Opportunities for Generating Electricity from Municipal Solid Waste: Case of Kampala City Council Landfill

Aggrey Mwesigye[1], Samuel B. Kucel[2] , Adam Sebbit[3]

[1] Assistant Lecturer, Department of Mechanical Engineering, Makerere University, P. O. Box 7062, Kampala, Uganda
Corresponding author email: amwesigye@tech.mak.ac.ug
[2] Senior Lecturer, Dean Faculty of Engineering, Busitema University, P.O Box 236, Tororo, Uganda
[3] Senior Lecturer, Department of Mechanical Engineering, Makerere University, P.O ox 7062, Kampala, Uganda

ABSTRACT
Municipal Solid Waste in most developing countries has for many years been looked at as a liability without any benefits. With the current limited access to energy services and poor sanitation in Kampala, alternative and beneficial uses of Municipal Solid Waste are inevitable. This paper presents findings of a study carried out to assess the possibility of electricity generation from landfill gas at the Kampala City Council landfill. Data about Municipal Solid Waste generation, collection and disposal for Kampala City was collected and analyzed using Microsoft excel and LandGEM model to determine the potential for electricity generation at the landfill. Findings show that Municipal Solid Waste collection in Kampala City has increased from approximately 7.76% in 1997 to 38.8% in 2007 of the estimated waste generated and that 70% of the landfilled Municipal Solid Waste is organic, giving the landfill a high methane generation potential. It was also estimated that the landfill has potential to generate 31,300MWh in 2009 (with an investment of US$ 9.35 million) and 26,600MWh in 2011 taking 2008 as the landfill closure year when Internal Combustion Engines without heat recovery are used. Further analysis showed that, if 100% of the Municipal Solid Waste generated since 1996 was collected the power production potential would be about 86,000MWh in 2011. An economic analysis using the 2008 feed-in tariffs for Uganda showed that a power generation project is not economically feasible due to low IRR and a poor NPV. Power generation only makes economic sense with improved feed-in tariffs, incentives, and converting of the environmental benefits in monetary terms. For example, the project, if registered under the Clean Development Mechanism (CDM) could bring in annual income of USD 1,655,800/= on average every year of the project improving on the NPV and IRR making its implementation viable.

Keywords: Landfill, Municipal Solid Waste, Clean Development Mechanism; IRR; NPV

1.0 INTRODUCTION
Uganda has one of the fastest growing populations of about 3.3% according to the Uganda Bureau of Statistics (UBoS, 2006). The rate of urbanization is also increasing steadily, according to the Uganda Statistical Abstract of the year 2006, 13.1% of the total population was living in urban areas and this has been increasing (UBoS, 2006). This increase in urbanization and population has put pressure on the available services such as Municipal Solid Waste management services, increased demand for health care, water supply and electricity. Most specifically the demand for electricity has been increasing at a rate of over 8% since 2007 and is still rising given the current levels of industrialization and urbanization. It is estimated that by 2025 Uganda will need over 2000MW of electricity to meet the energy needs of the country. This compared to the current 380MW of installed capacity at the two large hydropower plants of Nalubale and Kira (With power generation from these two stations just over half the installed capacity) and another 250MW is currently under construction at the Bujagali hydropower plant will need to be supplemented by other sources, also the 2005 energy crisis in the country led to the introduction of thermal electric power in the energy mix (150MW is cur-

rently being generated from thermal power), which in addition to being environmentally unclean increased the prices of a unit of electricity to almost the double (from about Ush 296 per kWh to Ush 426 per kWh) (Mackay, 2010).

In order to meet the current and future energy needs of this country in a sustainable, environmentally friendly and low cost manner, there is need to explore the different renewable energy options available in the country as put clearly the Country's Renewable Energy Policy (MEMD, 2007). Utilization of biomass for electricity generation is one of the available alternatives that can be explored since biomass is widely available in the country in many forms including; Municipal Solid Waste, agriculture residues, wood wastes and virgin biomass. In most urban centers in Uganda huge amounts of Municipal Solid Wastes are generated, most of which are not collected and disposed properly. In Kampala, of all the 1200 tons of Municipal Solid Waste generated daily, about 40% is collected and landfilled and the rest is either burnt or not collected and left to decay posing a danger to the environment and health. Even that dumped in the landfill decomposes producing landfill gas which is mainly composed of methane and carbon dioxide; methane is a potent greenhouse but can also be used to generate electricity or used as a source of energy for other applications. In Uganda there is currently no landfill gas utilization and little information is available on the potential of electricity generation from the gas. Landfill gas is produced from anaerobic decomposition of Municipal Solid Waste placed in a landfill and compacted well so that there is no leakage of air in the buried waste. Landfill gas is composed of mostly Methane 45 – 75% and 25% - 55% Carbon dioxide depending on the conditions under which the landfill is working. The conditions affecting gas quality and quantity include moisture content, age of the waste, waste composition, temperature and presence of favorable nutrients.

This paper will present the findings of a study that was carried out to explore the available opportunities for electricity generation for Municipal Solid Waste in Kampala with specific focus on the landfill gas from Kampala City Council landfill. The objectives of the study were to provide information on Municipal Solid Waste generation and collection, landfill gas availability, power generation potential and economics of the project.

2.0 MATERIALS AND METHODS

Available literature of previous researches done on Municipal Solid Waste in Kampala and Uganda at large as well as energy sector documents were reviewed. Municipal Solid Waste generation was estimated using the per capita generation rate of 1 kg per person per day; the waste was characterized by collecting samples from the waste that was being brought to the landfill. Samples were randomly collected and characterized to determine the fraction that can be categorized as organic or decomposable; 50 samples were collected daily for 30 days and characterized. The waste was characterized as vegetable matter, plastics, paper; wood related/tree cuttings, metals, saw dust/wood shavings, clothes, glasses, building debris and ash and also according to the city division (county) of origin. Records from the landfill were also accessed to ascertain the capacity of the landfill as of 2008. Eight samples were taken each month from 1996 when the landfill was opened to mid 2008 and averaged. The United States Environmental Protection Agency standard procedure for qualifying landfills for energy recovery projects (US.EPA, 1996) was then used to determine whether Kampala City Council landfill is a good candidate for energy recovery. It was found that the landfill qualifies for energy recovery; i.e. the landfill is a Municipal Solid Waste landfill, had more than 1million tons of waste in place, was still receiving waste, the area receives rainfall in the excess of 635mm on average. The study further investigated the amount of gas available from the landfill using the LandGEM model that uses the first order decay equation to approximate the gas production from a given quantity of waste that has been in a landfill for a given period of time in years as shown in equation 2.0.

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_o \left(\frac{M_i}{10} \right) e^{-kt_{ij}} \quad (2.0)$$

Where Q_{CH4} – Annual methane generation in the year of the calculation (m^3/year)
i – 1- year time increment
n – (Year of calculation)-(initial year of waste acceptance) or the age of waste
j – 0.1 year time increment
Lo – Methane generation potential (m^3/Mg)
M_i – Mass of waste accepted in the i^{th} year (Mg)
t_{ij} – Age of the j^{th} section of mass M_i accepted in the i^{th} year (Decimal years e.g. 3.2 years)

With the estimated generated gas amounts, various energy conversion technologies were assessed to select a suitable one; the technologies investigated were internal combustion engines, gas turbines and steam power plants. A preliminary cost estimate was done to determine the viability of energy recovery from landfill using the expression for gross power as

Power (kW) = Landfill gas flow (m^3/day) x Energy content (J/m^3) x 1/Heat rate (J/kWh) x 1/24 (2.1)

And the annual energy generation was calculated according to:

Annual Electricity Generated (kWh) = Net power generation potential (kW) x 24hr/day x 365 days/year x C.F (2.1)

3.0 RESULTS AND DISCUSSIONS

The following is a summary of the results obtained from the study with the corresponding discussion of results

3.1 Municipal Solid Waste Characterization

Analysis of the collected samples showed that most of the Municipal Solid Waste collected and taken to Kampala City Council landfill was largely organic (over 70% of the waste), as shown in Table 1.0. This compares well with the results from other researches that puts it over 80% e.g. Las (2005), the only difference being in the considered samples, the Las (2005) study considered waste at the dump site where as this study considers waste taken to the landfill.

Table 1.0: Characterization of Municipal Solid Waste generated in Kampala

	Divisions					
Item	**Central**	**Rubaga**	**Nakawa**	**Kawempe**	**Makindye**	**Average**
Vegetable Matter %	47	70	63	73	70	64.6
Plastics%	16.5	7	5.6	4.6	6	7.94
Paper %	18	6	8.2	4.2	4.4	8.16
Tree cuttings %	2.6	3.2	3.8	2.3	5.5	3.48
Dust/Soil %	3	1	2.6	3.8	1.3	2.34
Metallic %	4	4.8	5.4	1	2.6	3.56
Saw dust/wood chips %	1.2	2	3	5.4	1.8	2.68
Clothes %	1.4	1	2.4	1	2	1.56
Glasses %	4.3	2	2	1.1	3.4	2.56
Ash %	1	1	1.2	1	0.8	1.00
Building Debris %	1	2	2.8	2.6	2.2	2.12
Total percentage	**100**	**100**	**100**	**100**	**100**	**100**

The high organic content of the Municipal Solid Waste makes it suitable for anaerobic digestion and hence high methane generation rates from the landfill.

3.2 Municipal Solid Waste Collection

From the data accessed from the landfill, the waste generated was compared to the one collected and landfilled (an average per capita waste generation of 1kg per day was used in this estimate). It was found that throughout the years the waste collection rates has been below 40% of the estimated waste generated as shown in Figure 1.0. It has been assumed that all the waste collected is that taken to the landfill and therefore the amount of waste collected is the same as that accepted at the landfill.

Figure 1.0: Waste collected and landfilled 1996 – 2007.

Low levels of waste collection are evident as one move around Kampala, where most of the waste is openly dumped and left to decompose or even burnt on site all of which are not environmentally friendly and affect the health, this can be seen in the pictures in Figure 2.0

Figure 2.0: Ways of waste disposal in some Kampala suburbs (Photos, 2008)

3.3 Waste acceptance at the landfill

It was found from the study that there is about two million tons of Municipal Solid Waste in the landfill and therefore from the procedure for qualifying landfills for energy recovery projects Kampala City Council landfill qualifies with a score of 32 slightly above the recommended score of 30 (US.EPA, 1996) . There is more than one million tons of waste, it is an engineered landfill of depth over 40ft, and rainfall is about 1500mm per annum. Figure 3.0 shows waste acceptance at the landfill over years as obtained from the site records. Therefore, it is clear that the trend of waste acceptance has been increasing over years.

Figure 3.0: Waste acceptance at the landfill

3.4 Estimation of landfill gas generation

Using the LandGEM model and using values of Lo = 180m^3/ton, k = 0.08year^{-1} values for medium moisture climate and for highly decomposable matter (US.EPA, 1996). The model gave values for the amount of gas generated each year and methane generation taking 55% methane content as shown in Figure 4.0.

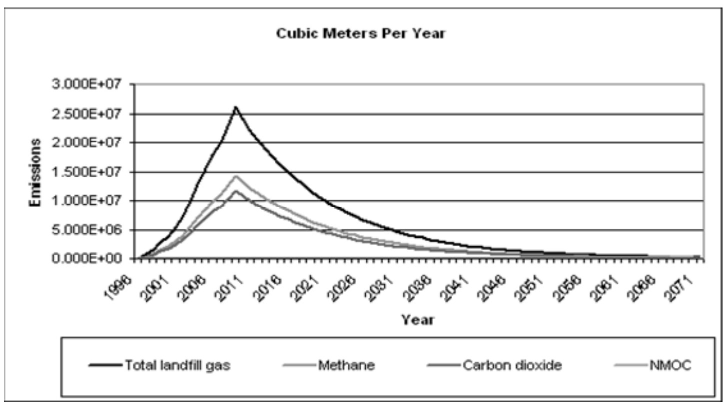

Figure 4.0: Landfill gas and methane emissions

From the model, it was found that about 1.5 x 107 m^3 of methane would be available for use in 2009 considering the fact that 55% of this gas is methane and that the landfill closure year is 2008. The daily methane emissions were calculated and Figure 5.0 shows the daily methane emissions and it can be seen that maximum methane emission will be 39,300m^3/day.

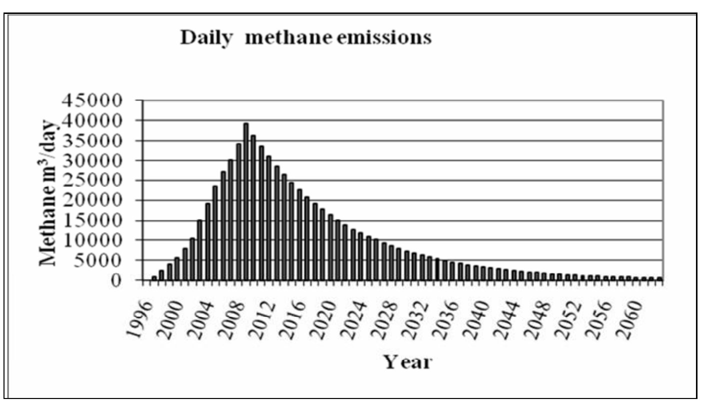

Figure 5.0: Daily Methane Emissions

Model Validation: The results of the above model were validated by manually entering the values of waste generation each year into the first order decay equation. The results are in the range of those obtained from the LandGEM model with an error less than 2% thus the results were taken to give a good approximation of the amount of gas available at the landfill.

3.5 Electricity Generation Potential

Comparison of the different power generation technologies showed that internal combustion engines were the best suited for the site given their better heat rates, capability to be designed on modular basis, low installation costs per kW, less parasitic loads thus higher net power developed.

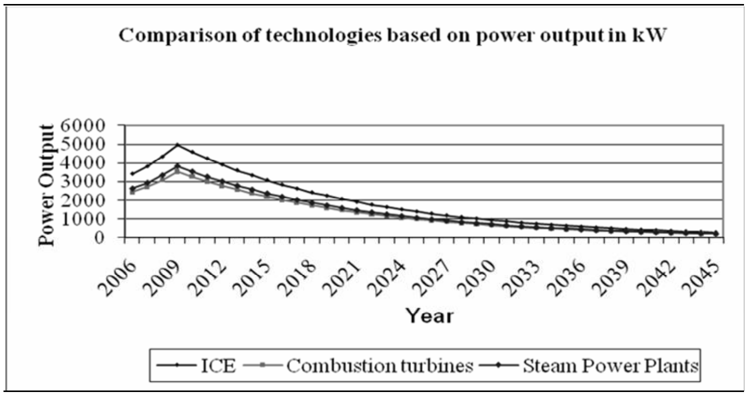

Figure 6.0: Power output from different technologies

With internal combustion engines it was estimated that the maximum net power potential (about 4MW) from the site would be available in 2009. And if the landfill was closed by then the power generated would go on decreasing every year for the next successive years. If all the waste ever generated since 1996 was collected and landfilled, a similar computation gives the power available of about 14MW.

Annual Energy Availability: The annual energy available was computed for all years using a capacity factor of 90% given that the gas is available 100% of the time. The calculation of annual energy generation gave 31,300MWh in 2009 and 26,600MWh in 2011 when 2008 was taken as the closure year. Further analysis showed that, if 100% of the Municipal Solid Waste generated since 1996 was collected the power production potential would be about 86,000MWh in 2011.

Using the available energy each year the preliminary cost estimates and revenues were computed using the prevailing feed-in tariffs of Uganda as of 2008 (average value of cents US$ cents 7.2 in the first six years and US$ cents 5.33 per kWh for the period 7 – 20 years) . The costs used were adopted from the United States Environmental Protection Agency online data as of 2005. (US.EPA, 2005) with inclusion of the relevant shipping and taxes on the machinery that will be imported into the country. From this analysis it was found that the energy recovery project at this landfill required an investment cost of about $ 9.4 million and a payback period of 17.5 years. Also the calculated Net Present Value (NPV) was negative at the current commercial interest rates in the country of about 19%; evaluation of the Internal Rate of Return (IRR) gave an IRR of 0.9% which is very making the project not economically feasible within the 17.5 years. Given that the landfill will continue to produce gas for a long time, the useful or beneficial life of the project was found to be about 26 years from 2011 – 2036 after which the revenues become less than the running costs. Having found the project not economically viable, a scenario for selling carbon credits was investigated. Using the landfill gas emission benefits calculator (US.EPA,2008) and an average power production over the life of the project (26 years), the direct (Methane emitted directly from landfill gas) and avoided (Offset of carbon dioxide from avoiding usage of fossil fuels) are 3,187 tons of methane per year and 9,114 tons of carbon dioxide per year. From Carbon positive (2008), on the European Union market the cost of each CER was about US$ 24 about (€15.8), the energy recovery project's economics improved with an average revenue from sale of CER of USD 1,655,760/= annually improving the Net Present Value and Internal Rate of Return to 22% which makes the project attractive.

4.0 CONCLUSION

From the study it can be concluded that:

(i) Municipal Solid Waste collection rates are still low in Kampala City, though there has been an increasing trend in the waste collection amounts. The Municipal Solid Waste collection percentages have increased from about 8% in 1996 to about 39% in 2007 but this is still low given that big percentages remain uncollected.

(ii) Municipal Solid Waste that is accepted at the Kampala City Council landfill is largely organic over 70% which gives the landfill a high methane generation potential and thus energy recovery potential.

(iii) The energy recovery project at the landfill without trading CER's is not economically viable having a negative NPV and a very low IRR. With CER trading, the projects NPV and IRR are improved and thus the project becomes economically attractive.

(iv) Generally, the landfill qualifies for energy recovery and the economic viability depends on the negotiated feed-in tariffs and trading of carbon emissions reduced.

5.0 ACKNOWLEDGEMENT

The authors would like to acknowledge the support received from the Royal Institute of Technology, Department of Energy Technology to carry out this study.

6.0 REFERENCES

Carbon Positive (2008), "*Projects and Activities*" http://www.carbonpositive.net last accessed June 2008

John H Perry (1963), "*Chemical Engineers Handbook*", McGraw-Hill Company, New York, 1963, Pg 9-9.

Lars Petter B. (2005), "*Opportunities for utilizing waste biomass for energy in Uganda*", Master of Science thesis School of Industrial Ecology, Norwegian University of Science and Technology.

Mackay Okure, Rafael Wiese, Diana Kraft (2010), "*Renewable Energies in East Africa"*, Country Chapter: Uganda, Department Water, Energy, Transport Dag-Hammarskjöld-Weg 1-5 65760 Eschborn, Germany

MEMD (2007), "*Renewable Energy Policy for Uganda*", Ministry of Energy and Mineral Development, Amber House, Kampala, Uganda

UBoS (2006), "*Statistical Abstract*", Uganda National Bureau of Statistics, Kampala Uganda

UBoS (2002), "Population and Housing Census", Uganda Bureau of Statistics, Kampala Uganda

US.EPA (1996), "*Turning Liability into an Asset*", a landfill gas to energy project development handbook, US.EPA 430-B-96-0004, September 1996

US.EPA (2005), "*First–Order Kinetic gas generation model parameters for wet landfills"*, United States Environmental Protection Agency, June 2005

US.EPA (2008), "Landfill Methane Outreach Program (LMOP): Landfill gas emissions calculator" available at www.epa.gov/lmop/projects-candidates/lfge-**calculator**.html last accessed November 2010