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Technical and Economic Assessment of Power Generation from Biogas

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Abstract. Production of methane through anaerobic digestion of organic wastes would benefit the society in general by providing a clean fuel from renewable feedstocks. The biogas production from organic waste represents a potential green energy or renewable energy from a sustainable development perspective as it consists of greenhouse gases like methane. Energy recovery from waste represents an important way to reduce the amount of electrical energy that is produced from fossil fuels. This would reduce and perhaps replace fossil fuel-derived energy and reduce environmental impacts including global warming and acid rain. The biogas could be converted easily into power using a gas engine. It was found that the OFMSW generate 122.4 x 10^3 m^3 of biogas per day from the degradation of 816 tons of OFMSW. The amount of power produced per unit mass of the OFMSW was found to be 222 kWh/tons of biowaste. The use of biogas would avoid 1.102 tons CO_2/MWh_e, 1.46 tons CO_2/MWhe, 0.72 tonsCO_2/MWh_e and 0.48 tons CO_2/MWh_e would be avoided if biogas is used instead of coal, oil and natural gas respectively. The pay back of the biogas to energy plant was found to be 9 years at a gate fee of 1250 MUR.

Keywords: Biogas, power, economic assessment, GHG

1. Introduction

The role played by energy in society is overwhelming. Many countries depend on fossil fuels for their energy needs. However, this is increasingly becoming unsustainable because fossil fuels cause ecological and environmental problems [1] and are depleting rapidly. Biogas energy which is a clean and renewable form of energy could be used as an alternative to fossil fuels. Biogas could be produced through anaerobic fermentation of organic fraction of municipal solid waste and it consists of between 40% and 70% methane, with the remainder being carbon dioxide, hydrogen sulphide and other trace gases [2]. Biogas could be burnt to produce power whereby displacing fossil fuels needed to generate the same amount of power. This study was therefore initiated to quantify the amount of power that could be generated for biogas of organic fraction of municipal solid waste (OFMSW).

2. Methodology

The total amount of biogas that would be generated from the anaerobic degradation of OFMSW could be calculated using methane yield. The following equation could be used to estimate the amount of biogas that would be produced.

$$\dot{m}_{biogas} = \dot{m}_{OFMSW} \times \Upsilon$$

Biogas can be used for the production of electricity. The following equation could be used to compute the amount of power generated from biogas.

Electrical energy, MW = $\dot{m}_{OFMSW} \times \Upsilon \times \delta \times \rho_{CH4} \times LHV_{CH4} \times 1.16 \times 10^{-5} \times \eta_{el}$

where,

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$\dot{m}_{biogas}$ = Mass flow rate of biogas, m^3/h
$\dot{m}_{OFMSW}$ = Mass flow rate of OFMSW, kg/h
Υ = Biogas Yield, m^3/kg
δ = Methane fraction, %
ρ_{CH4} = Density of methane, $tons/m^3$
LHV_{biogas} = Lower Heating Value of biogas, MJ/kg
η_{el} = Efficiency, %

3. Biogas Production

The amount of biogas could be computed using the above equation. The different inputs used to determine the amount of biogas generated are shown in Table 1. The amount of MSW generated was 1,200 tons/day which is equivalent to 50 tons/h which consisted of 68 % of yard and kitchen waste. The biogas yield was assumed to be 150 m^3/tons of biowaste [3]. The OFMSW that was considered to undergo anaerobic digestion was yard and kitchen waste only. It could be seen that the amount of biogas generated was 122400 m^3/day from the degradation of 816 tons of OFMSW.

Table 1: Parameters used as input to predict the amount of biogas

Parameters		Unit
Input		
Mass flow rate MSW	1200	tons/day
Organic fraction (Yard and kitchen waste)	68	%
Biogas yield	150	m^3/tons
Output		
Biogas flow rate	122.4 x 10^3	m^3/day

4. Power Production

The biogas production from organic waste represents one of the potential green energy or renewable energy from a sustainable development perspective as it consists of greenhouse gases like methane. Energy recovery from waste represents an important way to reduce the amount of electrical energy that is produced from fossil fuels. This would therefore reduce and perhaps replace fossil fuel-derived energy and reduce environmental impacts including global warming and acid rain. Biogas can be produced through anaerobic digestion of OFMSW which can therefore be used for the production of electricity. There are several technologies available in the market for the conversion of biogas into power directly. Gas engine is one of the mostly used technologies for burning the biogas for power generation.

Table 2: Parameters used as input to predict the power generation

Parameters		Unit
Input		
Mass flow rate of MSW	50	tons/h
Organic fraction (Yard and Kitchen waste)	68	%
Biogas yield	150	m^3/tons
% of methane by volume	60	%
LHV of methane	37.5	MJ/kg
Density of methane	0.000717	$tons/m^3$
Efficiency of gas engine	33	%
Output		

Power	7.54	MW

The biogas consisted of 60% of methane [4] by volume which represented a significant amount of energy. Table 2 below shows the input parameters required to calculate the amount of power that is generated from biogas. The energy content of methane was taken to be 37.5 MJ/kg [5] and the efficiency of the gas engine was taken as 33% [5]. It can be seen from Table 2 that 7.54 MW of power could be produced from OFMSW with a biogas yield of 150 m^3/tons. The amount of power produced per unit mass of the OFMSW was found to be 222 kWh/tons of biowaste.

5. GHG

Biogas consists mainly of methane and carbon dioxide and both are two greenhouse gases. However, the global warming potential of methane is 21 times higher than that of carbon dioxide. Using biogas as a source of power generation would eventually convert the methane into carbon dioxide after combustion thereby reducing the global warming effect. Table 3 indicates the amount of GHG that would be released when using biogas for electricity production.

Table 3: GHG emission from power production from biogas

		Unit
Mass of MSW	1,200	tons/day
Organic fraction (yard and kitchen)	68	%
Mass of organic waste	816	tons/day
Carbon dioxide	241.6	tons/day

It can be seen from Table 3 that 816 tons of OFMSW would release 241.6 tons of CO_{2eq} daily. The CO_{2eq} is 0.3 kg/kg of OFMSW and 1.33 kg CO_{2eq}/kWh of electricity produced. Since the OFMSW is of biogenic source, all the GHG released would eventually be recycled back by the plants during the process of photosynthesis. Therefore, the GHG released from combustion of biogas would not contribute in global warming.

The biogas produced through the process of anaerobic digestion of OFMSW is a source of renewable energy as it originates from organic source that is biomass. The use of biogas for power generation is therefore an environmentally sound option to mitigate global warming effect and to reduce greenhouse gases released as all the greenhouse gases released would be absorbed by the plant during the process of photosynthesis. Therefore, biogas can be said to be carbon neutral as it does not add to the effect of global warming. Moreover, it would displace some of the GHG which would have been produced if fossil fuels would have been used to generate the same amount of power that the biogas would generate. Table 4 shows the amount of GHG avoided if biogas would be used compared to other fossil fuels.

Table 4: GHG avoided by using biogas for power generation

	GHG produced, tons CO_2/MWh_e	**Amount of GHG avoided using biogas, tonsCO_2/MWh_e**
Electricity	1.102[6]	1.102
Coal	1.460[6]	1.46
Oil	0.720 [7]	0.72
Natural gas	0.480[7]	0.48
Biogas	0	-

The amount of CO_2 released during the production of power in Mauritius was found to be 1.102 tons CO_2/MWh_e (Bagha, 2009), therefore the use of biogas would avoid 1.102 tons CO_2/MWh_e. 1.46 tons CO_2/MWhe, 0.72 tonsCO_2/MWh_e and 0.48 tons CO_2/MWh_e would be avoided if biogas is used instead of coal, oil and natural gas respectively.

6. Economic Assessment

The economic assessment of an organic waste to energy plant through the anaerobic digestion process is very important to determine the feasibility of this option. A biogas plant usually requires certain investment in terms of digesters, gas engines and other auxiliaries. The revenue would be mainly from the sale of electricity to the national grid and also from the gate fee associated with the facility. Table 5 below shows the data required to calculate the annual profit from the plant.

Table 5: Data used to determine the annual profit

Parameters	Organic waste	Unit
Amount of organic waste	816	tons/day
Amount of biogas	122,400	m^3/day
Operation time	333	days/year
Cost of electricity	3	MUR/kWh
Capital Cost	5,186	M MUR

The capital cost for the biogas plant was estimated to a tune of 5,186 million MUR and the electricity produced would be sold to the national utility company.

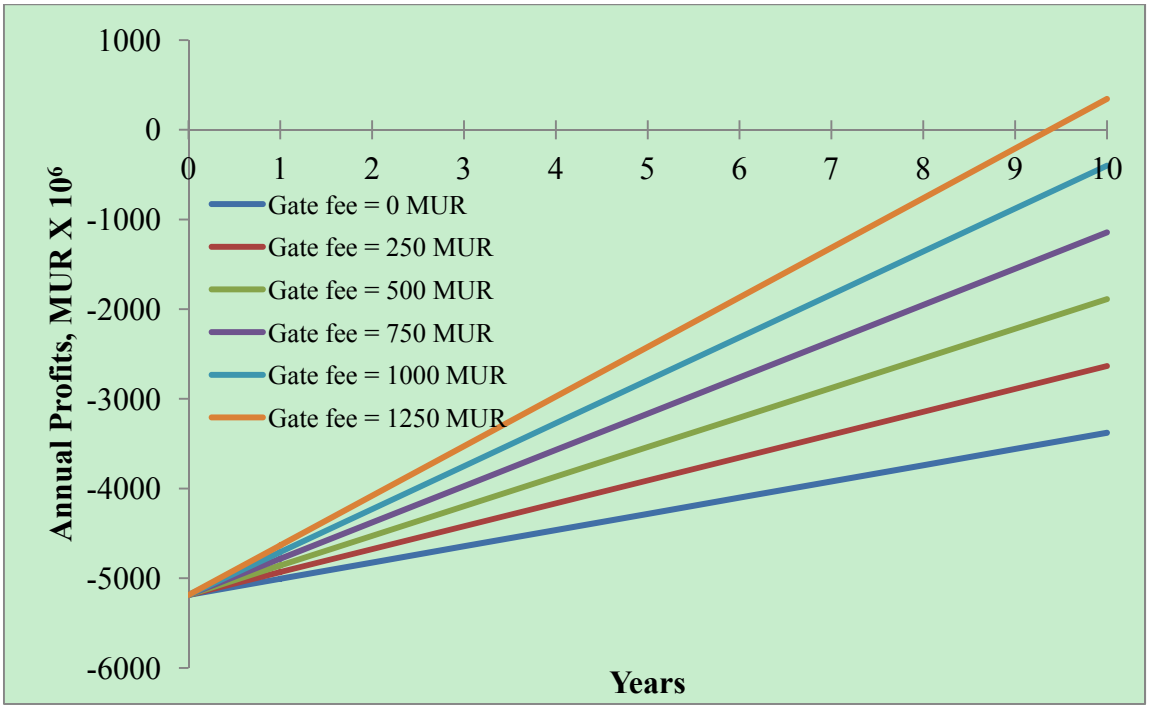

Fig. 1: Annual profit for biogas to energy plant

The gross annual profit was computed for different gate fees varying from 250 to 1,250 MUR. It can be seen from Figure 1 that the plant would not be profitable when gate fee was not applied to the facility. As the gate fee was applied, the plant would start being more profitable. It could be noticed that the higher the gate fee, the more profitable the plant becomes. The plant would start making profit after the twentieth year with a gate fee of 250 MUR while with a gate fee of 1,250 MUR, the plant makes a profit as from the ninth year.

7. Conclusion

Biogas can be produced through anaerobic digestion of OFMSW which can be used for the production of electricity. There are several technologies available in the market for the conversion

of biogas into power directly. Gas engine is one of the mostly used technologies for burning the biogas for power generation. The biogas production from organic waste represents one of the potential green energy or renewable energy from a sustainable development perspective as it consists of greenhouse gases like methane.

Energy recovery from waste represents an important way to reduce the amount of electrical energy that is produced from fossil fuels. 122400 m^3 of biogas is generated daily from 816 tons of OFMSW which is equivalent to 181 MWh of green power daily. The use of biogas would avoid 1.102 tons CO_2/MWh_e. 1.46 tons CO_2/MWhe, 0.72 tonsCO_2/MWh_e and 0.48 tons CO_2/MWh_e would be avoided if biogas is used instead of coal, oil and natural gas respectively. The biogas to energy plant has a pay back of 9 years at a gate fee of 120MUR.

8. References

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