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Sustained Carbon Emissions Reductions through Zero Waste Strategies for South African Municipalities

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1. Introduction

Greenhouse gas (GHG) emissions per person from urban waste management activities are greater in sub-Saharan African countries than in other developing countries, and increasing as the population becomes more urbanised (Couth and Trois, 2010). Waste from urban areas across Africa is essentially dumped on the ground with little or no control over the relative liquid and gaseous emissions. The Clean Development Mechanism (CDM), from the 1997 Kyoto Protocol, has been a vehicle to initiate projects to control GHG emissions in Africa. However, very few CDM biogas-to-energy projects have been implemented and properly registered in developing countries, and only one in Africa (Couth et al., 2010).

This chapter presents an integrated approach to quantifying greenhouse gas (GHG) emissions arising from the disposal of solid waste in Africa (and other developing countries) and reports on a large research project on Zero Waste and Waste Management Strategies towards the effective reduction of carbon emissions in the atmosphere from developing countries conducted by the University of KwaZulu-Natal since 2002. It has been estimated that over 60 million cubic metres of waste was produced in South Africa in the year 2010; 90% of these are managed by local authorities (LA) and are still disposed in landfills, at an estimated cost of over ZAR10 billion per annum (1ZAR=7US$). The focus of the study was to assist Local Authorities in the design of appropriate waste management strategies 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.

Africa is the world's second-largest and most-populous continent after Asia. With around one billion people in 61 territories, it accounts for almost 15% of the world's population, of which 60% is rural and 40% urban or peri-urban. The rural growth rate is reported as static (0%) with an increasing urban population growth rate of 6.6% (Earthtrends, 2008). Rural waste is traditionally managed through reuse, recycling and composting. Urban waste is primarily disposed in landfills generating methane (CH_4) gas, which is 21-25 times more potent as a GHG than the natural carbon dioxide (CO_2) also produced by anaerobically

degrading waste in landfills or through composting. The World Trade Organisation designated 96% of the countries in Africa with a low Human Development Index (HDI); 68% are designated by the United Nations (UN) as 'least developed countries' (LDCs), and all of the countries in sub-Saharan Africa are designated under the Kyoto Protocol as Non-Annex 1 parties (developing countries) (Couth and Trois, 2010). In most of the African countries, little of the gross domestic product (GDP) is allocated to waste management and therefore low cost, low technology solutions need to be provided.

A review of waste management practices across Africa (Couth and Trois, 2010, 2011) has concluded to date that the most practical and economic way to manage waste in the majority of urban communities is considered to be:

- Scavenging of waste at collection points to remove dry recyclables by door to door collection;
- Composting of the remaining biogenic-carbon waste in windrows, using the maturated compost as a substitute fertilizer. Non-compostable materials will need to be removed from the waste prior to composting; and
- Disposal of the remaining fossil-carbon waste to sanitary landfills.

This waste management practices will require limited capital in comparison to the complex and expensive waste treatment and landfill disposal systems in developed countries.

However, solid waste management in developing countries/emerging economies is generally characterised 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).

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.

Therefore this study is intended to provide data and information to municipal waste managers with regard to potential alternatives to landfill disposal, using their carbon footprint and potential for GHG reduction as discriminants for their choice. This study focuses exclusively on commercial and residential (post-consumer) municipal solid waste (MSW) as collected and disposed in urban areas in South Africa. Two South African Municipalities (eThekwini (City of Durban) and uMgungundlovu (City of Pietermaritzburg)) were selected as representative of the waste management context in Africa, as suggested by extensive research conducted over the past 15 years (among others:

Trois et al., 2007; Matete and Trois, 2008; Trois and Simelane, 2010; Couth and Trois, 2010 & 2011;).

A zero waste model was developed to simulate various scenarios based on a dry-wet waste model that maximises diversion of recyclable fractions from disposal to landfill, as illustrated in Figure 1.
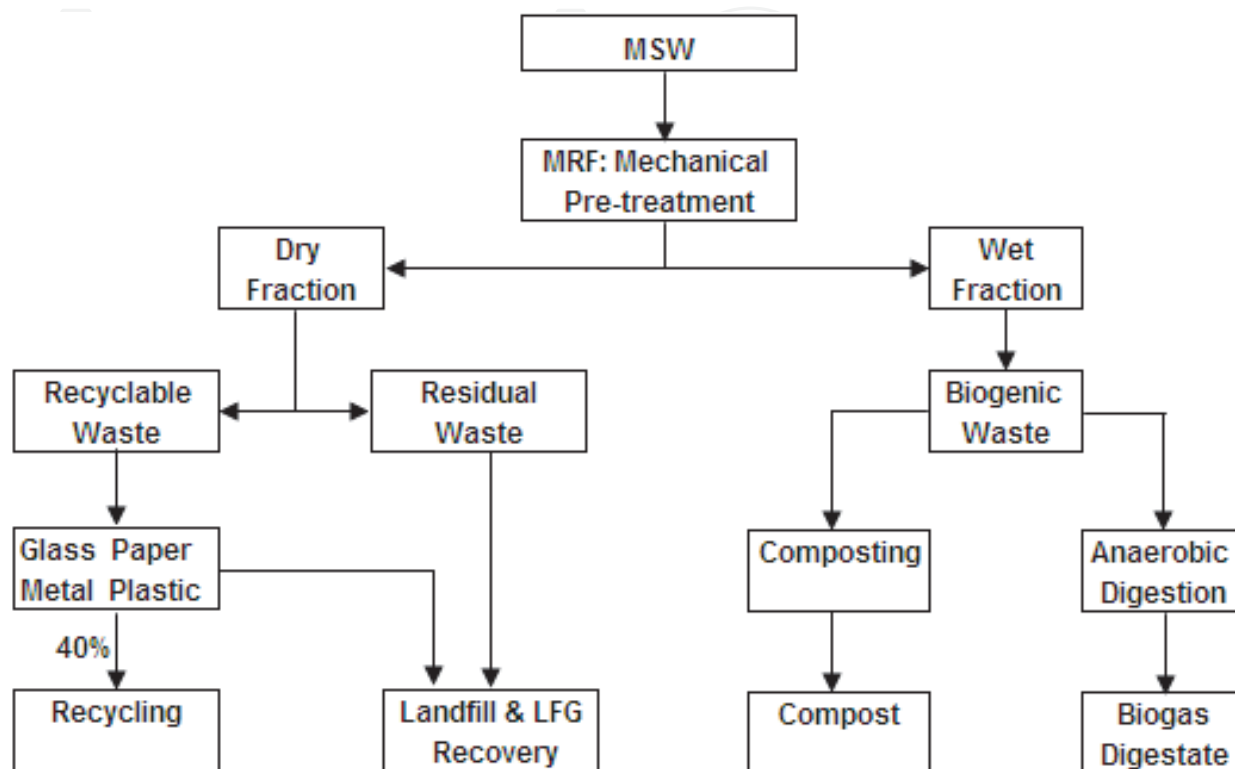

Fig. 1. A typical dry-wet waste diversion model (Matete and Trois, 2008; Trois and Simelane, 2010)

The zero waste model estimated the GHG impacts, landfill space savings and potential costs/income from the following simulated scenarios:

i.   Mechanical pre-treatment, recovery of the recyclables, recycling,
ii. Biological treatment: composting or anaerobic digestion of the wet biogenic fraction, and
iii. Landfilling of all waste or residual wastes, with landfill gas recovery.

The selected strategies were considered the most appropriate for the South African context in terms of the strategy's implementation requirements, technical feasibility, and potential environmental impacts or benefits to municipal waste management systems. The selected strategies, including the status quo were then applied at municipal level for two local landfill sites in various scenarios, where the approximate waste quantities diverted, GHG reductions or emissions and resulting landfill space savings were calculated. The five scenarios evaluated were:

Scenario one: Landfill disposal of unsorted, untreated MSW.

Scenario two: Landfill disposal of unsorted, untreated MSW with landfill gas recovery.

Scenario three: Mechanical pre-treatment (MPT) of MSW, recovery of the recyclable fraction through a Material Recovery Facility (MRF) with landfill gas recovery.

Scenario four: MBT (MPT, recovery of recyclables through an MRF and anaerobic digestion of biogenic food waste with landfill gas recovery).
Scenario five: MBT (MPT, recovery of recyclables through an MRF, composting of all biogenic waste, landfill gas recovery).

2. Methodology

This study comprised of four different components in assessing potential zero waste strategies: a waste stream analysis to determine the waste stream composition and quantities of specific fractions in the waste stream; a carbon emission/reduction assessment of each strategy, a landfill airspace assessment and finally an evaluation of the costs and potential income and savings associated with each strategy.

2.1 Strategies and scenarios evaluated

Zero waste strategies that promote effective waste diversion through mechanical pre-treatment, recycling and composting or anaerobic digestion of biogenic waste were evaluated through a case study of the eThekwini (eTM) and uMgungundlovu municipalities (UMDM). These municipalities were selected as representations of a typical South African population's (in terms of social profiling and socio-economic factors) waste stream in a medium to large municipality. Scenario 1 represents the baseline scenario and the current status quo of the majority of landfill sites in South Africa. There are currently no other waste diversion/treatment methods or landfill gas recovery employed at the New England Landfill site, and thus scenario one reflects the current status quo of waste management in the UMDM. Scenario two assesses landfill disposal of all MSW, along with recovery of landfill gas produced through degradation of organic waste under anaerobic conditions within landfill cells. The third scenario evaluates the mechanical pre-treatment or separation of the recyclable dry fraction of the MSW stream, while both the biogenic wet fraction and residual waste are landfilled. In this scenario recyclables are sorted, baled and sold to local private recycling companies. Scenario three represents the status quo of the Mariannhill landfill site in Durban (eTM) that currently has both a Material Recovery Facility and a landfill gas recovery system. Currently, the Mariannhill MRF recovers between 9-13% of recyclables. Both the current rate (9.82%) and a potential recycling recovery rate (40%) were considered for the eThekwini Municipality to provide a comparison between the status quo and the potential emission reductions obtained from improving the recovery rate to 40%. A 40% recovery rate was also considered for the UMDM scenario three, as well as all further scenarios considering recycling for both municipalities. Scenarios four and five consider Mechanical Biological Treatment strategies including anaerobic digestion with energy generation and windrow composting respectively. Anaerobic digestion is currently limited to small-scale pilot projects, and industrial waste treatment in South Africa. The Dome Aeration Technology (DAT) windrow composting was chosen as the most appropriate MBT method due to its efficiency and cost implications (Trois et al., 2007; Trois and Simelane, 2010). A schematic summary of the strategies evaluated in each scenario is presented in Figure 2.

2.2 Waste stream analysis

A waste stream analysis (WSA) determines the composition of the waste stream in a particular area or region. WSA is necessary for the planning and design of waste management systems, the subsequent assessment of the efficiency of such systems and for
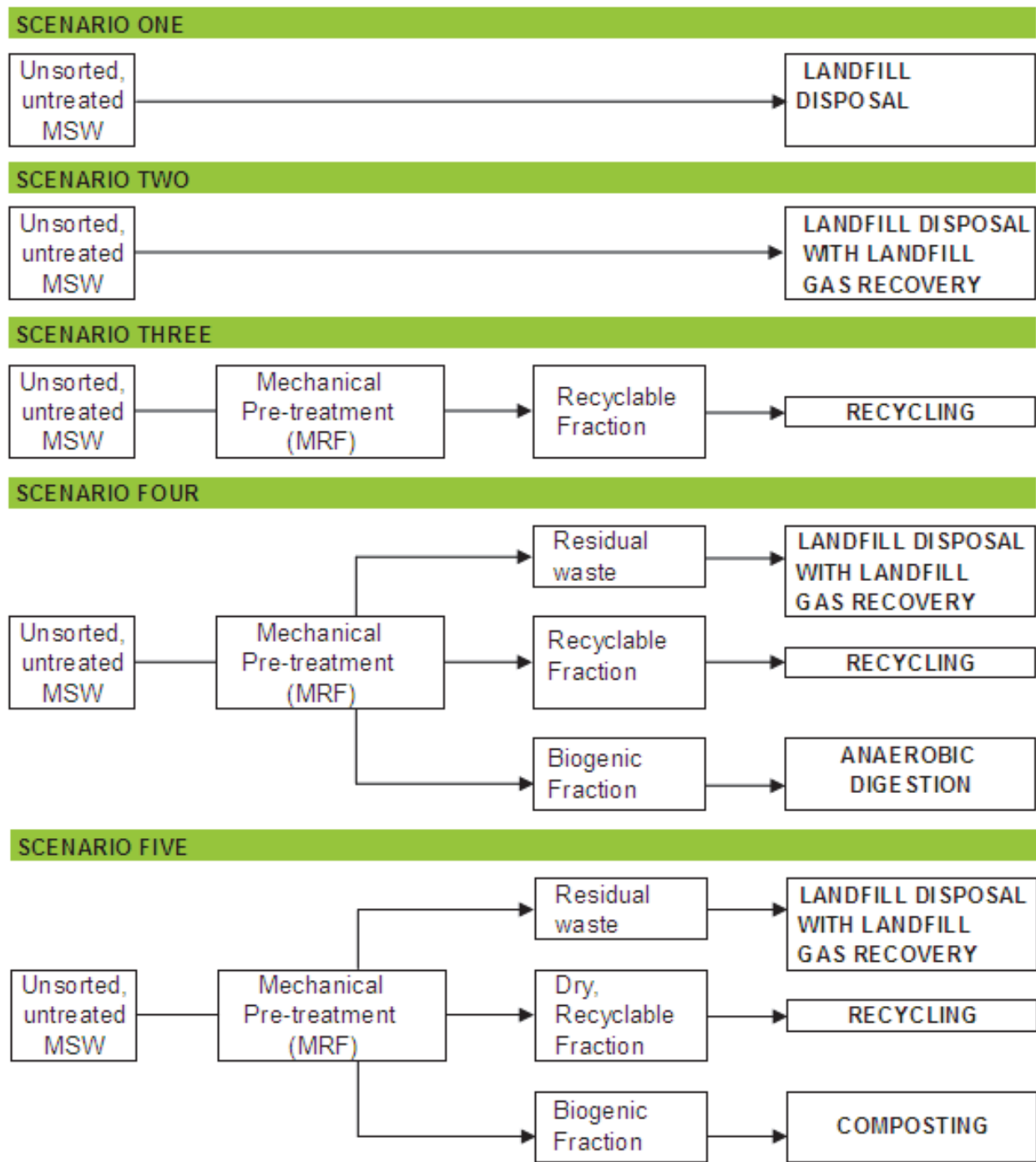
Fig. 2. Waste Management scenarios evaluated.

information and statistics reporting which is especially lacking in developing countries as far as current and up to date data is concerned. The data required was obtained through a WSA of the New England Landfill, which is the major landfill servicing the uMgungundlovu DM, and from Durban Solid Waste for the Mariannhill landfill in the eThekwini Municipality. Purnell (2009) identified two main issues concerning waste information. Firstly, the lack of reliable waste generation data which affects waste management planning; and secondly, the lack of guidelines regarding waste generation measurement, as currently only large municipal landfills operate weighbridges that

determine waste quantities. The study, therefore, addresses these issues and knowledge gaps through the WSA and the subsequent data generated. A direct site specific approach to the WSA was adopted entailing sampling of waste loads, sorting and weighing of individual waste materials into over 30 waste categories (Tchobanoglous, 1993; Reinhart and McCauley-Bell, 1996). Statistical analysis of this data was employed to generate commercial and general household waste profiles for the New England Road Landfill. The results of the WSA together with data from the 1998 eThekwini WSA are presented in Table 2. The study's approach is localized to major municipal landfill sites, thus the composition results were used to simulate the average annual waste fraction quantities of the MSW stream entering the Mariannhill and New England Road Landfills, presented in Table 3.

Landfill	Mariannhill Landfill		New England Road	
Waste Stream	Residential	Commercial	Residential	Commercial
% Paper & cardboard	17.88	16.11	14.75	33.08
% Plastic	19.01	6.08	8.64	11.43
% Glass	6.82	14.86	7.00	3.87
% Metal	5.34	4.94	5.19	2.70
% Biogenic waste	45.67	35.56	34.58	29.65
% Other waste	5.27	22.45	30.04	19.47

Table 2. Composition of MSW streams to landfill in the two selected municipalities

Waste Fraction	Mariannhill (tons)	New England Road (tons)
Newspaper		5453
General mixed paper (CMW)	10627	7234
Scrap Boxes & Cardboard (K4)	9229	11402
Low density polyethylene (LDPE)	7147	2450
High density polyethylene (HDPE)	2839	1401
Polyethylene-terephthalate (PET)	1815	2037
Polypropylene (PP)	2542	1613
Polyvinyl Chloride (PVC)	1089	8
Polystyrene (PS)	2593	1101
Glass	10020	6861
Steel Cans/Tins	4817	4245
Aluminium Cans	1149	547
Biogenic Food Waste	49153	36608
Garden Refuse: Green	7887	637
Garden Refuse: Wood	807	46
Other	10800	32287
Total Waste Diverted/Disposed	122514	113930

Table 3. Average annual waste fraction quantities

2.3 Carbon emissions/reduction assessment

In terms of GHG modelling, a wide range of models using Life Cycle Analysis (LCA) have been developed. Of the models researched, few provide analysis for anaerobic digestion of

biogenic wastes. The availability and applicability of the models were the limiting factors for their use and thus an ad hoc GHG quantification tool called the Waste Resource Optimisation Scenario Evaluation (WROSE) was developed as part of this study using emissions factors derived by the United States Environmental Agency (US EPA) for landfill disposal, landfill gas recovery, recycling and composting. The emissions factors used in WROSE are those derived by the United States Environmental Protection Agency using IPCC guidelines and were used as the most 'transparent' approach to modelling the GHG emissions or reductions. A streamlined LCA approach was used for the derivation of these factors – GHG impacts are considered from the point at which the waste is discarded by the waste generator, to the point at which it is disposed, treated, or recycled into new products (US EPA, 2006). The emissions factor for the anaerobic digestion of biogenic MSW was developed using the same streamlined LCA approach (on a wet weight basis) and considered the following emissions and reductions:

i. Direct emissions: Direct process emissions were determined using the IPCC greenhouse gas inventory guidelines (2006). The tier 1 approach was adopted, as this is the methodology for countries where national data and statistics are not available. The emissions factor for the biological treatment of biogenic MSW as listed by the guidelines is 1g CH_4/kg of wet waste. Nitrous oxide emissions are assumed to be negligible and an assumed 95% of methane is recovered for energy generation. Total direct emissions amounted to 0.00105 $MTCO_2$eq/ton.

ii. Transportation emissions from the collection and transportation of MSW: Transportation emissions were calculated using a similar methodology to that used in the 2009 study by Møller et al, 2009. The fuel efficiency of waste collection trucks over a 20mile distance was determined, assuming a typical value of 0.03L/ton/km. A 20mile distance to the AD facility was assumed to maintain consistency with the US EPA emissions factors. Total emissions from transportation of waste amount to approximately +0.0029794 $MTCO_2$eq/ton.

iii. Energy emissions/reductions: Energy emissions consist of emissions from the combustion of methane to produce energy; emission reductions from electricity generation and energy emissions from energy consumption. Energy reductions from substitution of fossil fuel energy due to energy recovery and electricity generation from waste. Total emissions from combustion amounted to 0.0024 $MTCO_2$eq/ton of wet waste. A typical emissions factor for combustion was chosen for the average yield of biogas from Møller et al. (2009). An average biogas yield of 110Nm^3/ton of waste digested and calorific value of 23 MJ/m^3 was used to calculate the total energy produced from combustion – with a 40% energy recovery rate (Møller et al, 2009). Approximately 18% of the total energy generated is assumed as the energy requirement for the anaerobic digestion process and operations on site. An average emissions factor of 1.015 kg CO_2/kWh was used for the electricity generated in South Africa by electricity provider ESKOM as derived by the University of Cape Town Energy Research Centre (2009). This factor is significantly higher than the average range of between 0.4 and 0.9 kg CO_2/kWh. This is likely due to the highly carbon intensive electricity grid in South Africa comprising of approximately 91.7% coal generated electricity (SA-Department of Energy, 2010). Emission reductions from the substitution of electricity amounted to -0.23397 $MTCO_2$eq/ton, thus producing an overall energy emissions factor of -0.23157 $MTCO_2$eq/ton of wet waste.

iv. Digestate Emissions: from digestate application and reductions from substitution of inorganic chemical fertiliser by compost produced from digestate. These emissions were approximated on the basis of European data (Boldrin et al, 2009; Møller et al, 2009) as no such data for the production of fertilisers is available for South Africa. A conservative value for fertiliser substitution was adopted as the nutrient composition of the digestate produced is variable and largely depends on the quality of input feedstock. The emissions from digestate amount to approximately -0.0443 $MTCO_2eq$/ton.

The resultant anaerobic digestion emission factor calculated was approximately -0.2718 $MTCO_2eq$/ton of wet waste, which is high due to the recovery of methane and production of electricity and substitution of fossil fuel energy in South Africa's carbon intensive energy supply. This factor has been calculated on a wet weight basis and therefore the WROSE model requires the amount of wet waste to be entered into the input screen under 'biogenic food waste'. For the modelling process, it was assumed 0.6 m^3 of water is added per ton of biogenic input feedstock.

2.4 Landfill space savings

The estimation of landfill space savings from waste diversion is largely an empirical calculation, as the unique conditions and operational activities on site, specifically, compaction of waste into landfill cells, influence the actual airspace saved. Actual landfill space savings (LSS) will therefore depend on the degree of compaction employed and the efficiency to which it is conducted. The calculation of LSS was based on three different methodologies to produce both a range of expected landfill space savings and an average LSS value for each scenario. The first methodology was used by Matete and Trois (2008) to calculate LSS for various zero waste scenarios. The total amount of waste in tons is divided by the average of compacted of MSW to yield the total landfill space savings. The value for the compacted density of MSW was assumed to be 1200kg/m^3 (1.2 tons/m^3) in accordance with the eThekwini Integrated Waste Management Plan (SKC Engineers, 2004). Landfill density factors of various waste fractions calculated by the United States Environmental Protection Agency (1995) and the Department of Environment and Conservation of Western Australia were used to produce further estimates, as these factors constitute a wide range of waste materials and specific fractions that can be diverted from landfill disposal.

2.5 Economic analysis

The parameters and assumptions used for estimating both capital and operational costs, and the potential income derived from the sale of recyclables, electricity, certified emissions reductions (CERs), and compost are based on research reports, journal publications, feasibility studies for local projects, and international projects where local data was unavailable. A full cost-benefit analysis should be undertaken to determine the costs and benefits over the duration of the design life for waste treatment and disposal facilities. Annual operating costs of landfill disposal amount to ZAR138 (approx. US$ 20) per ton of waste landfilled (Moodley, 2010). The capital cost of the eThekwini landfill gas to energy project for Mariannhill (0.5MW) was used as an estimate for the analysis.

A total throughput MRF capacity of 100,000 tons per year (385 tons per day) was assumed for the mechanical pre-treatment phase of the Mechanical Biological Treatment (MBT) scenarios for both landfill waste streams. The total fractions of biogenic and recyclable

fractions from each waste stream amount to between 80,000-90,000 tons. It is assumed that waste loads from areas where the composition of recyclables and biogenic waste is insignificant are immediately diverted to landfill disposal. Operational and capital costs were approximated using a 2005 study by Chang et al., which approximated a linear relationship between capital and operating costs and design capacity. The total capital cost for mechanical pre-treatment and materials recovery therefore amounts to approximately US$ 33.8 million while the total annual operational cost is US$ 9.9 million/year. Recycling prices have been sourced from two local studies: The Waste Characterisation Study Report (Strachan, 2010) and the City of Cape Town IWMP (2004). It should be noted, however, that recycling prices vary in accordance with market conditions. Depending on the price of virgin materials, and other commodities such as oil, it may be cheaper to produce products from virgin materials, rather then through recycling. This reduces the demand for recyclables, and therefore directly affects prices (Stromberg, 2004; Lavee et al, 2009).

A study by Tsilemou et al. (2006) evaluated the capital and operating costs of 16 anaerobic digestion plants. A study reviewing anaerobic digestion as a treatment technology for biogenic MSW used this data to produce cost curves by Rapport et al (2008). The total biogenic fraction of the Mariannhill and New England Landfill waste streams amount to approximately 49,153 and 37,000 tons/annum respectively and therefore the chosen capacity for each anaerobic digestion plant was 50,000 and 40,000 tons/annum respectively. Using the cost curves, capital costs for anaerobic digestion plants for both the Mariannhill waste and New England waste streams amount to US$ 15.24 and US$ 13.46 million respectively, while operating costs amount to US$ 28.2 and US$ 32.4 per ton of waste respectively. The capital and operating expenses for the implementation of DAT composting plants have been determined at local level as ton and US$ 22/ton of input waste (Douglas, 2007). A degradation factor is used to estimate the yield of compost obtained from the process, and consequently the resulting income from the sale of compost. A DAT composting facility processing 180 tpd requires a capital investment of US$ 350k (Douglas, 2007). This approximation was used to estimate the capital costs for DAT composting facilities for the Mariannhill waste stream (230tpd) and New England waste stream (150tpd).

3. Results

3.1 Case study

3.1.1 eThekwini municipality – Mariannhill landfill

The eThekwini municipality is located on the eastern coastline of South Africa in the province of KwaZulu-Natal. Sub-tropical climate conditions are pre-dominant in the coastal areas of eThekwini. The municipality covers a total area of 2297 km² and has an approximate population of 3.16 million people. Areas of eThekwini vary in socio-economic climate from well developed urban areas of the metropolitan to newly integrated rural/peri-urban areas with little service coverage and infrastructure. Waste generation rates for the formal sector range from 0.4 - 0.8kg per capita per day, and 0.18kg per capita for the informal sector whilst the total waste landfilled per annum is approximately 1.15 million tons (SKC Engineers, 2004). There are currently three engineered landfills being operated by Durban Solid Waste in the eThekwini municipality: the Bisasar Road, Mariannhill and Buffelsdraai landfill sites. The Mariannhill landfill was selected for the study as a leachate treatment plant, landfill gas recovery and energy generation system and MRF are located on site. The landfill is therefore representative of an integrated waste management approach,

which will be compared with other possible zero waste strategies. The landfill site has been operational since 1997, and has an approximate incoming waste stream of 550-700 tons per day. The landfill is expected to close in 2022 (Couth et al, 2010). The site incorporates environmentally sustainable engineering design and operational methods, and has been registered as a national conservancy site. The MRF was implemented in 2007 and recovers between 9-13% of recyclables from the waste stream (DSW, 2010). The MRF facility has since been upgraded, with the addition of mechanical sorting equipment and the extension of the pre-sorting line. The MRF has exceeded its potential in terms of initial greenhouse gas savings, has created jobs and resulted in landfill space savings, however problems have been experienced with regard to contamination of recyclable wastes by garden refuse.

3.1.2 uMgungundlovu municipality: New England road landfill

uMgungundlovu District Municipality (UMDM) is one of 11 district municipalities in KwaZulu-Natal (KZN) province and is situated within the KZN Midlands. uMgungundlovu District Municipality has a total of 234,781 households and a total population of 927,845 people (Statistics South Africa, 2005). The UMDM covers approximately 8,943 km² and encompasses areas of varying socio-economic conditions – from urban residential and commercial/industrial areas, to informal areas and rural, traditional areas. Waste generation rates range between 0.35-0.61 kg/capita/day for urban areas and between 0.1-0.61 kg/capita/day for rural areas (UMDM Review, 2009). An estimated 200,000 tons of waste is generated annually in the UMDM (Jogiat et al, 2010). The majority of municipal landfill sites in the UMDM does not have permits, or infrastructure such as weighbridges. This is characteristic of South African municipalities and highlights the need for improved infrastructure and waste reporting. Most of these landfill sites have been prioritised in integrated development plans. Consequently, weighbridge data is only available for the New England Road Landfill Site in uMsunduzi. The New England landfill was opened in 1950 as an open dumpsite, and was upgraded to an engineered landfill site in the 1980's, in accordance with the National Environment Act. The landfill receives an average of 183,531 tons of waste annually, which is equivalent to approximately 700 of tons of waste per day. Approximately 250,000 m³ of compacted waste is landfilled every year (UMDM, 2009).

3.2 Carbon emissions/reductions assessment

A summary of the results obtained from the Carbon Emissions/Reductions assessment using the WROSE model is illustrated graphically in Figure 3 and 4.

The results of the carbon emissions/reduction assessment confirm that the scenario 1 (landfill disposal of all MSW) produces the greatest GHG emissions, and is therefore the least favourable waste management strategy in terms of environmental benefit. This is largely due to the degradation of biogenic wastes (food waste and garden refuse), contributing to approximately 70% and 65% of total emissions for the eThekwini Municipality and UMDM respectively as shown in Table 4. The methane produced from anaerobic conditions prevailing in landfill cells is considered in the analysis as this methane is produced through anthropogenic activity of landfilling of waste. The second greatest contributor to GHG emissions is the paper fraction of the waste stream, comprising common mixed waste and the K4 cardboard and scrap boxes (27-32% in total). This is due to the degradable carbon fraction of these materials, which ranges from 30-50% and degrades under aerobic conditions. Although the carbon in both biogenic and paper fractions degrades under aerobic conditions,

some of the carbon that does not degrade is stored, causing a carbon sink. For example the degradation of lignin and cellulose varies depending on landfill conditions, and often, these compounds do not decompose to the full extent, and are stored within the landfill (landfill sequestration) (US EPA, 2006). This does not apply to other materials such as plastics, as the carbon present in plastic is obtained from fossil fuel sources and thus the carbon is considered to be transferred from one source to another (storage in the earth, to storage in a landfill). The emissions produced from landfill disposal of plastic, metal and glass fractions therefore comprise of emissions from transportation and the operation of vehicles and machinery on site.
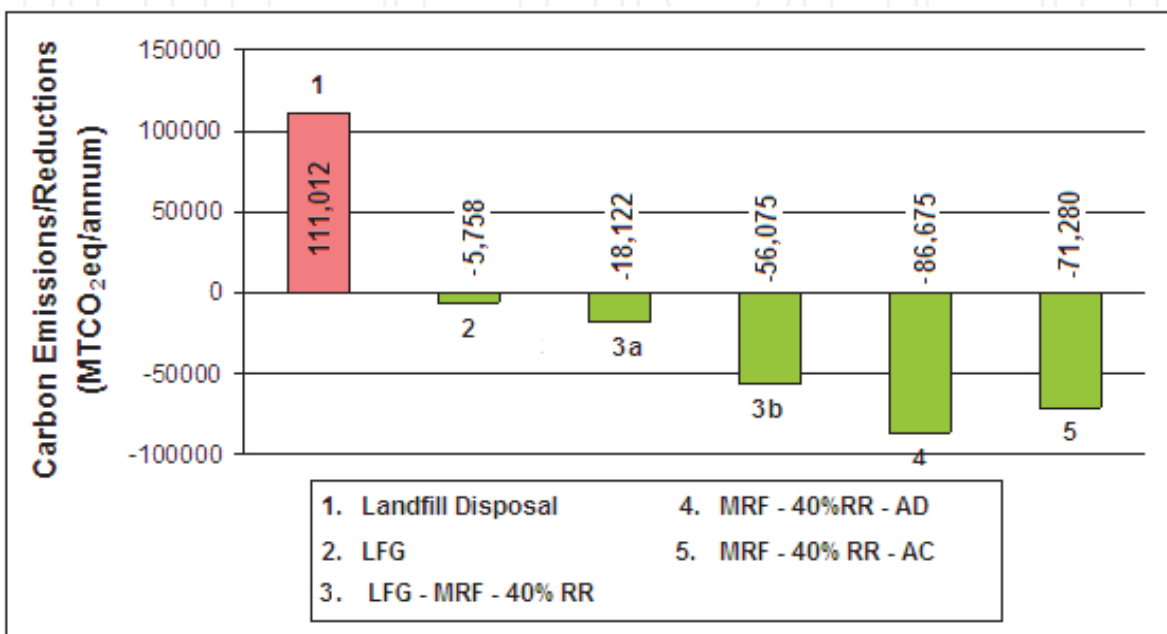
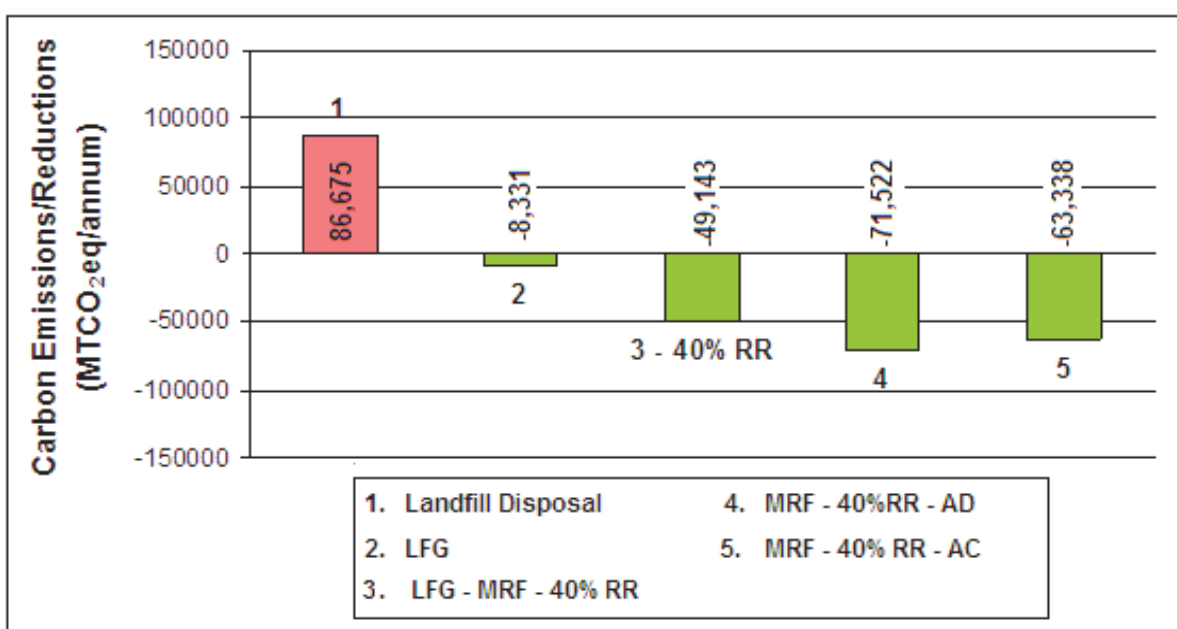Fig. 3. CERs Assessment of the Mariannhill Landfill waste stream

Fig. 4. CER Assessment of the New England Road Landfill waste stream

Waste Fraction	eThekwini Municipality		UMDM	
	Emissions (MTCO$_2$eq)	% Emissions Contribution	Emissions (MTCO$_2$eq)	% Emissions Contribution
General mixed paper (CMW)	15,814	14.25%	10,765	12.02%
Scrap Boxes & Cardboard (K4)	15,158	13.65%	18,727	20.91%
Low density polyethylene (LDPE)	315	0.28%	108	0.12%
High density polyethylene (HDPE)	125	0.11%	62	0.07%
Polyethylene-terephthalate (PET)	80	0.07%	90	0.10%
Polypropylene (PP)	112	0.10%	71	0.08%
Polyvinyl Chloride (PVC)	48	0.04%	0	0.00%
Polystyrene (PS)	114	0.10%	49	0.05%
Glass	442	0.40%	303	0.34%
Steel Cans/Tins	212	0.19%	187	0.21%
Aluminium Cans	51	0.05%	24	0.03%
Biogenic Food Waste	77,480	69.79%	57,705	64.43%
Garden Refuse: Green	522	0.47%	42	0.05%
Garden Refuse: Wood	62	0.06%	4	0.00%
Total Emissions from Landfilling	110,536	100%	89,560	100.00%

Table 4. Waste Fraction % contribution to GHG emissions from landfill disposal

The recovery of landfill gas at a 75% recovery rate through Scenario 2 produces a 110% and 105% decrease in emissions for the UMDM and the eThekwini Municipality respectively. These results highlight the value of landfill gas recovery for the reduction of GHG emission impacts from waste management and at the very least, landfill gas recovery systems should be employed at landfill sites. Landfill gas pumping trials would obviously be required to assess the actual yield of gas being produced as compared with the theoretical yield used in the model. The recovery of methane and generation of electricity results in GHG savings of 5,758 and 8,331 MTCO$_2$eq/annum from the eThekwini Municipality and uMgungundlovu DM respectively. Published carbon emission reductions for the Mariannhill landfill gas to energy project amounted to approximately 16,000 MTCO$_2$eq/annum (Couth et al, 2010). The difference between this data and the value calculated from the CER assessment differ by almost 10,000 MTCO$_2$eq/annum. This variation can be attributed to the nature of landfill gas production, which varies in composition and generation rate depending on the phase of degradation (Smith et al, 2001). Ritchie and Smith (2009) list factors such as waste composition, pH, moisture content, temperature and nutrient availability affect landfill gas generation. The amount of gas actually being generated and recovered could therefore differ from the calculated value depending on how these factors are taken into account. The parameters and assumptions used in the development of the US EPA emissions factors for landfill gas generation and recovery are based on experimental values; and have been identified as an area where more research is required (US EPA, 2006). The factors have also been based on the United States energy grid, which is less carbon intensive than the South African grid, and therefore a possible source of variation (underestimation of potential GHG savings) when considering the substitution of fossil fuel energy with electricity generated from landfill gas.

Recycling, which is implemented in Scenarios 3, 4 and 5, as expected produced significantly higher GHG emission reductions in comparison to all other strategies. This is largely due to substitution of recycled materials for virgin materials in production processes, and displaced energy emissions produced through the acquisition of raw materials. The status quo of waste management for the Mariannhill landfill site produces approximately 18,122 $MTCO_2eq$/annum. The current MRF recycling recovery rate produces approximately 13,000 $MTCO_2eq$/annum whilst an increase in the recovery rate to 40% produces 53,000 $MTCO_2eq$/annum. An MRF recycling facility recovering 40% of recyclables present in the New England waste stream together with landfill gas recovery would reduce emissions from the current status quo by approximately 160%. These savings (47,103 $MTCO_2eq$) could in reality be higher, as recyclables in the waste stream were found to be relatively clean and uncontaminated, as waste is not transferred, mixed and compacted at transfer stations as is the case in the eThekwini Municipality.

In terms of the treatment of the biogenic fraction of the waste, the energy generation capabilities of anaerobic digestion produce greater GHG reductions for the Mariannhill and New England waste streams: approximately 21,379 and 15,922 $MTCO_2eq$/annum respectively, and far outweigh the environmental benefits of both composting and landfill gas recovery therefore making it the most preferable strategy in terms of GHG impacts. Anaerobic digestion allows for the production of methane from the degradation of wastes to occur in a controlled environment and be captured efficiently (greater capture/collection efficiency in comparison to landfill gas recovery). The gas is produced, captured and converted into energy at a faster rate than the naturally occurring anaerobic processes in landfill cells (Ostrem, 2004). The environmental benefits of anaerobic digestion are clear; however they need to be weighed against the costs, in comparison with a less capital intensive and carbon neutral strategy such as composting. Scenarios four and five produce the greatest GHG emission reductions as they allow for integrated waste management where several strategies are implemented to target the biogenic, recyclable and residual waste fractions (Figure 5).
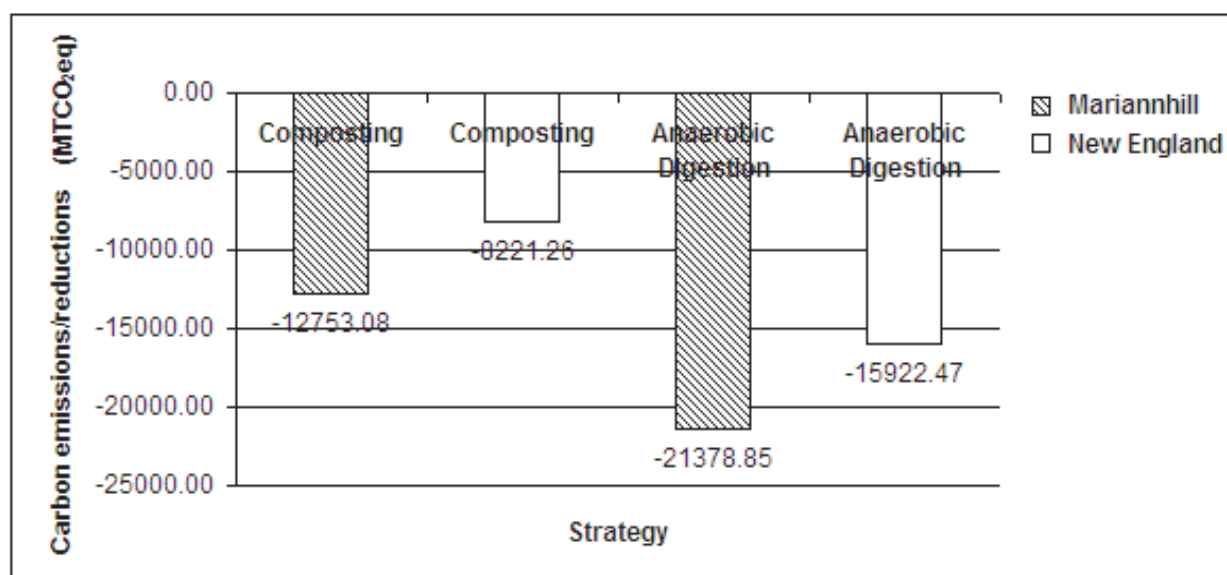

Fig. 5. Comparison of anaerobic digestion and composting

3.3 Landfill space savings analysis

The results from the landfill space savings estimate for the Mariannhill and New England Road Landfill waste streams are presented in Table 5.

Landfill Waste Stream	Landfill Space Savings (m^3)		
	Scenario 3	Scenario 4	Scenario 5
Mariannhill Waste Stream	48,503	94,375	103,302
New England Waste Stream	39,235	73,399	74,100

Table 5. Average landfill space savings

In both case studies Scenario five (MRF recycling and composting) results in the greatest average landfill space savings, with an annual saving of 103,302 m^3 for the Mariannhill landfill, and 74,100 m^3 for the New England Road landfill, as the scenario allows for the greatest amount of waste to be diverted from landfill disposal. It should be noted however that the greatest landfill space savings result from the diversion of recyclables (at a 40% recovery rate) which account for approximately 50% of the savings for both landfills if scenario five is implemented. The remaining airspace for the Mariannhill Landfill Site as at June 2002 was estimated to be 3.8 million m^3 (eThekwini Municipality, 2010). The expected date for closure of the site is in 2022 (Couth et al, 2010). Assuming 190 000 m^3 of waste is landfilled every year (3.8 million m^3 over a 20 year period), the current remaining landfill airspace amounts to 2.28 million m^3. This assumption is valid as currently 550-700 tons of waste is landfilled daily at the Mariannhill Landfill Site (Couth et al, 2010) which is equivalent to approximately 190 000 m^3 of MSW landfilled annually. The predicted landfill airspace capacity trends as illustrated by Figure 6 show that if Scenario 3 were to be achieved (40% recovery rate of recyclables) a further 4 years could be added to the landfill lifespan. The diversion of the recyclable and biogenic fraction to either composting or anaerobic digestion would extend the lifespan by 12-14 years.
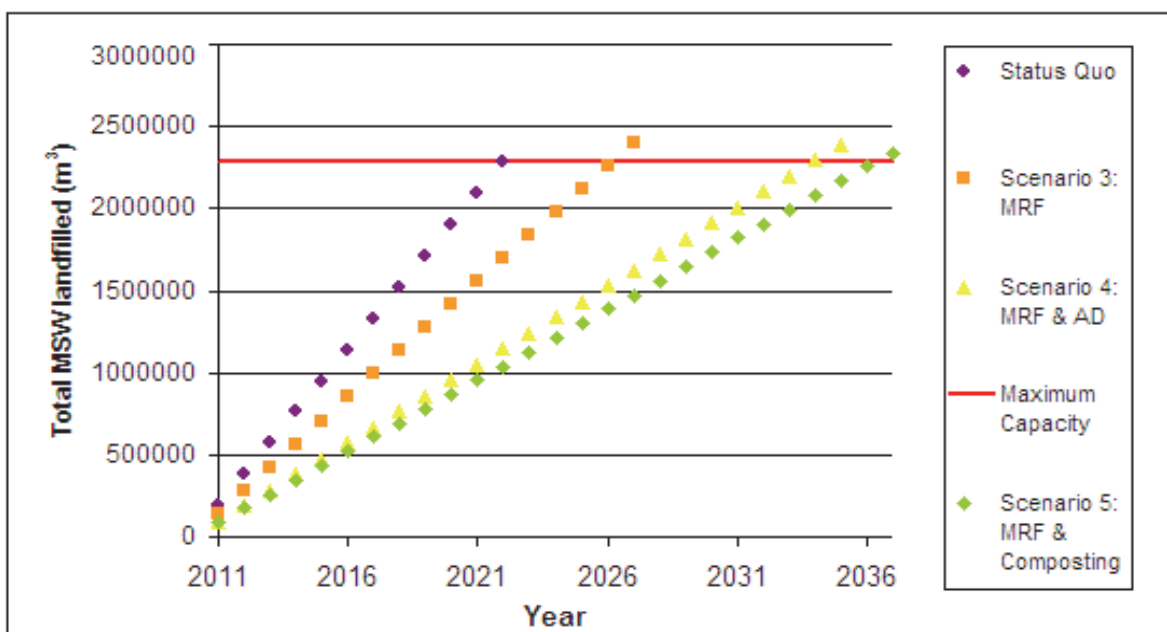

Fig. 6. Predicted airspace capacity trends: Mariannhill Landfill Site

An evaluation of landfill airspace of the New England Road Landfill estimated a remaining lifespan of six to nine years, provided that 250, 000 m³ of municipal solid waste is disposed of annually (Jogiat et al., 2010). Assuming a remaining average lifespan of eight years (expectant closure in 2016/2017 – a further six years landfill space currently remaining), the New England Road landfill currently has capacity for 1,500,000 m³ of municipal solid waste. The predicted landfill airspace trends are illustrated in Figure 7. If Scenario 3 was implemented, the landfill lifespan would be extended by a year, while if Scenario 4 or 5 were applied the lifespan would be extended by approximately two and half years.
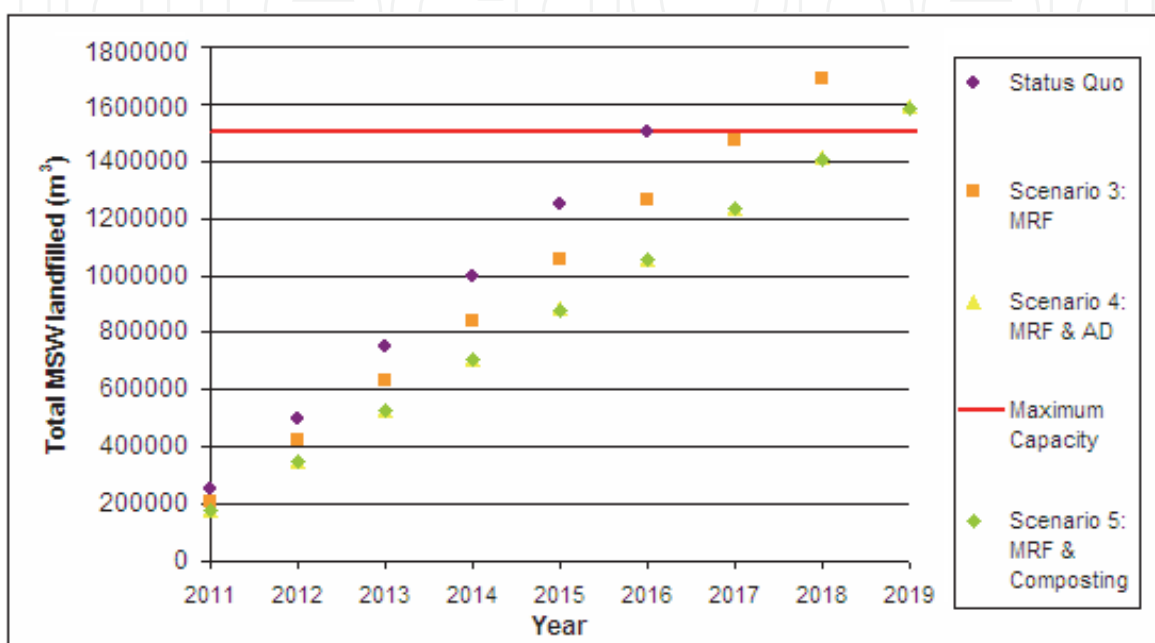

Fig. 7. Predicted airspace capacity trends: New England Road Landfill Site

3.4 Cost analysis
Table 6 presents the results of the economic analysis.

3.4.1 Landfill gas recovery
Landfill disposal with landfill gas recovery is the least capital intensive for the scale of application on both landfill sites. This highlights the previous recommendations that landfill gas recovery (at the very least) should be implemented at landfills planned in the UMDM. The actual operating costs for landfill gas recovery amount to 0.018$/kWh which equates to R 866,758/annum. The majority of operating costs stem from landfill disposal of waste (R13-14 million). Certified emissions reductions produce between R550, 458 and R796, 448 per annum. Income from the sale of electricity at the current tariff (0.047$/kWh) earns approximately R2.2 million per annum. This potential income could increase with the implementation if the Renewable Energy Feed in Tariff (REFIT), currently being developed by the government to provide incentives for investment in renewable energy sources. REFIT allows suppliers of renewable energy to sell electricity at a set price that covers generation costs and ensures a significant profit argue that both CDM and REFIT mechanisms should apply to landfill gas recovery projects, as long as it can be shown that such projects are only economically feasible with the implementation of both schemes (Couth et al, 2010).

Item	Unit	Mariannhill	New England
Landfill Gas Recovery System			
Landfill Gas Recovery System	R	1,100,000	1,100,000
Total Operating Costs	R/annum	16,906,932	15,722,340
Sale of Electricity	R/annum	2,263,201	2,263,201
Certified Emission Reductions	R/annum	550,458	796,448
Materials Recycling Facility			
MRF Capital Costs	R	33,848,875	33,848,875
MRF Operating Costs	R/annum	9,899,276	9,899,276
Sale of Recyclables	R/annum	19,598,660	15,714,260
Landfill airspace savings	R/annum	2,945,125	2,485,875
Anaerobic Digestion Plant			
AD Plant Capital Cost	R	104,066,340	90,545,910
AD Plant Operating Costs	R/annum	9,465,084	8,099,278
Sale of electricity	R/annum	5,818,124	4,333,202
Sale of Compost	R/annum	7,372,950	5,491,200
Certified Emissions Reductions	R/annum	2,043,797	1,522,172
Landfill airspace savings	R/annum	2,135,250	2,135,250
DAT Composting Plant			
Compost Plant Capital Cost	R	3,066,667	2,000,000
Compost Plant Operating Cost	R/annum	9,123,000	6,082,000
Sale of compost	R/annum	10,846,313	6,992,063
Certified Emissions Reductions	R/annum	1,219,182	785,944
Landfill airspace savings	R/annum	3,424,938	2,179,063

Table 6. Economic Analysis for all scenarios

3.4.2 Materials recycling facility

The implementation of an MRF processing 100,000 tons per annum requires significant capital investment of approximately R34 million (US$ 5m) however the greatest income and savings is achieved (approximately R19 million and R15 million (US$ 2.1m) for Mariannhill and New England Road waste streams per annum). Although price volatility in the recycling market is of concern, the MRF is still a requirement for mechanical pre-treatment phase of MBT strategies, as source separation is not implemented.

3.4.3 Anaerobic digestion and composting

A full scale anaerobic digestion plant with capacity of 40,000 and 60,000 tons for the New England Road and Mariannhill waste streams requires the greatest capital investment (R90-100 million – US$ 12.8-14.3m), with an estimated net profit of R 3 million (US$ 428k) for the NER waste stream and R 5 million (US$ 710k) for the MH waste stream. When compared to the 'carbon neutral' biological treatment of waste through composting plants, the capital expenditure required for an AD plant of this magnitude does not seem viable. A DAT composting plant produces a net profit per annum of R2 million and R3 million for a required capital expenditure of R2 million (US$ 285k) and R3 million (US$ 428k) for the NER and MH waste streams respectively, however this profit depends greatly on the establishment of a market for compost. Producers of compost often have to upgrade the nutrient content of composts, through blending with other nutrient rich organic sources,

and these costs are not accounted for. In this respect anaerobic digestion plants have a definite advantage over composting, as the major potential income sourced are through the sale of electricity, and certified emission reductions, which account for approximately 50% of the total net profit for both waste streams.

4. Conclusion and recommendations

The results of the study clearly show that all waste management strategies would produce some level of environmental benefit, either in terms of greenhouse gas emission reduction and/or landfill space savings. An MBT scenario with mechanical pre-treatment and separation of the wet and dry fractions through an MRF; the consequent recycling of recyclable fractions; anaerobic digestion of biogenic waste with energy generation, and landfill disposal of all residual wastes would produce the greatest GHG reductions in both municipalities. This said there are many challenges associated with implementing new technology and waste treatment methods. The main areas to consider are costs, public perception and participation, and legislation, regulations and incentives needed to establish markets for the products yielded from landfill gas recovery, materials recovery, aerobic composting and in particular anaerobic digestion.

The capital costs for implementing waste diversion/zero waste strategies, in particular anaerobic digestion (R90-100 million) and MRF recycling (R34 million) remain the greatest challenge toward implementation on a large scale for the treatment of biogenic and recyclable fractions of MSW. The capital costs and investment required raises the issue of the relevance of these waste management strategies/technologies to a country like South Africa, where basic needs are not being met, waste management budgets are insufficient and municipalities are not able to deliver waste service coverage to all areas. Possible rationale for implementing an expensive technology such as AD is the investment in infrastructure that promotes growth and in the form of job creation and skills development. The most pressing point in evaluating the applicability of such a technology is that of environmental benefit. South Africa is the greatest producer of GHG emissions on the African continent and therefore has a responsibility to reduce carbon emissions.

Creating a market for the products of anaerobic digestion, composting and recycling – chiefly energy, compost and recycled products is vital in ensuring long-term economic viability. The UK government has created the Renewable Obligations Scotland (ROS) Policy, which requires conventional electricity suppliers to distribute a proportion of the total electricity demand from renewable energy sources, and therefore effectively guarantees a market for biogas electricity. Energy providers then purchase electricity from these renewable energy producers to satisfy these legislative requirements (Baker, 2010). Similar schemes are in the process of development in South Africa such as the Renewable Energy Feed in Tariff. Commitment from the government and initiatives such as these are required to make biogas energy an attractive and financially viable waste management option. Legislation governing the anaerobic digestion plants will also have to be developed. There are also significant challenges with regard to the implementation of recycling chiefly, improving stability within the recycling market. Subsidizing recycling initiatives would assist in keeping recycling prices constant (Nahman, 2009). The formulation of specific legislation that governs and regulates recycling, provides incentives, identifies targets for the recycling industry and provides a framework that consolidates all recycling efforts on

both municipal and provincial levels into one concerted effort is necessary as currently recycling is governed by municipality specific by-laws.

This study evaluated the environmental impacts of various waste management strategies through the simulation of a zero waste management scenarios for local municipalities. The study focused on two landfill sites: the eThekwini Mariannhill landfill and UMDM New England landfill. The principal environmental impacts evaluated were GHG impacts. GHG emissions were quantified by developing the WROSE model, which primarily uses emissions factors developed by the United States Environmental Protection Agency. Herein lies the limitation of this research in that these factors are based on North American data and parameters, that may not be representative of actual emissions/reductions resulting from the implementation of these scenarios in South Africa. Despite this limitation, the research is intended to provide information and data for municipal waste managers and municipalities that will assist in assessing the alternatives to landfill disposal and derive the economic and environmental benefits of the MSW stream. The scenarios assessed are compared on the basis of theses benefits, and it is on this comparative premise that the results of the study are applicable for the purpose of assisting South African municipalities in evaluating sustainable and efficient waste management methods that promote both principles of waste diversion and GHG mitigation. The primary conclusion that can be drawn from this research is that Mechanical Biological Treatment (MBT) results in the greatest environmental benefit in terms of GHG reductions. The MBT strategy included mechanical pre-treatment of unsorted, untreated MSW which comprises sorting and separation of recyclables and biogenic wastes; recycling of the recyclable fractions and biological treatment of the biogenic fraction either through anaerobic digestion or composting. The study concluded that capital and operational costs of some technologies are the main barrier for implementation in developing countries, and the environmental and social benefits should also be evaluated further to truly gauge the costs/benefits involved.

5. Acknowledgments

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Integrated Waste Management - Volume II

Edited by Mr. Sunil Kumar

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