationalization of the system.

Table 1: Summary of parameters used for base case economic analysis

Parameter	Unit	Value
Cost of digester (20 m^3)	USD ($)	6600
Biogas flow rate (20 m^3)	m^3/day	2
Cost of digester(40 m^3)	USD ($)	9500
Biogas flow rate (40 m^3)	m^3/day	4
Life span	Years	15
Interest rate	%	0.16[a]
Operating cost of 40 m^3 biogas digester (15 % of capital cost of digester)	*USD/year	1,425
Operating cost of 20 m^3 biogas digester (15 % of capital cost of digester)	USD/year	990
Selling price of 25l of liquid fertilizer	USD	0.85
Exchange rate		GHS 1= $ 0.17
Cost of LPG gas	GHS/l	3.5
	GHS/m^3	3500
	USD/m^3	595
Operating days per year	Days	261
Selling price of biogas (LPG/3)	USD/m^3	160.8108

[a]Bank of Ghana reference rate

The cost of the installed system therefore constituted the first cash outflow item. The second cash outflow item was the operating cost which was a summation of the estimated annual cost of maintenance (5 % of cost of installed system) and the estimated cost of labour to man the system (10 % of cost of installed system). Using the 16 % Bank of Ghana reference rate, the operating cost was discounted over the 15 year life span of the system and used to compute the Net Present Value (NPV) using equation 1.

$$NPV = -C_O + \sum_{t=1}^{n} \frac{C_1}{(1+i)^t} \qquad (1)$$

Where

C_O= Cost of installed biogas digester system

C_1= Total operating cost

n = lifespan of biogas digester

t = number of years

i = discount (interest) rate

The Payback Period (PBP) which represents the duration needed for an investment to pay for itself was computed using equation 2

$$Payback\ Period\ (PBP) = \frac{Total\ cost\ of\ installed\ bio{-}digester\ system}{Annual\ Profits} \qquad (2)$$

Sensitivity Analysis

The volatile nature of micro/macro-economic indicators in developing countries makes it imperative to vary some of the parameters used in the economic analysis to better understand how they affect the profitability of the enterprise. The parameters varied during the sensitivity analysis were the discount rates, operating costs, selling price of liquid fertilizer and gas production volumes and selling price of biogas produced. These were varied at ±5 % interval as this was assumed to reasonably model the volatilities in the above mentioned parameters in a developing country. This was used to populate the sensitivity tables (Tables 2, 3, 4 and 5). Tornado charts were also used to study the relative comparative changes in parameters when it comes to NPV and PBP.

Results and Discussions

The economic analysis of the base case parameters (Table 1) showed the 20 m^3 and 40 m^3 biogas digesters to be profitable (NPV > 0). This was evident as an NPV of $ 457,881 and $ 922,062 was found for the 20 m^3 and 40 m^3 biogas digesters respectively over the 15 year lifespan of the system (Tables 2 and 3). This estimated NPV was however specific to operational parameters such as interest rate, system operating cost, selling price of liquid fertilizer, exchange rate, selling price of biogas and the gas production per day stipulated for the base case. The study therefore also investigated the profitability of the system when there is a ±5 % variation in the operational parameters for the 20 m^3 (Table 2) and 40 m^3 (Table 3) biogas digesters. The results also indicated profitability even with the ±5 % variations in the operational parameters of both systems.

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Table 2: Summary sensitivity Analysis of Net Present Value (NPV) for 20 m³ biogas digester system

20 m³ biogas digester (NPV)					
Interest Rate ± 5%		Operating Cost ± 5%		Selling price of liquid fertilizer ± 5%	
% Change	**NPV**	**% Change**	**NPV**	**% Change**	**NPV**
-5%	475857	-5%	458157	-5%	457782
0%	457881	0%	457881	0%	457881
5%	441006	5%	457605	5%	457980
Selling price of Biogas ± 5%		Gas production per day ± 5%		Exchange Rate ± 5%	
% Change	**NPV**	**% Change**	**NPV**	**% Change**	**NPV**
-5%	434480	-5%	434480	-5%	434381
0%	457881	0%	457881	0%	457881
5%	481282	5%	481282	5%	481381

Table 3: Summary sensitivity Analysis of Net Present Value (NPV) for 40 m³ biogas digester system

40 m³ biogas digester (NPV)					
Interest Rate ± 5%		Operating Cost ± 5%		Selling price of liquid fertilizer ± 5%	
% Change	**NPV**	**% Change**	**NPV**	**% Change**	**NPV**
-5%	958115	-5%	922459	-5%	921889
0%	922062	0%	922062	0%	922062
5%	888216	5%	921665	5%	922235
Selling price of Biogas ± 5%		Gas production per day ± 5%		Exchange Rate ± 5%	
% Change	**NPV**	**% Change**	**NPV**	**% Change**	**NPV**
-5%	875260	-5%	875260	-5%	875087
0%	922062	0%	922062	0%	922062
5%	968864	5%	968864	5%	969037

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The study also used Tornado charts to determine which operational parameters had the most impact on the profitability of the system. This is to enable managers of the system to proportionately focus their effort on the operational parameters for profit maximization. The charts showed that for both 20 m^3 (Figure 1) and 40 m^3 (Figure 2) systems, the most impactful operational parameters (from most to least) where exchange rates, gas production per day, selling price of biogas and the interest rate. Due to the fact that managers of the system have no control over exchange rates, it therefore becomes important that all effort is made to optimize gas production and negotiate better prices for the biogas produced as well as interest rates from their lenders. The selling price of liquid fertilizer and the operational cost were the least impactful when it came to the profitability of the system. The selling price of liquid fertilizer (digestate) from the system was low relative to the other operational parameters because fertilizer (commercial) in general is relatively cheap because of government subsidies. The operational cost was also low because the systems as piloted is mostly automated and requires little human effort.

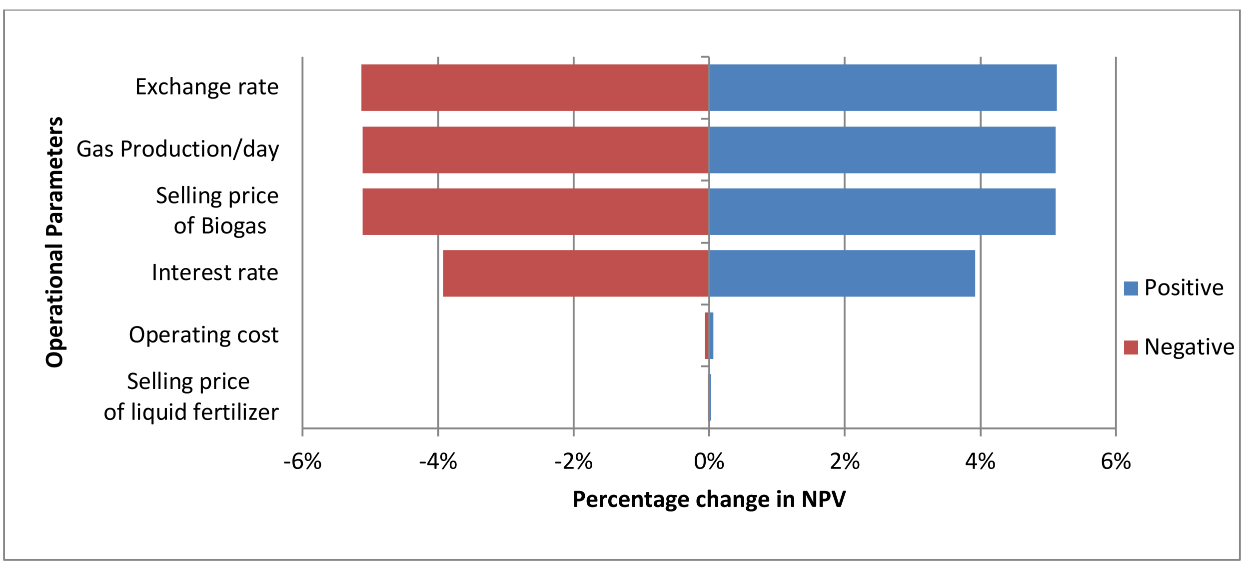

Figure 1: Impact on Net Present Value (NPV) by percentage change in operational parameters for 20 m^3

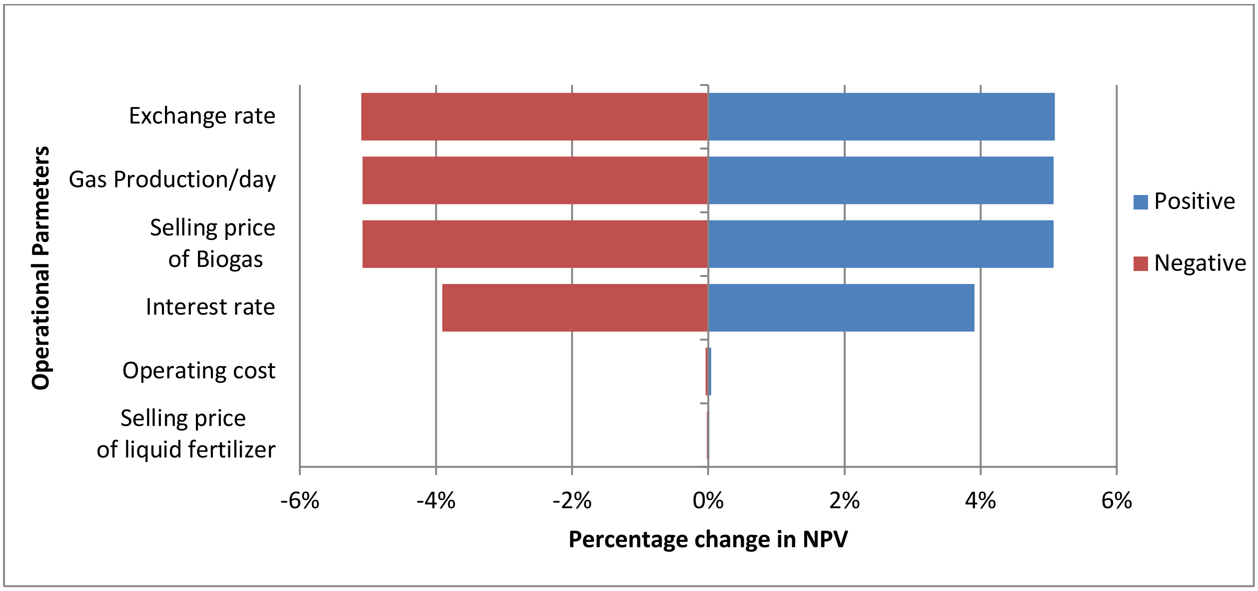

Figure 2: Impact on Net Present Value (NPV) by percentage change in operational parameters for 40 m³

Another critical estimate that was satisfactorily low for both biogas digesters was the Payback Period (PBP). This factor is important because, in developing countries, some renewable energy projects are funded with loans which must be repaid for the sustainability of the fund (Donastorg et al., 2017). The ability of a system to pay for itself quickly ensures that users are able to pay off all loans needed for the system. The PBP for the 20 m^3 and 40 m^3 in the base case were 0.079 years and 0.057 years respectively. A ± 5 % variation in all the operational parameters only showed marginal deviation from the base case for both the 20 m^3 and 40 m^3 systems.

Table 4: Summary sensitivity Analysis of Payback Period (PBP) for 20 m³ biogas digester system

20 m³ biogas digester (PBP)					
Interest Rate ± 5%		Operating Cost ± 5%		Selling price of liquid fertilizer ± 5%	
% Change	**PBP**	**% Change**	**PBP**	**% Change**	**PBP**
-5%	0.079223891	-5%	0.079176846	-5%	0.079240772
0%	0.079223891	0%	0.079223891	0%	0.079223891
5%	0.079223891	5%	0.079270992	5%	0.079207017
Selling price of Biogas ± 5%		Gas production per day ± 5%		Exchange Rate ± 5%	
% Change	**PBP**	**% Change**	**PBP**	**% Change**	**PBP**
-5%	0.08342704	-5%	0.08342704	-5%	0.083445761
0%	0.079223891	0%	0.079223891	0%	0.079223891
5%	0.075423947	5%	0.075423947	5%	0.075408652

Table 5: Summary sensitivity Analysis of Payback Period (PBP) for 40 m³ biogas digester system

40 m³ biogas digester (PBP)					
Interest Rate ± 5%		Operating Cost ± 5%		Selling price of liquid fertilizer ± 5%	
% Change	**PBP**	**% Change**	**PBP**	**% Change**	**PBP**
-5%	0.056858082	-5%	0.056833846	-5%	0.056868654
0%	0.056858082	0%	0.056858082	0%	0.056858082
5%	0.056858082	5%	0.056882339	5%	0.056847515
Selling price of Biogas ± 5%		Gas production per day ± 5%		Exchange Rate ± 5%	
% Change	**PBP**	**% Change**	**PBP**	**% Change**	**PBP**
-5%	0.059865771	-5%	0.059865771	-5%	0.059877491
0%	0.056858082	0%	0.056858082	0%	0.056858082
5%	0.054138152	5%	0.054138152	5%	0.054128571

The effect of the various operational parameters on the PBP was also investigated using Tornado charts (Figure 3 and 4). The exchange rate, selling price of biogas and gas production per day were the most impactful parameters with respect to the PBP. This is consistent with what was found with respect to the NPV as regards the effect of the respective operational parameters.

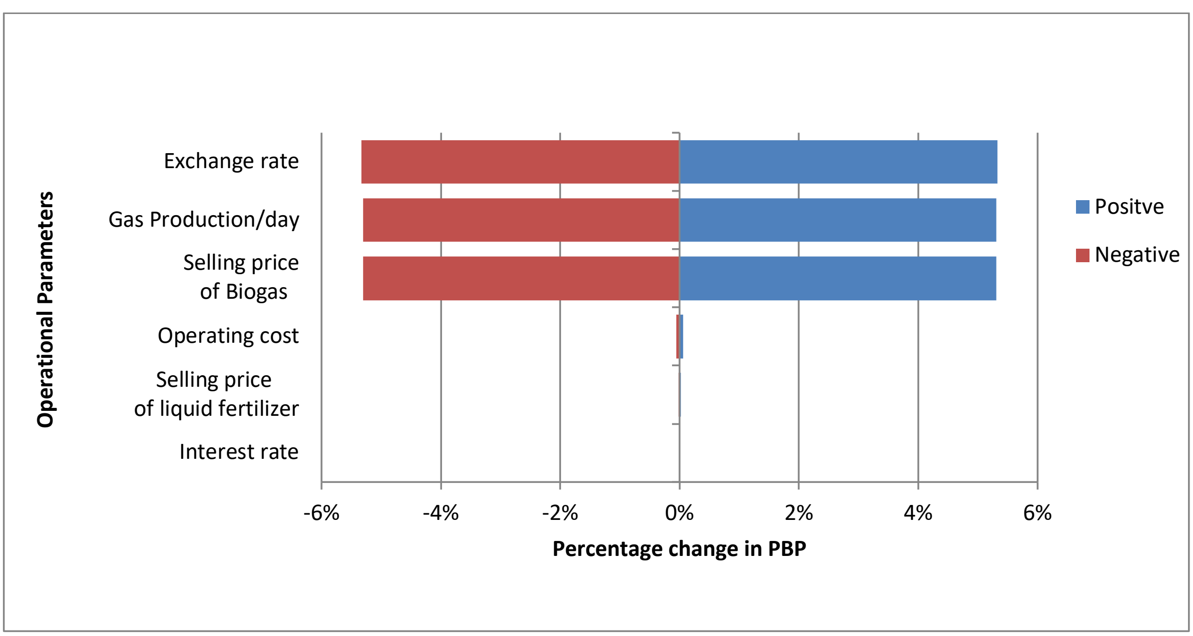

Figure 3: Impact on Payback Period (PBP) by percentage change in base operational parameters for 20 m³

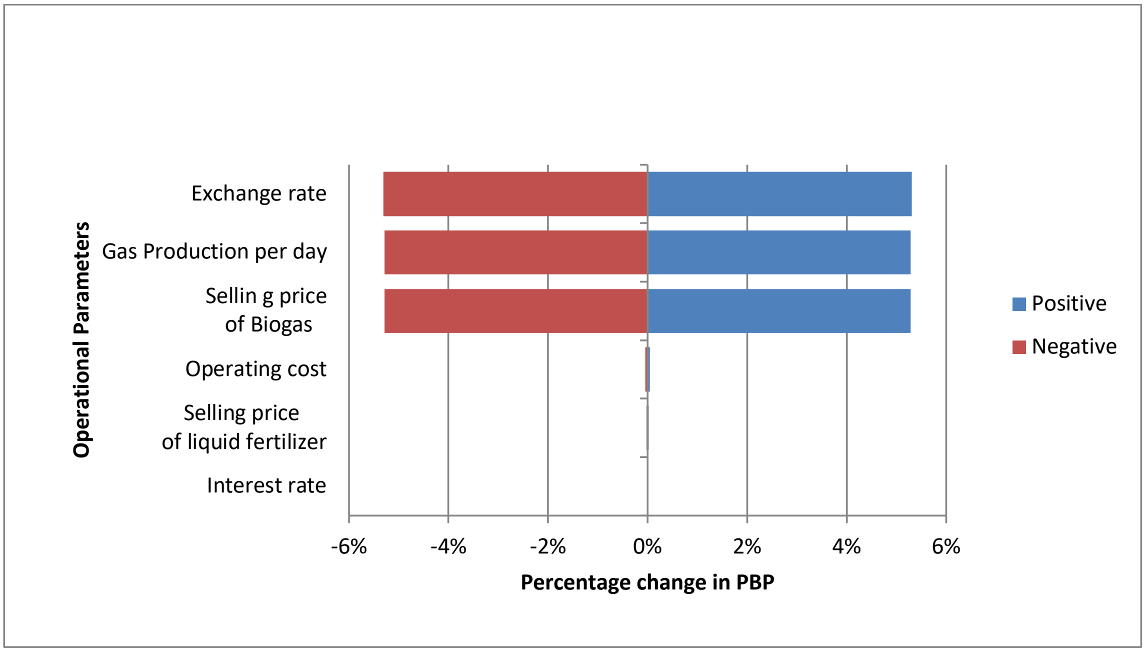

Figure 4: Impact on Payback Period (PBP) by percentage change in operational parameters for 40 m³

As seen in the Table 1, the capital cost for such renewal energy project may be beyond the ability of the artisanal palm oil processors. The profitability illustrated in this study could be used to convince commercial banks to provide funding for such projects. The most impactful operational parameters found in this study could also be used as key performance indicators by relevant parties to ensure that the system and its managers remain efficient at all times.

In addition to other works on economic feasibility of biogas digesters in a developing country context ((Kemausuor et al., 2016; Mohamed et al., 2017), this work also confirms that biogas projects are an economically viable alternative to waste management and treatment. This confirmation is necessary as both works considered biogas capacities (300 m^3 and 9000 m^3) which are impractical for most oil palm processors due to the cost implications. The sizes of these larger systems also introduced other parameters such as skilled labour requirements which are not relevant for small scale users. This work therefore covers the scenario which is relevant for small scale palm oil processors and other small scale food processors and the economic viability of using biogas plants for waste treatment.

Conclusion

The study found the 20 m^3 and 40 m^3 biogas digester systems to be profitable judging from the NPV and PBP values from the base case and the sensitivity analysis. The factors most impactful of the profitability of the system analyzed were exchange rate, selling price of biogas and gas production per day as seem in the tornado charts. It is therefore imperative that managers of the system work hard to continuously improve the gas production volumes as well as negotiate better prices for the biogas produced. Although the liquid fertilizer produced by the system was the least impactful due to its relatively low cost, better marketing could allow the managers to get better pricing from its use. A lean and efficient operation would also enable managers significantly cut down on operations cost therefore boosting the profitability of the system.

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