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FEASIBILITY OF LANDIFLL GAS UPGRADE FOR USE AS A FUEL SOURCE FOR REFUSE TRUCKS: A CASE STUDY IN SOUTH AFRICA

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ABSTRACT

The overall aim of this study is to determine the feasibility of the upgrade of landfill gas extracted from a typical large MSW landfill in South Africa, to be used as a fuel source for the fleet of municipal refuse trucks. The outcome of this study aimed to determine the economic feasibility of the upgrade of landfill gas for use as fuel as well as the associated environmental benefits. Landfills contribute to 11% of the total (GHG) greenhouse gas emissions globally. The reduction of GHG emissions can be achieved through the extraction of landfill gas. At landfills in the major municipalities in South Africa, landfill gas is primarily extracted and flared or used for electricity generation. As a non-renewable highly priced commodity, the use of fossil fuels to haul refuse trucks proves to be an expensive endeavour for municipalities. Therefore, there is a need for alternative fuel sources.

The feasibility of the use of landfill gas as a fuel source was achieved by the analysis of the case study municipal facility and its process. The Waste Resource Optimization and Scenario Evaluation (WROSE) model, developed at the University of KwaZulu-Natal, was employed to determine the environmental, technical and economic benefits of implementing alternative waste treatment technologies. Municipal weighbridge and emissions data was collected from a number of landfills across South Africa and the WROSE model was used to analyse the environmental and financial benefits of three scenarios: 1. Landfilling of unsorted waste with LFG extraction and flaring, 2. Landfilling with LFG extraction for energy generation and 3. Landfilling of unsorted waste with LFG extraction and upgrading to fuel for municipal trucks. The outcome of the research shows that the landfill used as a case study presented great potential for the upgrade of landfill gas to a fuel source.

1. INTRODUCTION

Due to rapid urbanization and the increased generation of waste, large volumes of greenhouse gases (GHG's) associated with the waste sector are released into the atmosphere every year. In developing countries like South Africa, the primary method for municipal solid waste management is the collection and disposal of waste to landfills. Landfills are responsible for 11% of the total GHG emissions globally.

According to Bogner et al. (2008), the global waste sector contributes to 3% of all GHG emissions, and as much as 18% of global methane emissions. The waste sector in South Africa contributes approximately 4.3% of greenhouse gas emissions (Nahman, et al., 2012). However, its emission rate of 9 million tons of CO_2 equivalents is far greater than the African average of 5.8 tons and more than 6 times the sub-Saharan average of 1.4 tons (WRI, 2016).

The South African government has therefore expressed the need to reduce the amount of waste disposed of at landfill sites and has encouraged the use of internationally funded schemes, such as the Clean Development Mechanism (CDM) or similar, under the Kyoto Protocol, for the implementation of biogas-to-energy and waste-to-energy projects that would not have been possible without such incentives.

However, solid waste management in developing countries/emerging economies is generally characterized by highly inefficient waste collection practices, variable and inadequate levels of service due to limited resources, lack of environmental control systems and appropriate legislations, limited know-how, indiscriminate dumping, littering and scavenging and, most of all, poor environmental and waste awareness of the general public (Matete and Trois, 2008).

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South Africa, as an emerging economy, is also facing the challenge of meeting high standards in service delivery with limited resources. The disparity in service coverage between different communities in the same area is a characteristic of waste management practices in South Africa.

The Polokwane Declaration in 2001 has set as very ambitious targets the reduction of waste generation and disposal by 50% and 25%, respectively, by 2012 and the development of a plan for Zero Waste by 2022, forcing South Africa to invest in the valorization of waste as a resource.

The rationale for this research stems from several factors influencing the waste management sector in South Africa, including legislative developments, national imperatives and international obligations (Kyoto Protocol, Basel Convention etc.): the growing emphasis on GHG mitigation; landfill space shortages; waste diversion and zero waste goals increased focus on waste to energy technology implemented under the CDM and similar schemes, and the requirement for waste quantification and development of a national Waste Information System as mandated by the 2008 Waste Act.

Moreover, municipalities in South Africa, despite being among those geared towards innovation in waste management through effective implementation of the waste hierarchy, face many challenges, those in line with other developing countries which include: lack of capacity to improve service delivery and lack of investment in the use of waste as a by-product. These have hampered the development of the biogas and bioenergy sector in South Africa.

The province of KwaZulu-Natal (among the most populous in South Africa) houses 68 registered landfills, however only 3 landfills in the eThekwini Municipality (City of Durban) have registered CDM projects and are among the very few across the African continent. LFG is generally extracted and flared in most engineered landfills across the country.

In addition, the recent drop on the CDM market has shifted the uses of LFG therefore local authorities are now looking at cleaning the landfill gas for use in applications such as fuelling fleet for long hauling/collection trucks.

The University of KwaZulu-Natal, in collaboration with national and local government as well as the private sector has been involved in mapping the potential for bio-energy/waste-to-energy projects across the country since 2010 and developed the Waste Resource Optimization and Scenario Evaluation (WROSE) model to assist municipalities and industry in the decision-making process of implementing waste management strategies.

This article has the dual objective to explore the potential for the optimization of biogas as a fuel source using a typical South African case study municipality by assessing the viability of producing biomethane for co-generation or use in the automotive industry, in comparison to current biogas management practices used in municipalities such as LFG extraction and flaring, as well as LFG extraction for energy co-generation. The economic and environmental sustainability/feasibility of the three scenarios, for an averaged typical waste stream of a local municipality, have been evaluated using the WROSE model.

The model aids municipal officials in determining the best alternative waste treatment strategies relevant to their specific needs using waste volumes and composition. The outcome of the model is greenhouse gas emissions reduction potentials and economic assessments of each potential scenario (Trois & Jagath, 2011).

In addition to assisting municipalities in the optimisation of biogas management options, the study also looks at the use of waste as a resource, the overall reduction of greenhouse gases into the atmosphere.

Therefore, this study is intended to provide data and information to municipal waste managers with regard to different use of the landfill gas produced by the existing landfills, considering the carbon footprint and potential for GHG reduction as discriminants for their choice.

2. LANDFILL GAS MANAGEMENT IN SOUTH AFRICAN MUNICIPALITIES

According to the National Waste Information Baseline Report 2012, South Africa generates 108 Million tonnes (Mt) of waste per annum, of which 98 Mt (90%) is landfilled (DEA, 2012). Of this, 55% was 'general waste', 44% was 'unclassified waste' and 1% 'hazardous waste'. Furthermore, approximately only 10% of the total waste generated is recycled (DEA, 2012). The average South African produces 0,7 kg of waste a day, with 42 million cubes of general waste being produced per year (DEA, 2012).

GHG emissions data for South Africa also reflect these trends, with the waste sector contributing to 2% of the total emissions and waste management activities contributing to 12% of total methane emissions as seen in (DEAT, 2011). South Africa's primary mode of waste management is still landfilling (Greben and Oelofse, 2009) and available land near areas of large waste generation is becoming scarce, the GHG emissions and leachate from organic fraction of municipal solid waste (OFMSW) makes the use of landfill sites less attractive (Greben and Oelefse, 2009).

Moreover, within South Africa, 26%±2.6% of the total waste generated is organic waste, which, when digested and decomposes produces biogas. Biogas has the potential to be used as a fuel source to produce electricity or fuel. At present, South Africa is heavily dependent on the import of petroleum products. The rising costs of these products put strain on an already struggling economy. It is therefore necessary to find alternative fuel sources that are renewable and locally produced to reduce the country's reliance on imported products.

Zietsman et al (2008) postulate that the use of landfill gas as a vehicular fuel has the potential to make the process of landfilling more self-sustaining in addition reducing the dependence on fossil fuels and ultimately reducing GHG emissions. The liquefaction of natural gas is viewed as a safer and economical alternative for use in transportation technology. Liquefied natural gas (LNG) is an eco-friendly cryogenic fuel for sustainable development. Significant progress has been made in developing more energy efficient, low cost, small-scale natural gas liquefiers. However, the process of the conversion of biomethane to LNG is higher in electricity usage than that of compressed natural gas (CNG), therefore in this study the conversion technology considered will be for CNG. Heavy-duty vehicles are high volume fuel users and rely solely on fossil fuels. Technological advancements are being made globally to convert landfill gas to fuels in addition to developing natural gas vehicles.

There is an increase in efforts made towards zero waste management strategies and the use of waste as a resource. Through the use of processes such as landfill gas extraction, methane gas is converted into electricity or flared to reduce the GHG impacts on the atmosphere. However, South Africa, as a developing country, faces another important issue, which is the high cost of fossil fuels that, as a non-renewable resource, constitute a high demand commodity in the country according to the 2016 Energy Price Report. Due to the fluctuation in costs of fossil fuels the transportation costs at municipal solid waste facilities are high. This is due to the standard waste management practice being the collection of waste from households and the disposal to landfills. Therefore, it is important to assess the potential for alternative measures to assist municipalities in cost cutting measures. Various South African municipalities have invested in waste to energy technology, one such example is the extraction of landfill gas for the generation of electricity. However, in many cases the methane gas is extracted from the landfill facility and flared. It is therefore necessary to explore the alternative use of methane gas a fuel source for hauling refuse trucks. Not only does this address the issue of GHG emission reduction into the atmosphere but it also has the potential to reduce the cost of fuel for municipalities.

3. METHODOLOGY

The WROSE model was developed by UKZN to assist Local Authorities in the design of appropriate waste management strategies for the implementation of waste-to-energy projects, by providing a quantitative estimate of the potential for GHG reductions and landfill space savings that can be achieved through ad hoc zero waste strategies, assessing their economic feasibility and so addressing specific knowledge gaps regarding the quantity and quality of the local MSW stream. The WROSE model is a multi-criteria analysis model. The WROSE model is designed to evaluate five waste management scenarios:

- Scenario 1: Landfill disposal of unsorted, untreated MSW
- Scenario 2: Landfill disposal of unsorted, untreated MSW with landfill gas recovery
- Scenario 3: Mechanical pre-treatment of MSW, recovery of recyclable fraction through a Material Recovery Facility (MRF) with landfill gas recovery
- Scenario 4: MBT (MPT, recovery of recyclables through MRF and anaerobic digestion of biogenic food waste with landfill gas recovery).
- Scenario 5: MBT (MPT, recovery of recyclables through MRF and composting of biogenic food waste with landfill gas recovery).
- (Trois and Jagath, 2011)

At present, the model provides the user with information such as landfill space savings and GHG emission reduction figures as well as basic economic viability of alternative waste treatment technologies present in each scenario (Trois & Jagath, 2011).

The methodological approach adopted in developing WROSE was based on a dry-wet zero waste model that required the selection of zero waste strategies suitable for MSW management in South Africa and the development of possible waste management scenarios incorporating these strategies. Input to the model is a detailed qualitative and quantitative Waste Stream Analysis (WSA). The GHG impacts of every scenario were estimated using emissions factors that were developed into a GHG quantification model/tool (Friedrich and Trois, 2016).

The model can calculate also other indicators such as landfill space savings resulting from each scenario, as well as the potential income, capital and operating costs produced by each strategy.

The purpose of this research was to determine if the use of landfill gas for power generation or the upgrading of biomethane to be used as fuel source for the municipal trucks fleet in South African municipalities is a more competitive option than conventional biogas management strategies.

A large district municipality was selected as representative case study for this scenario analysis, and averaged weighbridge data across the province was used as input in the WROSE model.

The methodology used to achieve this included the following steps:

- Development and selection of waste management scenarios relevant and representative of typical South African Municipalities. Three scenarios were selected after an extensive review of waste management strategies in South Africa, as presented in Figure 1.
  - Scenario 1: Landfilling with gas extraction and flaring
  - Scenario 2: Landfilling with gas extraction and electricity generation
  - Scenario 3: Landfilling with gas extraction and upgrading
- Data collection of average waste data consisting of waste quantities and waste composition disposed of into the selected case study landfills (Figures 2 and 3).
- Using the information represented above from the case study municipality, an analysis was conducted to determine the economic indicators and environmental sustainability of each of the selected scenarios. The economic analysis takes into consideration the capex and opex costs to be incurred and the revenues generated by each scenario. While the environmental analysis is based on prediction of emissions of CO_2 generated or avoided in each scenario. Table 1 and 2 present the basic economic and environmental parameters used for the scenario analysis with a descriptive narrative of the rationale used in the definition and evaluation of each indicator.

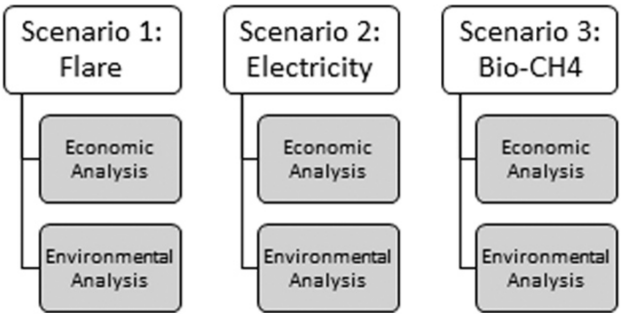

FIGURE 1. Selected scenarios representative of a typical South African municipality

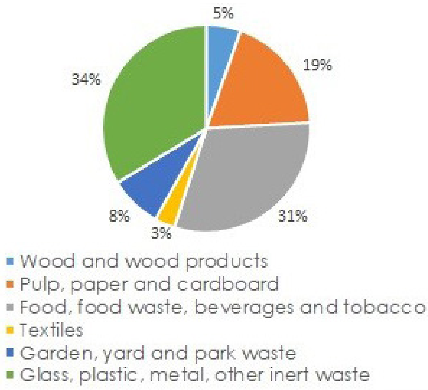

FIGURE 2: Average waste composition of the selected case study municipality.

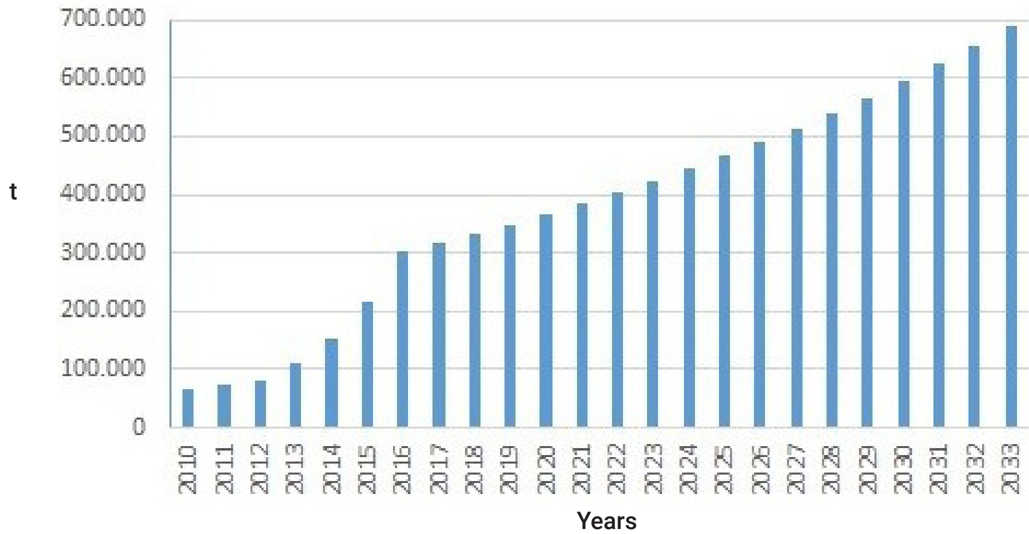

FIGURE 3: Waste quantities disposed of at the case study landfills to date with projected quantities over the next 15 years.

4. RESULTS AND DISCUSSION

4.1 Economic Analysis

Table 1 and Figure 4 clearly indicate that Scenario 3, with biomethanation for transportation, has similar costs as the previous 2 scenarios without LFG upgrading, however it also realises positive and higher savings from the use of biomethane as fuel for municipal trucks which offsets the costs for oil fuel, as compared with the scenario with production of biomethane for energy co-generation.

4.2 Environmental analysis

Table 2 and Figure 5 clearly indicate that all three scenarios realise similar CO_2 emissions reduction potential, with Scenario 2 (LFG upgrading for electricity generation) presenting a better performance than the other two scenarios assessed. The result of the scenario number 2 depends on the benefit of the CO_2 equivalent (the CO_2 not produced by a fossil fuel).

It is however to note that in neither of the scenarios the CO_2 emissions due to collection and transportation of MSW is considered.

5. CONCLUSIONS

This study assessed the feasibility and environmental impacts of applying the waste management strategy of upgrading LFG into a source of fuel to power a fleet of refuse trucks for a typical municipality in South Africa, in comparison to baseline strategies for biogas management. The principal environmental impacts were greenhouse gas emissions quantified by the WROSE model.

The research intended to provide South African municipalities with a methodology and a decision-making framework for the comparison of various waste management scenarios/strategies using the WROSE model. The three scenarios were found to be comparable in terms of environmental benefits but upgrading of biomethane as trucks fuel proved to realize higher revenues than the other two scenarios.

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TABLE 1: Economic indicators used for the cost-benefit scenario analysis.

		Scenario Flare € cent/kg waste	Scenario Electricity € cent/kg waste	Scenario Bio-CH_4 € cent/kg waste
COSTS - CAPEX		0,020	0,079	0,154
COSTS - OPEX	Waste collection	-5,830	-5,830	-5,830
	Transportation	-5,830	-5,830	-5,830
	Suction and flare	-0,006	-0,006	-0,006
	Power generation plant		-0,112	
	Upgrading and dispensing			-0,082
REVENUES or COSTS REDUCTION	CERs	*	*	*
	Selling of electricity		0,312	
	Use of biomethane to power the trucks to collect and transport the waste. The costs referred to fuel oil consumption for waste collection and transportation			11,660
	Use of the biogas generated for the generation of electrical energy and heat necessary			0.022
RESULTS (excl. CAPEX)		**-11,666**	**-11,466**	**-0,066**

TABLE 2: Environmental indicators (CO_2 emissions) used for the scenario analysis.

		Scenario Flare t_{CO2}/t_{waste}	Scenario Electricity t_{CO2}/t_{waste}	Scenario CH_4 t_{CO2}/t_{waste}
EMISSION OF CO_2	Waste collection with trucks	0,011300	0,011300	0,011300
	Transportation to landfill with trucks	0,011300	0,011300	0,011300
	Emission of CO2 for the upgrading			0,012
REDUCTION OF CO_2	t CO_2 avoided	-0,2066	-0,2066	-0,2066
	t CO_2 equivalent		-0,0394	
	Use of biomethane to power the trucks working with waste collection as an alternative to diesel.			-0,023
	Reduction for the use of Bio CH_4 istead of diesel.			-0,012
TOTAL		**-0,184**	**-0,223**	**-0,207**

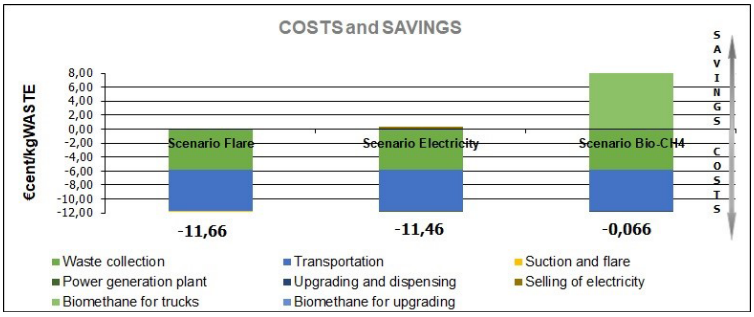

FIGURE 4: Economic analysis of the three scenarios.

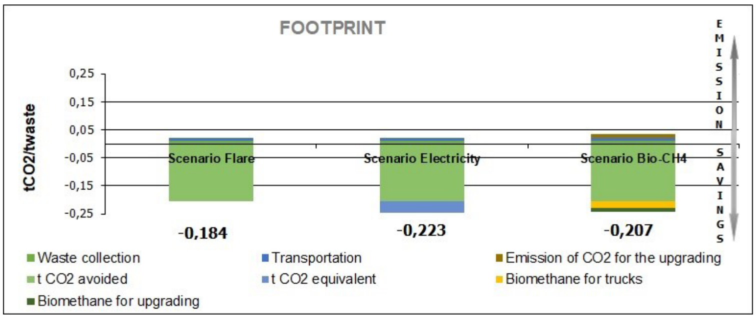

FIGURE 5: Environmental analysis of the three scenarios.

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