AN ASSESSMENT OF CARBON EMISSIONS REDUCTION POTENTIAL THROUGH ZERO WASTE ACTIVITIES IN SOUTH AFRICAN MUNICIPALITIES

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in fulfilment of the requirements for the degree of Masters of Science in Engineering,
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DECEMBER 2010

Supervisor: Prof. Cristina Trois
EXAMINERS COPY

As the candidate's supervisor I agree/do not agree to the submission of this dissertation.

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Dedicated to all those who put the colour in my world, and continue to inspire, transcend and achieve.

ABSTRACT

The inception of global warming has resulted in mitigation efforts across all relevant sectors. Waste management activities produce approximately 12% of methane emissions in South Africa. The current scope of waste management favours sustainable strategies targeting zero waste and waste diversion, however landfill disposal of municipal solid waste (MSW) is still the primary strategy employed by South African municipalities. This study evaluated the greenhouse gas (GHG) impacts of various waste management scenarios that included recycling, composting, anaerobic digestion, and landfill gas recovery through case studies of the eThekwini Municipality (Mariannhill landfill) and uMgungundlovu District Municipality (New England Road landfill) MSW streams. Each waste management strategy was assessed on the basis of GHG emissions, landfill space savings and economic feasibility. A waste stream analysis (WSA) was conducted to obtain both the qualitative and quantitative data required. The results of the WSA determined that the biogenic fraction of the MSW stream for typical South African municipalities varies between 32-40% while the recyclable fraction ranges between 38-44%.

The Waste Resource Optimisation Scenario Evaluation (WROSE) model was developed for the quantification of GHG emissions and is based on the US EPA emissions factors for landfill disposal, landfill gas recovery, recycling and composting. An emissions factor was derived to include the GHG impacts of anaerobic digestion using a streamlined life cycle analysis approach. The results confirmed that recycling, anaerobic digestion and composting all produce GHG reductions, in comparison with the baseline scenario of landfill disposal, and a combination thereof through Mechanical Biological Treatment (MBT) produced the greatest net GHG reductions (between -63,338 to -71,522 $MTCO_2e$/annum for the New England Road MSW stream, and -71,280 to -86,123/annum $MTCO_2e$ for the Mariannhill MSW stream). The results indicated that the implementation of MBT scenarios would produce landfill space savings of 94,375 to 103,302 m^3 for the Mariannhill landfill, extending the landfill lifespan by 12-14 years, while savings of 73,399 – 74,100 m^3 could be realised for the New England Road landfill, extending the landfill lifespan by 2-3 years. The study concluded that while the focus of waste management has changed and zero waste/waste diversion goals require alternative waste management methods to be implemented, the capital and operational costs of some technologies are the main barrier for implementation in developing countries, and that the environmental and social benefits should be evaluated further to truly gauge the costs/benefits involved.

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LIST OF ABBREVIATIONS

CER	-	Certified Emissions Reduction
CH_4	-	Methane
CO_2	-	Carbon dioxide
DEAT	-	Department of Environmental Affairs and Technology
DAT	-	Dome Aeration Technology
DWAF	-	Department of Water Affairs and Forestry
EASEWASTE	-	Environmental Assessment of Solid Waste system and Technologies Model
GHG	-	Greenhouse Gas
IWM	-	Integrated Waste Management
IPCC	-	Intergovernmental Panel on Climate Change
LCA	-	Life Cycle Analysis
MBT	-	Mechanical Biological Treatment
MPT	-	Mechanical Pre-treatment
MRF	-	Materials Recycling Facility
MSW	-	Municipal Solid Waste
MSW-DST	-	Municipal Solid Waste Decision Support Tool
$MTCO_2eq$	-	Metric tons of Carbon Dioxide Equivalents
N_2O	-	Nitrous oxide
RDF	-	Refuse Derived Fuel
TS	-	Total Solids
UMDM	-	uMgungundlovu District Municipality
US EPA	-	United States Environmental Protection Agency
WARM	-	Waste Reduction Model
WRATE	-	Waste and Resources Assessment Tool for the Environment
WSA	-	Waste Stream Analysis

CHAPTER 1: INTRODUCTION

1.1 Introduction and motivation

It is now fully understood that the impacts of global warming have been caused by anthropogenic activities such as rapid urbanization, deforestation and continual use of fossil fuels which have accelerated the earth's natural climate change processes (Houghton, 2002). The consequent increase in greenhouse gas (GHG) concentrations has resulted in several changes in climatic conditions such as temperature increases and rising sea levels as highlighted by the 2007 Intergovernmental Panel on Climate Change (IPCC) synthesis report (Forster et al, 2007). These changes have resulted in increased focus on mitigation and adaptation to climate change which is evident through the Kyoto Protocol, climate change summits, and the development of the carbon trading market, Clean Development Mechanism (CDM) and other similar schemes (Forster et al, 2007; Bogner et al, 2008).

Although the waste sector contributes to approximately 3% of global GHG emissions, waste management activities release as much as 18% of global methane emissions (Bogner et al, 2008). GHG emission data for South Africa also reflect these trends, with the waste sector contributing to 2% of total emissions and waste management activities contributing to 12% of total methane emissions as seen in Figure 1.1 (DEAT, 2009b).

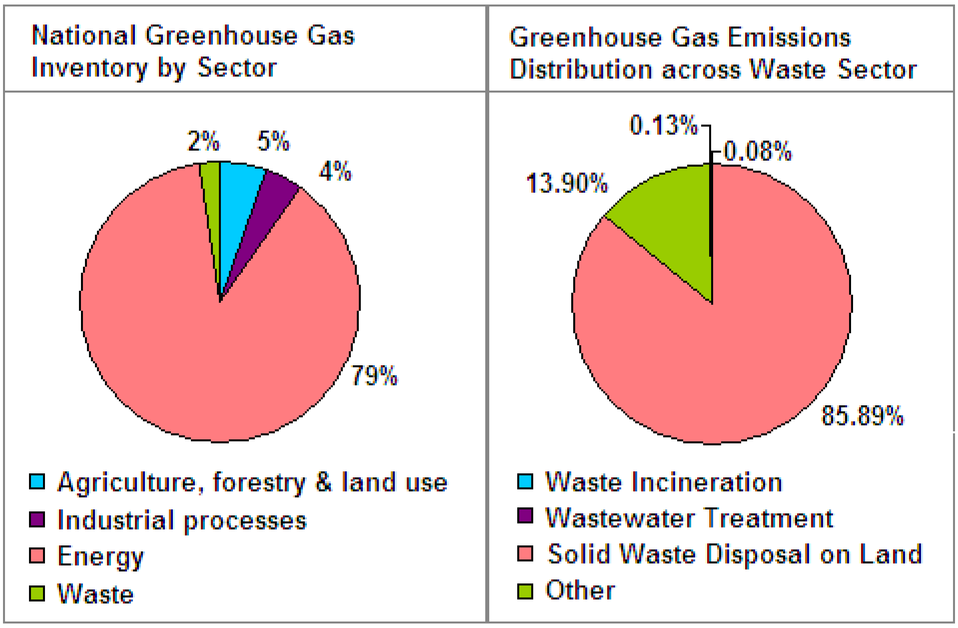


Figure 1.1 – National GHG statistics

(Source: DEAT, 2009b)

The GHG which result in the greatest climate change impacts are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), all of which are produced from the landfilling of municipal solid waste (MSW) (Smith et al, 2001). These emissions, coupled with the continual increase in waste generation and limited landfill space necessitates improved MSW management methods and technologies that will present the way toward sustainable and efficient waste management. A major trend in national GHG emissions is the increase (76.5% from 1990 to 2000) in total methane emissions, as shown in Table 1.1. The significance of this increase resides in the fact that methane is a far more potent GHG than carbon dioxide, with a global warming potential twenty one times greater (Smith et al, 2001). There is, however, some uncertainty in these statistics as different GHG accounting methodologies were used between 1990 and 2000, specifically, the 1996 IPCC guidelines for both the 1990 and 1994 national inventories and the 2006 IPCC guidelines for the 2000 inventory (Friedrich and Trois, 2010).

Table 1.1 – National GHG emissions (1990-2000)

(Source: DEAT, 2009b)

Greenhouse Gas (Gg)	Year			% increase from 1999 to 2000
	1990	1994	2000	
CO_2	280,932	315,957	353,643	18.60%
CH_4	2,053	2,057	3,624	76.50%
N_2O	75	67	76.7	2.70%
CF_6	-	-	0.303	
C_2F_6	-	-	0.021	

The South African government has committed to GHG mitigation across all sectors including the waste sector, however, landfill disposal of MSW still remains the predominant waste management strategy in South Africa (DEAT, 2009a). Many studies have suggested that zero waste and waste diversion strategies could result in significant GHG/carbon reductions (Smith et al, 2001; Mohareb et al, 2008; Couth and Trois, 2010). This study therefore seeks to identify waste strategies which can be applied at municipal level in South Africa and assess their potential for MSW diversion and GHG mitigation.

This objective was achieved through a case study which featured the eThekwini Municipality and the uMgungundlovu District Municipality (UMDM). Both these municipalities comprise of urban and rural areas; formal and informal households; and low, medium and high income groups (SKC engineers, 2004). These characteristics are common throughout South African municipalities, where there is a general inequity in MSW service coverage (Matete, 2009; Purnell, 2009). The municipalities selected are therefore considered to be representative of a typical population's waste stream (in terms of social profiling and socio-economic factors) in a medium to large municipality in South Africa.

1.2 Research background

This research is intended to provide data and information to municipal waste managers with regard to potential alternatives to landfill disposal of MSW. MSW refers to all waste that is generated through municipal activities or sources for which municipalities are responsible for in terms of collection, treatment or disposal (Tchobanoglous et al, 1993). This study focuses exclusively on commercial and residential (household) MSW which is also referred to as „post-consumer' waste (Matete, 2009). The MSW stream comprises of a dry and wet fraction (Matete and Trois, 2008; Couth and Trois, 2010). The dry fraction contains recyclable wastes and other inert residual waste, while the wet fraction contains biogenic food and garden wastes. Both the recyclable and biogenic fractions of the waste stream may be recovered, recycled or treated to produce new products or energy (Ostrem, 2004; Matete, 2009). In this sense the MSW stream could be viewed as a potential source of resources (Coulon, 2010). Figure 1.2 illustrates the possible diversion of specific fractions of the MSW stream using a typical dry-wet waste diversion model.

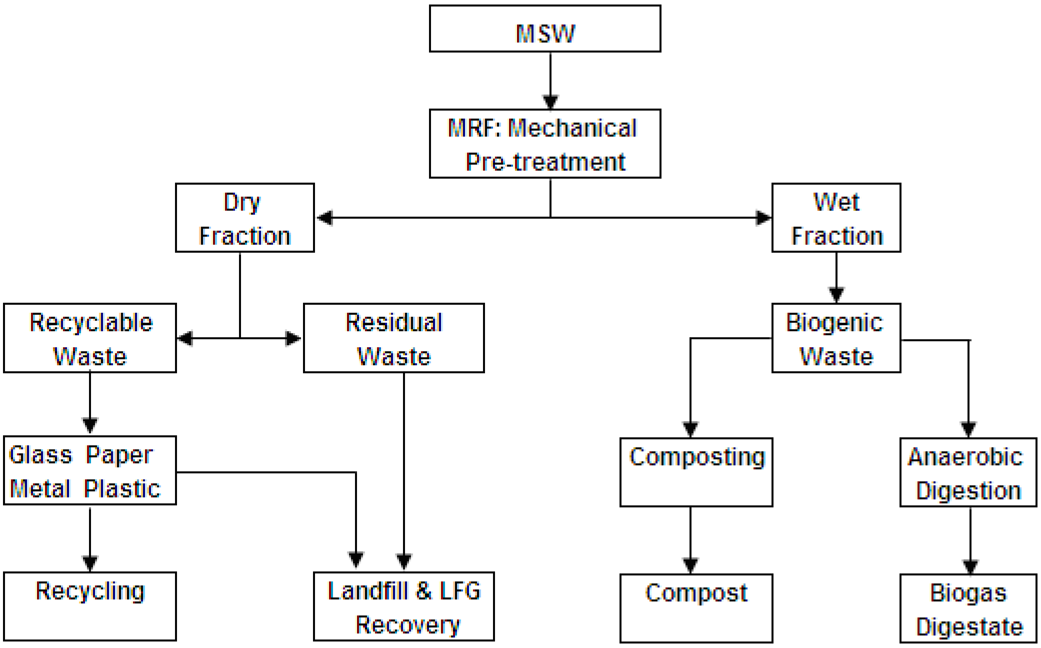


Figure 1.2 – A typical dry-wet waste diversion model

(DEFRA, 2005; Matete and Trois, 2008; Trois and Simelane, 2010)

A zero waste model was developed, which simulated various scenarios that divert these „valuable' waste fractions from landfill disposal on the basis of this dry-wet waste diversion model. The model estimated the GHG impacts, landfill space savings and potential costs/income from these simulated scenarios which comprise different combinations of zero waste strategies. From preliminary research conducted, the following strategies were selected to form the basis of the models' scenarios which were evaluated as alternatives to the status quo of waste management in South African municipalities:

i. Mechanical pre-treatment, separation of recyclables and 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, as detailed in the Methodology chapter. The selected strategies, including the status quo were then applied at municipal level for two local landfill waste streams. Various scenarios were defined, where the approximate waste quantities diverted, GHG reductions or emissions and resulting landfill space savings were calculated. The five scenarios evaluated were:

i. Scenario one: Landfill disposal of unsorted, untreated MSW.
ii. Scenario two: Landfill disposal of unsorted, untreated MSW with landfill gas recovery.
iii. Scenario three: Mechanical pre-treatment (MPT) of MSW, recovery and of the recyclable fraction through a Materials Recovery Facility (MRF) with landfill gas recovery.
iv. Scenario four: MBT (MPT, recovery of recyclables through an MRF and anaerobic digestion of biogenic food waste with landfill gas recovery).
v. Scenario five: MBT (MPT, recovery of recyclables through an MRF, composting of all biogenic waste, landfill gas recovery).

1.3 Motivation and objectives

The motivation and objectives of this research stem from several factors and developments in legislative directives including the growing emphasis on GHG mitigation (DEAT, 2009a); landfill space shortages; waste diversion and zero waste goals of the Polokwane Declaration (DEAT, 2001); increased focus on waste to energy technology implemented under the CDM or similar schemes (Couth et al, 2010) and, the requirement for waste quantification and development of a national Waste Information System as mandated by the 2008 Waste Act (Purnell, 2009). The principle aim of this study is to provide a quantitative estimate of the total potential GHG reductions due to zero waste strategies and assess these strategies in terms of waste diversion and economic feasibility. The objectives paramount to achieving this aim are:

- To identify potential zero waste strategies for South African municipal waste management systems that target specific fractions of the waste stream.
- To provide data regarding the typical waste composition in South African municipalities using data records and waste stream analysis methodology through case studies of the eThekwini and uMgungundlovu municipalities.
- To assess the potential for GHG/carbon emission reductions from implementing these strategies through various scenarios.
- To estimate the total potential landfill space savings from diversion of waste from landfill disposal.
- To evaluate costs, potential income and savings generated from implementing the selected waste management strategies using available literature and cost data.

1.4 Methodological approach

The simulation modelling of various zero waste strategies that promote effective waste diversion through mechanical pre-treatment, recycling, and aerobic composting or anaerobic digestion of biogenic waste was explored through a case study of the eThekwini Municipality (Mariannhill landfill site) and uMgungundlovu District Municipality (New England Road landfill site). The environmental benefit (GHG impacts and landfill space savings) and economic feasibility (potential costs, income and cost savings) of waste diversion were the main criteria for the evaluation of each waste management scenario.

Currently there is little/inconsistent data available on the GHG emission reduction potential of zero waste/waste diversion strategies in developing countries in general and in Africa in particular (Couth and Trois, 2010). This can be partly attributed to the lack of current data concerning waste generation, composition and quantity (Purnell, 2009; Fricke et al, 2007). The study therefore attempts to address two main knowledge gaps:

i. The lack of current/consistent data regarding the quality (composition) and quantity of the MSW stream in South Africa.
ii. Uncertainties in the efficiency and sustainability of zero waste strategies in achieving sustained GHG emission reductions.

The objectives outlined were achieved through a literature review and two case studies which included practical field work, data collection, data analysis and modelling - thus both a qualitative and quantitative approach was adopted. The data required was obtained through a waste stream analysis (WSA) of the New England Road landfill site and the assimilation of available data from Durban Solid Waste (DSW) for the Mariannhill landfill waste stream. A WSA of the Mariannhill landfill was not conducted as sufficient data was available to assess the quantity and quality of the Mariannhill MSW stream. A site specific approach to the WSA was deemed appropriate and in line with the objectives of any study of this nature as it is better suited to quantifying local waste streams. The sampling and sorting of MSW was conducted on site at the UMDM New England Road landfill and a general waste profile for the municipality was produced.

Using the data obtained from the WSA, the selected waste diversion strategies were then reviewed on the basis of their environmental impacts for both municipalities. Various waste management strategies and combinations thereof were evaluated through a total of five scenarios as listed in section 1.2. The primary focus was placed on global warming impacts, as currently targets regarding GHG emissions are high up on the agenda toward achieving environmental sustainability (DEAT, 2009a). In terms of GHG modelling, a wide range of models using Life Cycle Analysis (LCA) have been developed. Of the models researched, only two provide analysis for anaerobic digestion of biogenic wastes. This is an important factor, as the model/method ultimately chosen should quantify GHG emissions for all the selected strategies, in order for comparisons to be made and to maintain consistency in results; however the models evaluated did not exhibit a suitable level of transparency. The availability, applicability and transparency of the models were the limiting factors for use and thus a GHG quantification model called the Waste Resource Optimisation Scenario Evaluation (WROSE) model was developed. The model uses emission factors derived for landfilling, landfill gas recovery, recycling and composting by the United States Environmental Protection Agency (US EPA). An emission factor was then derived for the anaerobic digestion of biogenic waste using a streamlined life cycle analysis approach in keeping with the principles used in the derivation of the US EPA factors. The average landfill space savings were calculated using three different methods: the compacted density of MSW (Matete, 2009); the Environmental Benefits of Recycling Calculator (Department of Environment and Conservation of Western Australia, 2008) and the United States Environmental Protection Agency (US EPA) landfill space factors (US EPA, 1994).

Lastly, the capital investment and operating costs, as well as any possible income generated from implementing zero waste strategies were estimated using available literature and cost studies. The potential income that can be generated from each scenario comprises of the sale of recyclables, compost or soil conditioners produced from composting or anaerobic digestion, certified emissions reductions (CER's) that may be sold under the Clean Development Mechanism (CDM) or other schemes, and electricity produced from landfill gas/biogas. Figure 1.3 overleaf summarises the overall research approach.

1.5 Summary

This study focuses on the evaluation of various zero waste strategies in terms of the total potential environmental and economic benefits that can be obtained from implementation. In the context of this research a „zero waste' strategy refers to any waste management strategy that diverts waste from landfill disposal. The intention of the study is to produce meaningful results that establish the positive contribution of zero waste or waste diversion strategies while also providing data that will assist in the possible implementation of sustainable waste management solutions and the development of both waste information systems and waste management policy for emerging technologies. Ideally, the results of the research will assist municipalities in managing and utilising the full potential and economic value of the MSW stream for long-term growth and sustainability. With growing environmental concern due to global warming and increased focus on sustainable waste management this research will be fundamental in assisting municipalities to review the effectiveness of waste strategies (in the South African context) as both waste diversion and mitigation tools.

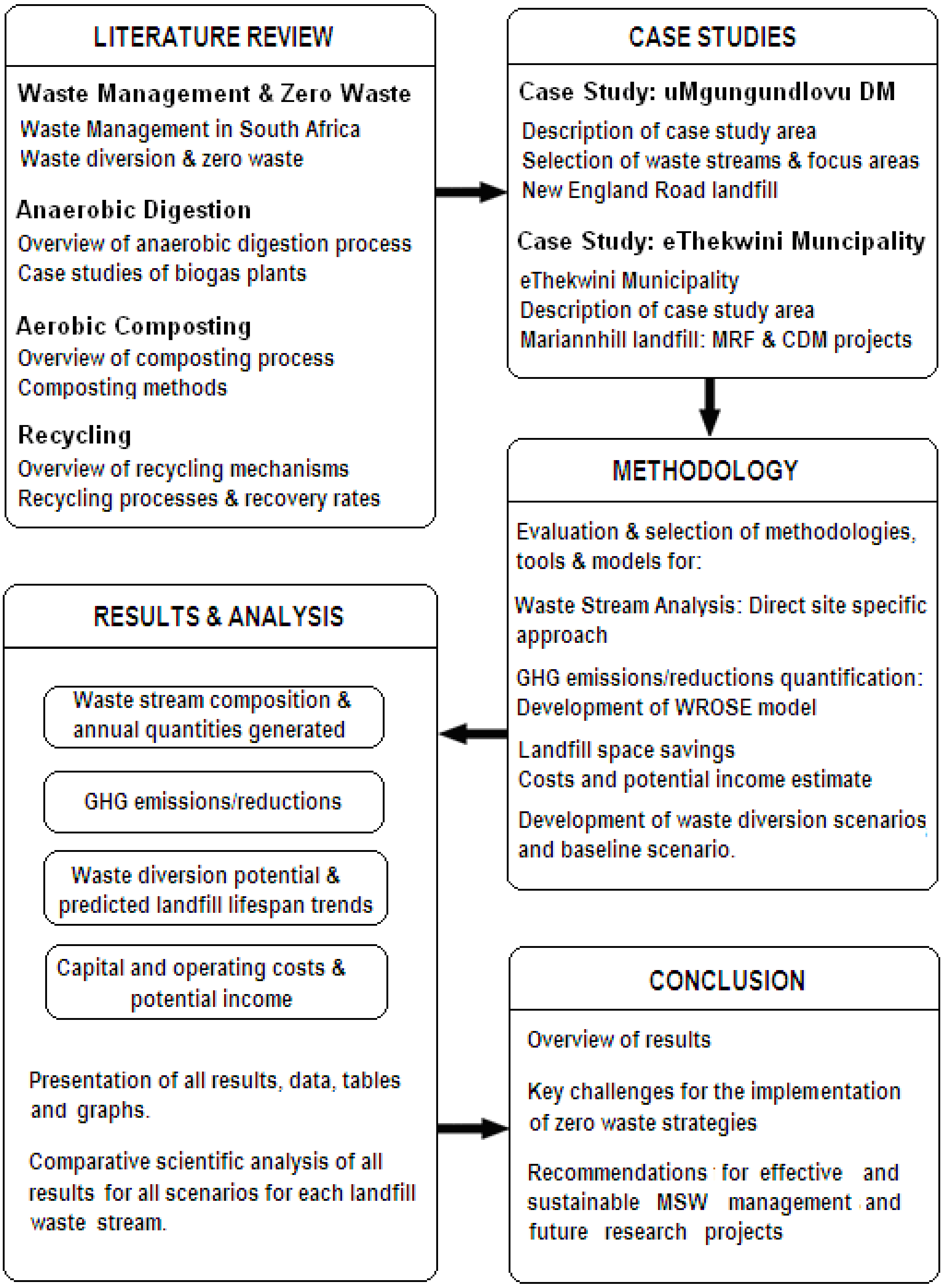


Figure 1.3 – Research approach/framework

CHAPTER TWO: WASTE MANAGEMENT and ZERO WASTE

2.1 Introduction

As defined in the Introduction, the primary objective of this research is to determine the potential GHG reductions from employing waste diversion strategies in South African municipalities. This chapter introduces the concept of zero waste and provides an overview of both current waste management practices and emerging waste treatment and waste to energy technologies.

2.2 Waste and waste management

The term „waste' may refer to any item, material or product that is unwanted, discarded or is no longer considered useful for its intended purpose (Tchobanoglous et al, 1993). Waste is currently defined by the White Paper of Integrated Pollution and Waste Management for South Africa as:

"*An undesirable or superfluous by-product, emission, or residue of any process or activity, which has been discarded, accumulated or been stored for the purpose of discarding or processing. It may be gaseous, liquid or solid or any combination thereof and may originate from a residential, commercial or industrial area*" (DEAT, 2000).

Waste is produced from human activities every day, and thus the need for effective waste management arises. Poor waste management results in severe environmental, health and aesthetic issues (Tchobanoglous et al, 1993; Robinson, 1996). Although discarded, components of a waste stream may be reused or converted into useful products or energy by means of various technologies, and waste recovery methods (Ostrem, 2004; Matete, 2009). The United Nations (1997) describe the characteristic activities of waste management as:

i. The collection, transportation, treatment and disposal of waste.
ii. The control, monitoring and regulation of the production, collection, transport, treatment and disposal of waste.
iii. The prevention of waste production through in-process modifications, reuse and recycling.

Waste management therefore refers to all activities intended to provide efficient systems that dispose of or reuse wastes. Waste management strategies may be classified or ranked by the „waste hierarchy' illustrated in Figure 2.1. The ranking of a waste management strategy is based on its ability to reduce the quantity of waste generated and minimise both environmental impacts and health risks (Robinson, 1996). The main tiers or levels of the hierarchy as described by Robinson (1996) are:

- *Waste Prevention:* minimising the waste generated by making changes at a production level, for example reduced packaging and source reduction.
- *Re-use:* Re-using materials or items before they enter the waste stream.
- *Waste Recovery:* Recovering waste through recycling, and energy recovery through landfill gas recovery, anaerobic digestion and other technologies.
- *Disposal:* Landfilling of waste.

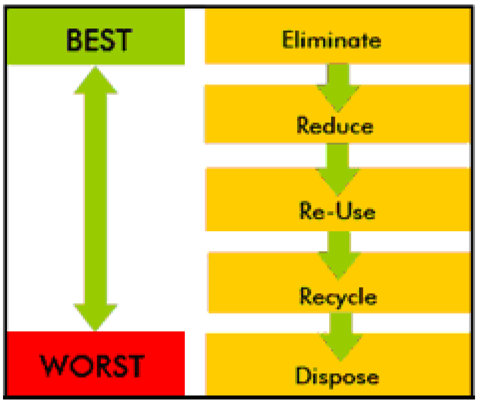


Figure 2.1 – The waste hierarchy

(Source: www.reclite.co.za, 2009)

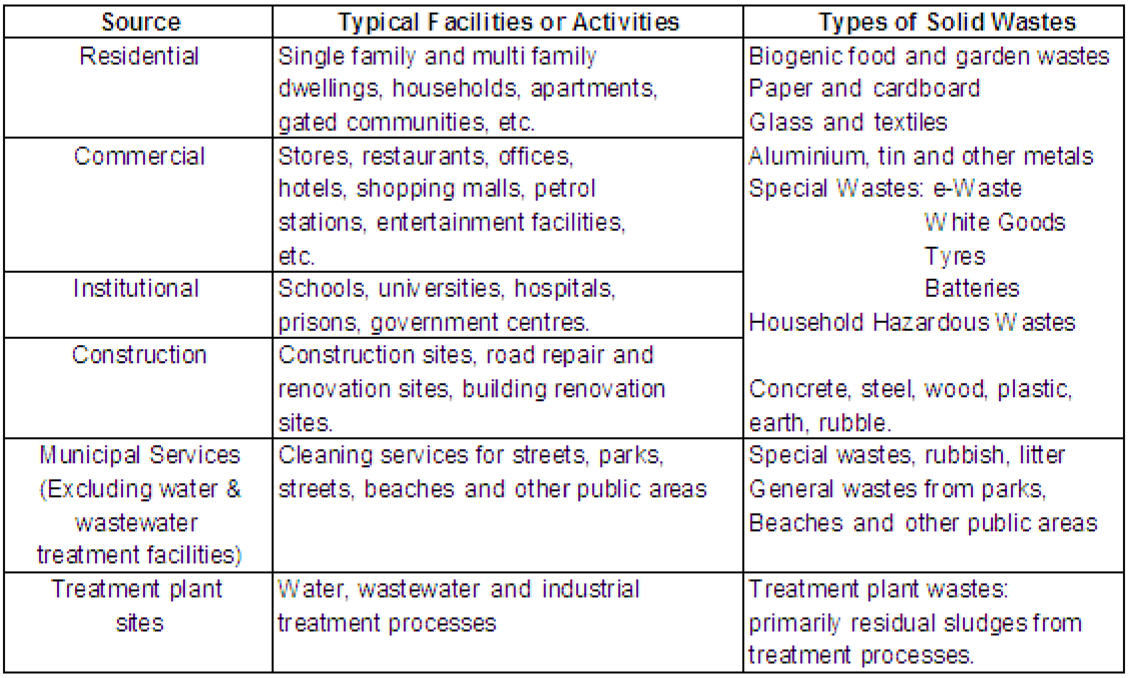
2.3 Municipal Solid Waste (MSW) management

Solid waste is defined by Tchobanoglous et al (1993) as: "*all waste arising from human and animal activities that are normally solid and are discarded as useless or unwanted".* Solid waste may be further classified into two broad categories: general and hazardous waste, as per the Minimum Requirements for Solid Waste Disposal by the Department of Water Affairs and Forestry (DWAF, 1998a).

General waste constitutes "*all waste that does not pose a significant threat to public health or the environment if properly managed*" (DWAF, 1998a). General waste includes residential and household wastes, garden refuse, commercial and industrial wastes. Hazardous wastes are defined as "*any wastes which may, by the circumstances of its use, quality, concentration, physical or infectious characteristics cause or be likely to cause, danger to health or the environment, whether by itself or when in contact with other wastes*" (DWAF, 1998a). Hazardous wastes include pesticides, poisons, chemicals, medical, carcinogenic and radioactive wastes. MSW is all solid waste generated in a municipality for which municipal service providers are responsible (Tchobanoglous et al, 1993). MSW includes waste generated by communities from residential, industrial, institutional and commercial activities (Schübeler et al, 1996). Typical sources and activities producing MSW are presented in Table 2.1. With waste quantities increasing annually due to population growth, urbanisation, and to an extent increasing affluence and over consumption in some areas, there is a continual need for the evaluation and improvement of MSW management methods and services.

Table 2.1 – Sources of Municipal Solid Waste

(*Source: Adapted from Integrated Solid Waste Management, Tchobanoglous et al, 1993)*



Source	Typical Facilities or Activities	Types of Solid Wastes
Residential	Single family and multi family dwellings, households, apartments, gated communities, etc.	Biogenic food and garden wastes Paper and cardboard Glass and textiles Aluminium, tin and other metals Special Wastes: e-Waste White Goods Tyres Batteries Household Hazardous Wastes Concrete, steel, wood, plastic, earth, rubble.
Commercial	Stores, restaurants, offices, hotels, shopping malls, petrol stations, entertainment facilities, etc.	
Institutional	Schools, universities, hospitals, prisons, government centres.	
Construction	Construction sites, road repair and renovation sites, building renovation sites.	
Municipal Services (Excluding water & wastewater treatment facilities)	Cleaning services for streets, parks, streets, beaches and other public areas	Special wastes, rubbish, litter General wastes from parks, Beaches and other public areas
Treatment plant sites	Water, wastewater and industrial treatment processes	Treatment plant wastes: primarily residual sludges from treatment processes.

2.4 Solid waste generation rates and waste stream composition

Solid waste generation data provides an estimate of the quantity of waste to be treated or disposed, which is vital for the design and operation of waste management systems. Generally, wealthier, developed countries have higher waste generation rates, while less affluent developing countries that may practice informal recycling and reuse of waste are characterised by lower waste generation rates (Bogner et al, 2008). The waste generation rate in South Africa varies from between 0.50 - 2.00 kg of solid waste produced per capita per day (DEAT, n.d). This wide range can be attributed to the variations in population demographics, income and social differences. Solid waste generation rates of developing and developed countries are listed in Table 2.2.

Table 2.2 – Waste generation rates by country

(Source: Troschinetz and Mihelcic, 2009; Nationmaster, 2010)

Country	Rate (kg/capita/day)
United States	2.08
Australia	1.89
Denmark	1.81
Canada	1.75
Netherlands	1.67
United Kingdom	1.53
Germany	1.48
Italy	1.37
China	1.08
Turkey	0.97
Brazil	0.85
Indonesia	0.70
India	0.46

The composition of the MSW stream refers to the relative fraction of each type of waste contributing to the MSW stream as a whole. The composition may be assessed using a waste stream analysis to determine the types and proportions of waste through sampling methods (Gaillot et al, 2005). Factors affecting MSW generation rates and/or waste composition include:

- Education level and environmental awareness: Waste generation rates are dependant to an extent on knowledge and consumer awareness, for example purchasing products with reduced packaging, or reusing items before they are discarded such as beverage bottles reduces waste generation (DEAT, n.d).
- Income Level: Consumption and waste generation is generally higher among higher income groups while low income groups often practice greater levels of recycling as an income source (Gaillot et al, 2005; Bogner et al, 2008).
- Seasonal variations: The MSW generation rate and composition is affected seasonally, being higher in summer due to increased garden refuse and during holiday seasons due to increased activity/purchasing (Gaillot et al, 2005).
- Household type and dynamics: Single and multi-person households generate different quantities of waste. The type of dwelling also affects waste

composition, for example apartment blocks would have little or no garden refuse. The average age of householders affects the quality of the waste stream, for instance younger consumers tend to purchase more convenience and pre-packaged foods (Gaillot et al, 2005).

2.5 Classification of Municipal Solid Waste

Aside from the broad definition of wastes (general waste, commercial waste etc.) the specific classification of waste is essential in determining the composition of the MSW stream. Wastes being used for a similar purpose or having the same constituent materials or elements are classified together. Classification of waste is imperative when conducting waste stream analyses to allow for comparisons with data from national and international studies (Olver et al, 2009). Compatibility of waste data with the waste classification used in GHG modelling software is also important. For example, data records may list all plastic materials as „plastic’ whereas GHG models provide detailed classifications such as „High Density Polyethylene’ (HDPE). Although representative assumptions can be made in the modelling process it is preferable to have a compatible and consistent waste classification system. MSW may be classified into two basic fractions (Trois and Simelane, 2010). The wet fraction comprises biogenic wastes such as food and garden waste. The dry fraction comprises materials such as recyclables (primarily paper, glass, plastic and metals) and other inert dry materials. Table 2.3 presents a typical waste classification system.

Table 2.3 – Classification of Municipal Solid Wastes

(Source: Adapted from California Statewide Waste Characterisation Study, 2009)

<table>
<tr><th>Paper and cardboard</th><th>Plastics</th><th>Special wastes</th></tr>
<tr><td rowspan="3">Corrugated cardboard
Newspaper
Office paper
Mixed paper
Magazines
Miscellaneous paper
Graphic paper</td><td>HDPE PVC
LDPE PET
Mixed plastics</td><td>Tyres Batteries
Oil Electronic wastes</td></tr>
<tr><th colspan="2">Biogenic Wastes</th></tr>
<tr><td colspan="2">Organic food waste
Green garden refuse
Woody garden refuse</td></tr>
<tr><th>Metal</th><th>Glass</th><th>Other wastes</th></tr>
<tr><td>Steel cans
Aluminium cans
Other ferrous metals
Other non-ferrous metals</td><td>Clear glass
Green glass
Brown glass
Miscellaneous glass</td><td>Concrete Textiles
Asphalt Soil/Sand
Residual inert wastes
Other construction wastes</td></tr>
</table>

2.6 Zero waste

The only internationally accepted and peer reviewed definition of zero waste is that adopted by the Zero Waste International Alliance (ZWIA, 2010):

"Zero waste means designing and managing products and processes to systematically avoid and eliminate the volume and toxicity of waste and materials, conserve and recover resources and not burn or bury them. Zero waste is a goal that is ethical, economical, efficient and visionary, to guide people in changing their lifestyles and practices to emulate sustainable natural cycles where all discarded materials are designed to become resources for others to use. Implementing zero waste will eliminate all discharges to land, water or air that may be a threat to planetary, human, animal or plant health."

From this definition it can be deduced that zero waste is essentially a design principle used in the design of products, processes and waste management that promotes the elimination of waste either by changing products on a production level (replacing toxic/hazardous ingredients/materials, producing products with less/recyclable packaging, that have the least environmental impact (eco-design) etc.) or by diverting waste from the waste stream resulting in „zero waste' being landfilled. In theory „zero waste' would render landfills obsolete, however in reality, residual waste that cannot be re-used, recycled, diverted or treated effectively will ultimately be disposed at landfill sites. Glavic and Lukman (2007) give the following definition of zero waste:

"*Zero waste maximizes recycling, minimises waste toward zero, reduces consumption and ensures that products are planned to be reused, regenerated, repaired, and recycled internally or back into nature or the marketplace".*

This definition exemplifies the principles behind zero waste and any waste management strategy that achieves the goal of diverting waste from landfill disposal can therefore be considered a „zero waste' strategy. The goals of zero waste can be achieved; however there are economic, legislative and institutional factors that inhibit the implementation of zero waste strategies (Matete, 2009). A study by Matete (2009) determined that while zero waste schemes are sustainable in terms of social and environmental feasibility in South Africa, institutional feasibility is an issue as many municipalities lack both infrastructure and financial capacity to implement zero waste strategies. This is where waste management strategies such as anaerobic digestion are of interest as potential income may be derived through sale of certified emissions reductions, compost and energy.

2.7 Waste legislation in South Africa

Waste legislation serves to regulate and control waste management activities while promoting waste minimisation and sustainable waste management (Austin and Gets, 2009). The management of waste in its entirety (including MSW, mining wastes, industrial and agricultural wastes) has been governed by various components of legislation such as the Environment Conservation Act (Act 73 of 1989), Environment Conservation Amendment Act (Act 50 of 2003) and the Mineral and Petroleum Resources Development Act (Act 28 of 2002). The National Environmental Management: Waste Act 59 of 2008 is currently the most comprehensive regulatory framework for waste management activities in South Africa. The following are just some of the main objectives/regulations established by the institution of the act and are related to the primary objectives of this research (Government of South Africa, 2008):

- The establishment of a National Waste Management Strategy for fulfilling objectives of the Waste Act (waste minimisation, recycling, reuse, and recovery).
- The provision for the establishment of norms and standards regarding waste classification and National and Provincial Waste information Systems regarding collection, recording and analysis of data pertaining to quantities and types of waste generated, stored, transported, treated or disposed of.
- The affirmation of every individual municipality’s responsibility to provide waste management services including waste collection, storage and disposal whilst meeting financial, environmental and sustainability requirements.

The first national Waste Management Summit was held in September 2001 and led to the formulation of the Polokwane Declaration which necessitates renewed commitment toward sustainable waste management and waste minimisation goals. An overview of these goals highlighted by Austin and Gets (2009) includes a 50% and 25% reduction in waste generation and disposal respectively by 2012; the promotion of recycling activities to produce an increase of 30% in the recycling industry and the achievement of zero waste by 2022. These targets are ambitious, as currently 87% of municipalities lack infrastructure and capital required to achieve these goals (Oelofse, 2009).

2.8 Energy from Waste (EfW)

The term 'Energy from Waste' refers to any process or technology that converts waste into electricity, heat or steam (Smith et al, 2001). MSW contains materials from which energy can be recovered, such as food waste, garden refuse and plastics (Smith et al, 2001). EfW strategies may be thermal or non-thermal processes. South Africa has committed to renewable energy targets (10,000 GWh by 2013 generated from biomass, wind, hydroelectric and solar power) which places focus on EfW strategies that produce energy such as anaerobic digestion (Department of Minerals and Energy, 2003).

2.9 An overview of waste management practices

2.9.1 Landfill disposal and landfill gas recovery

Landfill disposal of waste is currently the principal method of waste management in South Africa and is governed by the "Minimum Requirements for Waste Disposal by Landfill" (DWAF, 1998b). Landfills are engineered sites that allow for controlled disposal of wastes. Landfill disposal of MSW is generally regarded as being the most inexpensive and simple solution to waste management (Ostrem, 2004). Landfilling typically includes the placement and compaction of MSW into landfill cells, with each cell being covered by soil or cover material to hold the waste in place, prevent infestation of parasites and control odours and the ingress of water (Tchobanoglous et al, 1993). The degradation of biogenic waste occurs through both aerobic and anaerobic processes (Tchobanoglous et al 1993). Anaerobic conditions in landfills prevail when oxygen trapped between layers of waste is depleted, and the depth of waste causes oxygen to be consumed at a faster rate then which it is diffused from the surrounding air (Smith et al, 2001). Anaerobic degradation of waste produces landfill gas. The composition and rate of production of landfill gas varies during different phases of the degradation process as shown in Figure 2.2. The duration of each phase is dependent on nutrient availability, degree of compaction and moisture content (Tchobanoglous et al, 1993).

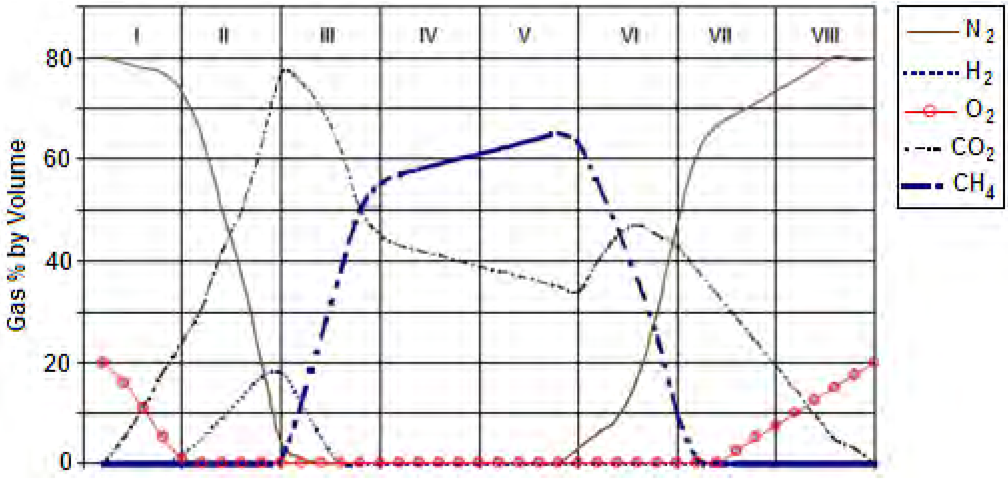


Figure 2.2 – Changes in landfill gas composition

(Source: Smith et al, 2001)

It usually takes between 1-3 years from deposition of waste for a considerable amount of landfill gas to be obtained and production peaks after 5-7 years of operation (UK Environment Agency, 2002). Landfill gas may be collected using a system of extraction wells and trenches. These systems may be either passive (the pressure of the landfill gas is used as the sole driving force for movement) or active (a negative pressure system creates a vacuum which sucks out landfill gas) (UK Environment Agency, 2002). The collected landfill gas is either flared (combusted in oxygen) or used for energy generation as illustrated in Figure 2.3. Landfill gas recovery reduces GHG emissions; however other issues such as odours, parasites, and groundwater contamination by leachate are still considerable (Smith et al, 2001). The focus of waste management has shifted from landfill disposal to more sustainable methods with fewer environmental impacts however; to label landfilling as completely obsolete would be inaccurate and overly optimistic, as it is likely that some fraction of the waste stream that cannot be reused, recovered or recycled will need to be disposed via landfills.

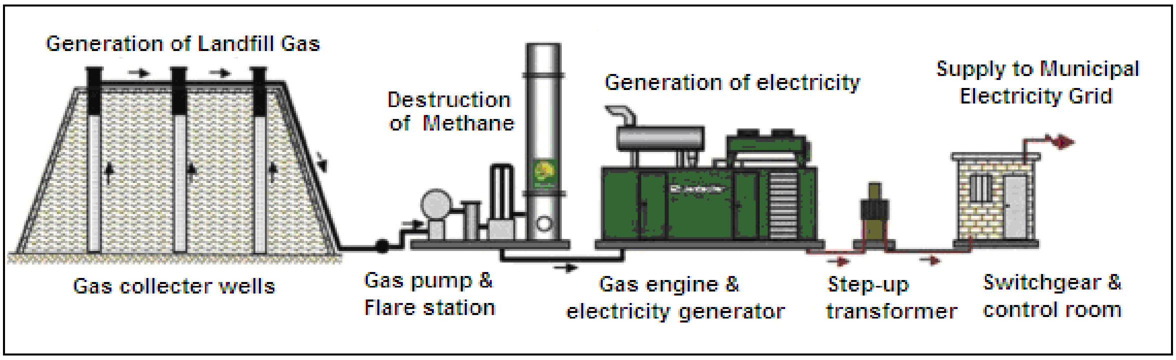


Figure 2.3 – Schematic layout of landfill gas recovery

(Source: www.envirofill.co.za, 2010)

2.9.2 Source separation and collection of MSW

Source separation of waste may be viewed as a zero waste strategy as it is a preliminary process that separates the wet (biogenic) and dry (recyclable) fractions of MSW at the source of generation thus preventing contamination of recyclables by „wet' biogenic waste (Dahlen et al 2007; Trois and Simelane, 2010). Private recycling companies report that recyclables are often imported from other countries as recyclables recovered from the South African waste stream are not of sufficient quality due to the degree of contamination (DEAT, n.d). This effect is mirrored when considering treatment of the wet fraction. Contaminants such as metals and glass must be removed before undergoing biogenic waste treatment processes such as anaerobic digestion thus preventing damage to equipment and producing a higher quality digestate or compost (Ostrem, 2004). Two types of at source separation may be employed, namely, curb side collection and the drop off system (Matete, 2009). The drop off system requires waste producers to drop off source separated wastes at recycling centres and collection sites whereas the curb side collection system entails weekly collection of source separated wastes from households. The curb side collection system generally operates more efficiently due to higher levels of compliance as there is less effort or cost to the waste producer (Gonzalez-Torre and Adenso-Diaz, 2005). Source separation would produce the highest yield of clean uncontaminated recyclables, however enlisting public participation and compliance with such strategies is the greatest challenge toward implementation. Some element of source separation is already employed in areas of eThekwini and uMgungundlovu, where paper and cardboard are separated by waste generators and collected separately. Source separation on a large (macro) scale in the eThekwini municipality was evaluated in the eThekwini Municipality Integrated Waste Management Plan and was found to unfeasible due to the high costs involved (Douglas, 2007).

2.9.3 Thermal treatment of MSW

Mass burn incineration is a form of thermal treatment whereby waste is combusted in incinerators producing incinerator ash, flue gases (CO_2 and water vapour), particulates and heat (Smith et al, 2001). Incineration reduces the volume of waste, and with an efficient processing method, residual organic matter is reduced completely into an inert ash, which may be safely disposed of on landfill sites without the formation of leachates (Smith et al, 2001). Refused Derived Fuel (RDF) refers to MSW that has undergone mechanical pre-treatment in order to remove non-combustible materials such as metals and glass, similar to the separation and sorting processes of materials recycling facilities (Smith et al, 2001). The waste to be combusted is then compressed into bricks or pellets and combusted in on-site facilities or sold (Fitzgerald, 2009). The combustion of waste generates steam which can be used for energy recovery. Advanced thermal treatment options such as pyrolysis and gasification may result in reduced emissions of pollutants however further research into these processes is required (Smith et al, 2001). The emission of pollutants from incineration is a significant drawback to incineration, and has resulted in the closure of many incineration facilities throughout South Africa due to concerns over pollutants and air quality (DEAT, 2007). Incineration technology has become more advanced and includes many pollution control measures, however due to uncertainty and concerns over emissions and pollutants, it remains "*a highly contentious waste management option*" (Smith et al; 2001).

2.9.4 Biological treatment: anaerobic digestion and composting

The treatment of the biogenic fraction of the waste stream is the main focus of a large part of this study, as currently most biogenic MSW is landfilled in South Africa. The zero waste model allows for the majority of biogenic waste to be either anaerobically digested or composted. Anaerobic digestion refers to the degradation of biogenic waste substrates through the action of micro-organisms under anaerobic conditions (Tchobanoglous et al, 1993). Anaerobic digestion produces useful products in the form of digestate, which may be used as soil conditioner/fertiliser, and biogas, composed primarily of methane and carbon dioxide, which may be used for energy generation (Ostrem, 2004). Composting refers to the degradation or decomposition of biogenic waste through the action of micro-organisms under aerobic conditions (Polprasert, 1996). Composting produces carbon dioxide, water, and a stabilised, nutrient rich biomass termed „humus' which may be used as compost or soil conditioner (Polprasert, 1996). Composting is particularly useful for the treatment of woody garden refuse that contains lignin and requires oxygen for degradation.

2.9.5 Recycling and Material Recycling Facilities (MRF)

Recycling is the reprocessing of waste materials into new materials/products (DEAT, n.d). A wide array of materials may be recovered and recycled from the MSW stream, from common recyclables such as paper and plastics to scrap metals and electronic wastes. Studies show that recycling produces significant GHG reductions by reducing the consumption of virgin materials and the energy required for production processes

(WRAP, 2006). Despite this, there is great potential for growth in the recycling markets and recovery rates to maximize this benefit (DEAT, n.d). Materials Recycling Facilities (MRF's) are facilities designed for the separation and sorting of recyclable materials. Sorting may occur through manual separation, and through mechanical equipment such as bag breakers, trommels, and baling machines (Purchase, 2008).

2.9.6 Mechanical Biological Treatment (MBT)

Mechanical Biological Treatment (MBT) refers to the treatment of waste using both mechanical and biological processes. The separation processes used in MRF's are used as preliminary treatment in MBT, where recyclables are separated from the waste stream through the mechanical processes discussed in section 2.9.5, and organic wastes are treated biologically through anaerobic digestion or composting (Smith et al, 2001). MBT may be implemented when and if at source separation of MSW is not feasible.

2.10 Greenhouse gas impacts from waste management activities

The primary GHG's produced from waste management activities are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_20), and chlorofluorocarbons (CFC's) (Smith et al, 2001). The relative contributions of these gases to global warming and global warming potentials that are based on radiative forcing estimates from the IPCC Fourth Assessment Report are listed in Table 2.4 below. The strength of a GHG is dependant on the concentration of the gas in the atmosphere and the ability to absorb infrared radiation. Global Warming Potential (GWP) is defined as the ratio of the radiative ability that would result from the emission of one kilogram of a GHG to that from the emission of one kilogram of carbon dioxide over a particular time period (Forster et al, 2007). The radiative ability of carbon dioxide is essentially used as a base unit to quantify the effects of other GHG's. Although the contribution of methane is lower, over a 100 year time period, methane is 21 times more potent than carbon dioxide. Recent studies have shown that the GWP of methane may range to as high as 33 (Shindell et al, 2009). Carbon dioxide emissions from waste management include those from the provision and combustion of fossil fuels required for waste transportation, treatment, recovery or disposal. Methane is primarily produced by anaerobic degradation of wastes and nitrous oxide is emitted during the combustion of waste and the application of compost (Smith et al, 2001; Møller et al, 2009).

Table 2.4 – GHG Global Warming Potentials and contributions

(Source: National Institute for Environmental Studies, Japan, www.gosat.nies.go.jp)

Greenhouse Gas	Contribution (%)	GWP
Carbon dioxide	63%	1
Methane	18%	21
Nitrous oxide	6%	310
Halocarbons	13%	99-1100

Waste management activities that result in GHG emissions are termed GHG sources, and those that result in reductions are termed GHG sinks (US EPA, 2006). Emissions from waste management may be summarized as (US EPA, 2006; Møller et al, 2009):

- Direct emissions from waste treatment processes such as the release of landfill gas from landfill disposal, or emissions from burning waste during incineration.
- Energy emissions that are produced from energy generation required to fuel processes such as anaerobic digestion and mechanical pre-treatment.
- Transportation emissions released during the collection and transportation of wastes to or from transfer stations, landfill sites, MRF's and so forth.

Waste management strategies reduce GHG emissions in the following ways as listed by the United States Environmental Protection Agency (US EPA, 2006):

- Reducing energy required for the acquisition of virgin materials and production processes, through the reuse and recycling of products.
- Reducing non-energy emissions from production processes: for example methane produced during the processing of natural gas during plastic manufacturing.
- Reducing GHG emissions through waste diversion: for example recycling products instead of landfilling prevents direct emissions.
- Energy recovery from anaerobic digestion and landfilling captures gases and generates electricity resulting in avoided fossil fuel energy emissions.
- Carbon sequestration: recycling paper saves trees, which use up carbon dioxide – thus increasing long term storage of carbon.

2.11 Summary

The Zero Waste model considers three core strategies – anaerobic digestion, composting and recycling. The model operates on the premise that the wet and dry fractions of the MSW stream are separated through mechanical pre-treatment methods; much like the separation of recyclables in MRF's described in section 2.9.5. The recyclable fraction is then sorted and sold to recycling companies. The wet fraction, primarily comprising of biogenic food wastes and garden refuse is either composted aerobically to produce compost, or digested anaerobically to produce energy and digestate. All residual or remaining waste is landfilled. Landfill disposal together with gas recovery is assessed to provide comparisons with current landfill gas recovery projects (the status quo of eThekwini landfills). The three principal zero waste/waste diversion strategies are discussed in the following chapters. Anaerobic digestion is of particular focus as it is a relatively new technology for the treatment of biogenic MSW in South Africa.

CHAPTER 3: ANAEROBIC DIGESTION

3.1 Introduction

Anaerobic digestion is a biological process (employing micro-organisms) that comprises the breakdown of biogenic wastes in the absence of oxygen (Tchobanoglous et al, 1993). This process occurs naturally on landfill sites when little or no oxygen is present as well as in various other environments such as wetlands (Ostrem, 2004). Anaerobic digesters are controlled, contained and optimised versions of the natural breakdown of biogenic waste on landfill sites which allow for the end products of biogas and digestate to be captured and utilised efficiently. Anaerobic digestion is used in a wide array of applications including agricultural, wastewater and industrial waste treatment (Monnet, 2003; Ostrem, 2004).

3.2 The Anaerobic Digestion Process

The anaerobic digestion process comprises the following series of phases and biochemical reactions as outlined by Ostrem (2004):

i. Hydrolysis: insoluble organic waste substrates (which include carbohydrates, proteins and lipids) are broken down into soluble organics (respective monomers of simple sugars, amino acids and fatty acids) by hydrolytic bacteria.

ii. Acidogenesis: This phase comprises the further breakdown of the soluble monomers formed during hydrolysis into simple organic compounds (volatile fatty acids, ketones and alcohols) through the action of acidogenic bacteria.

iii. Acetogenesis: Acetogenic bacteria convert the resulting organic compounds from acidogenesis into organic acids (principally acetic acid), carbon dioxide (CO_2) and hydrogen (H_2).

iv. Methanogenesis: Products from acetogenesis are converted into methane (CH_4). Methanogenesis occurs primarily through the conversion of the acid formed during acetogenesis into methane (acetotrophic methanogenesis) or through the reduction of carbon dioxide by hydrogen (hydrogenotrophic methanogenesis).

Figure 3.1 illustrates the typical reactions and phases throughout anaerobic digestion, using the chemical formula for a mixture of biogenic waste ($C_6H_{10}O_4$) (Themelis and Verma, 2004).

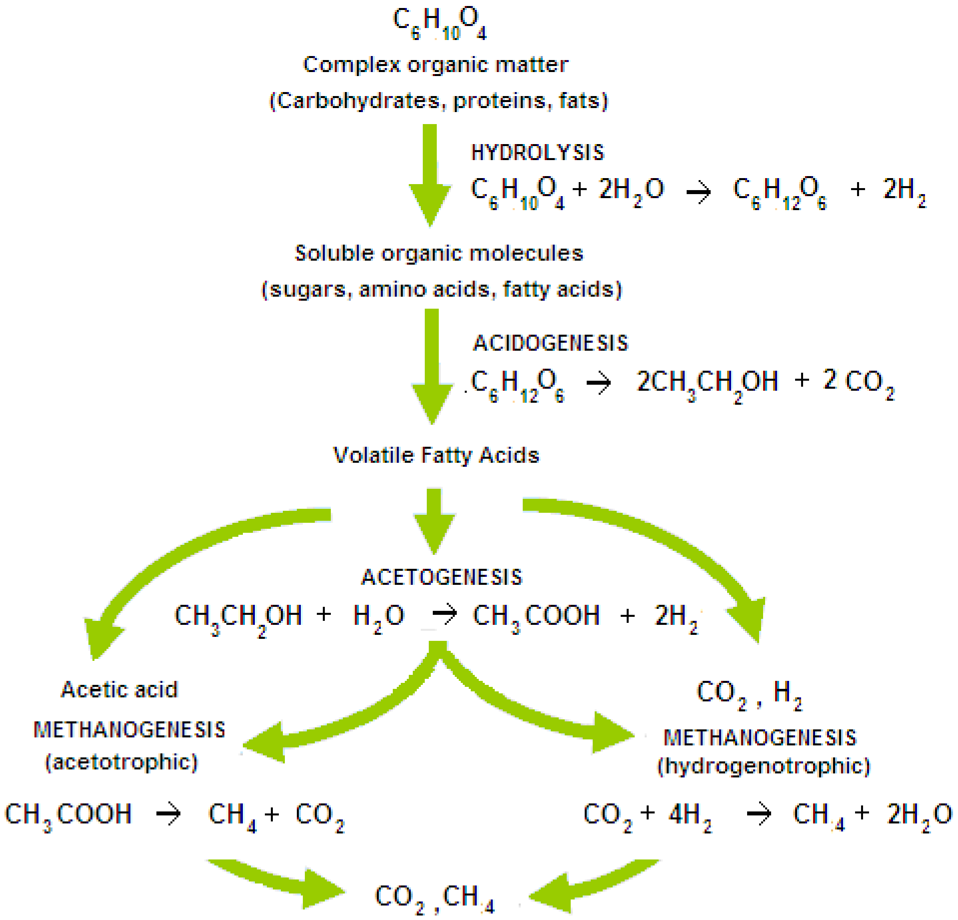


Figure 3.1 – Schematic representation of anaerobic digestion

(Source: www.biogas-renewable-energy.info, 2010)

3.3 Products of Anaerobic Digestion

3.3.1 Biogas

In the context of this study, biogas refers to the gaseous product produced through anaerobic digestion of biogenic MSW. The composition and yield of biogas produced varies with the composition of the feedstock used. Biogas generally contains between 55-70% of methane, 30-45% of carbon dioxide and trace gases (Monnet, 2003). Biogas is a colourless, flammable, and stable end product (Igoni et al, 2007). The average calorific value for biogas is approximately 23 MJ/m^3 (Møller et al, 2009). Biogas may be used to generate either electricity or heat, or a combination of both, termed co-generation or Combined Heat and Power (CHP). CHP units are often used to provide the energy required for the anaerobic digestion process itself, and the remaining energy may be sold to the national power grid in the case of large plants, or to power operations/processes elsewhere on site for smaller applications. Biogas is generally scrubbed and other gases present are removed to meet any environmental standards and prevent the corrosion of metal components of equipment (Ostrem, 2004). Biogas may be used for other applications, for instance an alternative to natural gas in the production of biofuel. Biogas may require further treatment and upgrading to yield a 90% methane content thereby increasing the calorific value (Monnet, 2003). Biogas has also been found to be an efficient and economic fuel in fuel cells which are traditionally fuelled by hydrogen or natural gas (Renewable Energy Focus, 2009).

3.3.2 Digestate

The digestate or sludge comprises of liquid and solid residue produced through the anaerobic digestion process and is essentially immature compost (Ostrem, 2004). Once matured, digestate can be used as fertilser or soil conditioner. The consistency of digestate varies, for instance, wet digestion produces thinner slurry than dry digestion due to the higher water content (Ostrem, 2004). Digestate requires dewatering and maturation before use. Screening and pasteurization processes may also be required to remove contaminants and ensure pathogen control for a higher quality compost or soil conditioner (RIS International, 2005; Coulon, 2010).

3.4 An overview of anaerobic digestion

3.4.1 Reactor and process type

Anaerobic digestion systems consist of one or more sealed reactors. Typical reactor volumes range from between 50 - 5000 m^3 (Krieg and Fischer, 2010). Reactors may operate as a single or multistage process. A single stage process allows for the entire process to occur in a single reactor whereas a multistage process allows for each phase of the process to occur in a separate reactor. The multistage process presents an advantage in that the optimum conditions such as the temperature, pH or nutrient requirements for a particular phase or micro-organism group can be maintained in a separate reactor allocated to that phase (Igoni, et al, 2007). Phases in multistage reactors occur simultaneously, allowing for lower retention times. Output products are produced at a faster rate which may compensate for the higher construction costs and the larger land uptake required for a multistage process (Ostrem, 2004).

3.4.2 Wet and dry digestion

Total solids (TS) content refers to the fraction of solid feedstock present in the wet input mass. A wet digestion process is characterised by a TS content of less than 15% (85% water content) whilst a dry digestion process has between 20-40% TS (Rapport et al, 2008). The input mixture contains less water in the case of dry digestion and thus allows for smaller reactors. The main disadvantage, however, is due to the issue of propagation/movement of the input feedstock through the system as heavy duty pumps, conveyers and other machinery is required for this purpose (RIS International, 2005). Wet digestion requires larger reactors, and a greater energy input to maintain the equivalent temperature environment for micro-organisms (Ostrem, 2004).

3.4.3 Temperature range

Anaerobic digesters operate in two temperature ranges, namely, mesophilic (30-38 ^{o}C), and thermophilic (44-57 ^{o}C) (Ostrem, 2004). The thermophilic temperature range results in more effective pathogen elimination, higher reaction rate and lower retention time of between 12-14 days in comparison with 15-30 days for mesophilic temperatures (Monnet, 2003). Igoni et al (2007) argue that although the rate of the digestion process becomes more rapid at higher temperatures, there are disadvantages to the thermophilic temperature range. Firstly, the extra energy input required in maintaining higher temperatures increases operating costs, and secondly thermophilic bacteria have a greater sensitivity to changes in temperature and other environmental conditions (Igoni et al, 2007). Extremely high levels of process control are therefore required for operation under thermophilic conditions. Pathogen elimination can instead be accomplished through pasteurization if the process is operated in the mesophilic temperature range.

3.4.4 Input waste or feedstock and co-digestion

The input feedstock for anaerobic digestion may consist of any biogenic material, depending on the particular application of the system. In terms of MSW, the feedstock is likely to include food waste from households and restaurants and „green' garden waste (Ostrem, 2004; RIS International, 2005). „Woody' garden waste contains lignin which cannot be digested without oxygen and reduces the yield of biogas if included in the feedstock. The quantity of feedstock should also be adequate to ensure a continuous and consistent yield of biogas. The minimum recommended capacity for an economical system is 50,000 tons of waste per year (Ostrem, 2004). Contaminants such as plastic or metal found in the mix cannot be digested and must be removed to prevent blockages and damage to equipment (Rapport et al, 2008). This is achieved through source separation or mechanical pre-treatment.

Co-digestion refers to the inclusion of two or more types of feedstock (Ostrem, 2004; Greben et al, 2009). Often, the quantity (variations in the amount of waste due to seasonality) or quality (in terms of the potential biogas yield) of the input feedstock is insufficient and co-digestion is implemented to improve efficiency of the process. Input wastes can be obtained from a variety of sources: biogenic MSW; industrial wastes from food and beverage industries; agricultural wastes; sewage sludge and animal wastes (Monnet, 2003). The characteristics of different waste types are often complimentary: for example, the high total solids content of biogenic food waste and the high microbial concentrations in sewage sludge improve the overall efficiency of the anaerobic digestion process (Greben et al, 2009). Greben et al (2009) maintain that co-digestion of wastes improves physical properties such as propagation, nutrient and microbial balances while also supplementing feedstock to maintain a constant input without being affected by seasonal variations in waste production.

3.4.5 Pre-treatment

Pre-treatment of the feedstock is essential for the optimisation of the process. The biogenic waste is usually shredded or crushed mechanically in order to reduce the particle size and thus increase the surface area of the substrate available for the action of bacteria (Igoni et al, 2007). The reduced particle size also provides some homogeneity to the mixture, reducing the formation of scum which tends to clog pumps and pipe work and damage equipment (Monnet, 2003). Water is added to the mix to enhance propagation of waste through the system as MSW is largely „non-flowing' (Ostrem, 2004). Essentially, pre-treatment serves to:

i. Improve efficiency of the process by sorting and separating wastes, and reducing particle size in order to increase reaction rates.
ii. Protect the system from being damaged and reduce potential for blockages.
iii. Produce a higher quality digestate by removing inorganic, indigestible materials.

3.4.6 Post-treatment: dewatering and disposal of digestate

The treatment or disposal of both the solid and liquid digestate is a major challenge in the implementation of anaerobic digestion. Dewatering of the digestate is necessary for practical purposes regardless of whether the final product is disposed of or composted, as volume reduction is required to reduce transportation costs, and allow for easier handling (Ostrem, 2004). The liquid fraction may be „recycled' back into the process (to achieve the desired TS content), treated at municipal wastewater facilities, or sold as fertilser, whilst the solid fraction is composted and used as soil conditioner (Ostrem, 2004). Both liquid and solid fractions of the digestate can therefore be reused, sold as fertilser/soil conditioner or disposed. A variety of different processes and technologies are available for dewatering purposes. Thermal drying is often used in conjunction with dewatering to increase the solids recovered. Potential dewatering methods to be considered include mechanical treatment through centrifugation, pressure or vacuum filtration and sludge drying beds (Metcalf and Eddy, 2004). The choice of dewatering method is dependant on the size of the plant. Large plants process a greater amount of biogenic waste and produce greater amounts of digestate. These plants require more sophisticated and efficient dewatering methods such as pressure filtration and centrifugation, which produce digestate of high solids concentration (Metcalf and Eddy, 2004).

3.5 Benefits of anaerobic digestion

The main attraction of anaerobic digestion resides in the growing emphasis on environmental benefits from waste diversion from landfill disposal. The average biogenic composition of the MSW stream in Africa is estimated at 56% (Couth and Trois, 2011). Anaerobic digestion uses this biogenic fraction thus reducing landfill volumes. Reducing dependency on landfills for biogenic waste disposal would also reduce contamination of soil by landfill leachate. Anaerobic digestion reduces GHG emissions through recovery of methane and generation of electricity (Smith et al, 2001; Mohareb et al, 2008). Instead of biogenic waste naturally degrading on landfill sites, and releasing GHG's into the atmosphere, anaerobic digestion enables degradation of waste in a controlled environment, where the energy of GHG's is captured and used. GHG savings also result from the reduced use of fossil fuel and the energy it takes to mine, process and produce energy from it. The associated waste diversion, GHG savings and renewable energy also achieve the targets set by environmental directives governing zero waste, waste minimisation, renewable energy production and GHG mitigation.

The digestate produced may be used as soil fertiliser or conditioner after dewatering and maturation. The use of digestate fertiliser is beneficial to the agricultural sector and the environment, reducing dependency on artificial chemical fertilisers. Digestate may also be used for landfill rehabilitation, and landscaping (Ostrem, 2004). The resulting income generated from the sale of both digestate product and electricity is yet another benefit of anaerobic digestion however this income depends on whether a market can be created for these products (Monnet, 2003). Anaerobic digestion can be integrated successfully with other strategies, such as recycling and composting and the process can be modified to suit specific requirements of each unique application. In summary, the benefits of anaerobic digestion are:

i. Greenhouse gas/carbon emission reductions.
ii. Renewable energy.
iii. Satisfies environmental legislation.
iv. Flexible technology that is easily integrated with other zero waste strategies.
v. Income generation from compost, electricity and certified emission reductions.

3.6 Economic considerations

The capital investment required for anaerobic digestion depends on the required capacity of the plant. Feasibility studies are essential to evaluate and compare economic feasibility of different anaerobic technologies. The total investment required is difficult to estimate due to the lack of real cost information from established projects, however approximations for the costs (per tonnage capacity) are available (Rapport et al, 2008). Such an estimate by Monnet (2003) lists a capital investment of R33 to R144 million and operational costs of between R1.4 to R10 million per year for plants varying from 5000 – 100 000 tons/year. Revenue can be generated from the sale of electricity and compost to the commercial and agricultural sectors. The use of anaerobic digestion produces certified emission reductions (CER's) and other possible monetary government incentives awarded such as tax reductions and subsidies for renewable energy (Rapport et al, 2008; Monnet, 2003; Couth et al, 2010).

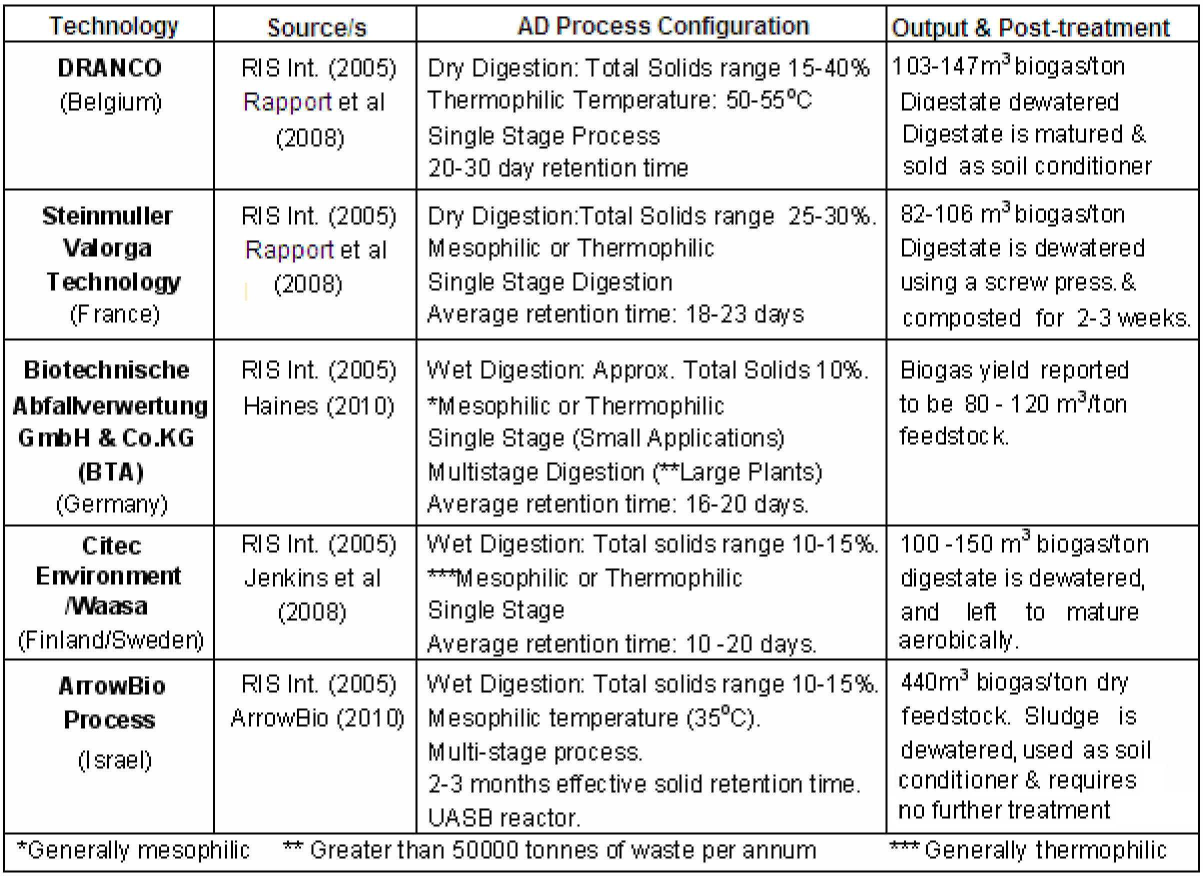
3.7 Overview of anaerobic digestion technologies

The general process comprises of three phases: the pre-treatment of feedstock, the anaerobic digestion process, and the post-treatment of anaerobic digestion products (Smith et al, 2001; Ostrem 2004). Pre-treatment of the feedstock may include mechanical separation depending on the degree of source separation. Elements of feedstock pre-treatment are illustrated in Figure 3.2.

Figure 3.2 – Elements of pre-treatment: BTA hydropulper and Arrow Bio separation Tanks *(Source: Arrow Bio, 2010; BTA Technology, 2010 and Biogen Greenfinch, 2009)*

Various technologies employ different methods of separation, for example, the BTA technology utilises hydro-mechanical pre-treatment to separate the biogenic fraction of the incoming waste stream through a waste pulper and grit removal system. Biogenic waste, light materials (plastics, textiles) and heavy materials are separated using natural buoyancy and sedimentation forces of materials. The impurities and grit present in the resultant biogenic suspension are removed by the BTA grit removal system (BTA Technology, 2010). Similarly, the Arrow Bio process separates the biogenic fraction through separation by density in water. The biogenic fraction stays in solution, and is pulverized using a „hydrocrusher' (Arrow Bio, 2010). Separation by drum screens, raking and trommels as used in MRF's may also be employed. After the biogenic fraction has been separated the waste is crushed and shredded into a homogenous mixture (Igoni et al, 2007). Wastewater from the anaerobic process is recycled back into the system to achieve the desired total solids content. The degree of treatment of the solid and liquid digestate varies in accordance with the intended use of the digestate. The digestate sludge is usually dewatered, aerobically composted and matured into compost or soil conditioner (Ostrem, 2004). The liquid fraction may be discharged into public drainage/sewer systems to be treated at municipal wastewater facilities, or further treated to acceptable discharge standards, and discharged into natural watercourses. The liquid contains valuable nutrients is used as liquid fertilisers in some cases (Ostrem, 2004). Table 3.1 provides a comparative analysis of several anaerobic technologies and process configurations.

Table 3.1 – Comparison of selected technologies



Technology	Source/s	AD Process Configuration	Output & Post-treatment
DRANCO (Belgium)	RIS Int. (2005) Rapport et al (2008)	Dry Digestion: Total Solids range 15-40% Thermophilic Temperature: 50-55°C Single Stage Process 20-30 day retention time	103-147m^3 biogas/ton Digestate dewatered Digestate is matured & sold as soil conditioner
Steinmuller Valorga Technology (France)	RIS Int. (2005) Rapport et al (2008)	Dry Digestion:Total Solids range 25-30%. Mesophilic or Thermophilic Single Stage Digestion Average retention time: 18-23 days	82-106 m^3 biogas/ton Digestate is dewatered using a screw press.& composted for 2-3 weeks.
Biotechnische Abfallverwertung GmbH & Co.KG (BTA) (Germany)	RIS Int. (2005) Haines (2010)	Wet Digestion: Approx. Total Solids 10%. *Mesophilic or Thermophilic Single Stage (Small Applications) Multistage Digestion (**Large Plants) Average retention time: 16-20 days.	Biogas yield reported to be 80 - 120 m^3/ton feedstock.
Citec Environment /Waasa (Finland/Sweden)	RIS Int. (2005) Jenkins et al (2008)	Wet Digestion: Total solids range 10-15%. ***Mesophilic or Thermophilic Single Stage Average retention time: 10 -20 days.	100 -150 m^3 biogas/ton digestate is dewatered, and left to mature aerobically.
ArrowBio Process (Israel)	RIS Int. (2005) ArrowBio (2010)	Wet Digestion: Total solids range 10-15%. Mesophilic temperature (35°C). Multi-stage process. 2-3 months effective solid retention time. UASB reactor.	440m^3 biogas/ton dry feedstock. Sludge is dewatered, used as soil conditioner & requires no further treatment

*Generally mesophilic ** Greater than 50000 tonnes of waste per annum *** Generally thermophilic

3.8 The status quo of anaerobic digestion in South Africa

Anaerobic digestion of biogenic MSW is not currently utilised as a MSW management strategy in South Africa. Large scale anaerobic digestion plants have been employed mainly to treat industrial wastes, such as the SAB Miller biogas plant, and the Petro S.A Biogas Project. The SAB Miller biogas plant treats wastewater (5 million litres/day) and biogenic waste (25 tons/day) from the manufacturing process which would ordinarily be treated at municipal wastewater treatment plants. The 9,265 m^3 of biogas produced daily contains a reported 85% of methane gas and is used to generate electricity required for both manufacturing and anaerobic digestion processes (Engineering News, 2009). The project has resulted in both financial and environmental benefits, including electricity savings of approximately R7000/day as the plant generates energy and reduces GHG emissions through reduced dependency on fossil fuel energy producing a saving of 10.4 tons of coal daily (Engineering News, 2009). These savings and benefits highlight the potential of the anaerobic digestion process. The status quo of anaerobic digestion as described by Greben and Oelofse (2009) comprises of a few small scale/pilot projects such as the Ivory Park Ecovillage biogas digester treating human waste and the „eThekwini small holding' treating sewage and manure from livestock. The extent of anaerobic digestion projects show that anaerobic digestion as a general waste management strategy is still in the developing stages and the potential for applications throughout South Africa is great. Many areas are undeveloped and without proper sanitation and electricity. Implementing small scale household digesters similar to other developing countries such as India would serve a dual role in providing heat and power whilst improving sanitation conditions. Many rural households own livestock and poultry, and animal waste could be supplemented into the feedstock where necessary.

3.9 Anaerobic digestion in developing and developed countries

The general attitude toward anaerobic digestion in developed countries varies: while use in the United States has been limited to wastewater treatment facilities and small agricultural applications, anaerobic digestion of biogenic food waste is far more widespread in European countries (Ostrem, 2004). Currently 97% of all food waste is landfilled in the United States (Levis, 2010). The hesitancy to use anaerobic digestion as a waste management strategy stems from the lack of incentives and environmental policy with regard to reducing landfill volumes and lower landfill tipping fees and energy prices in comparison to Europe which makes it difficult for anaerobic digestion to be cost competitive with landfilling (Ostrem, 2004; Rapport et al, 2008). The high failure rate of previous plants also been cited as a primary barrier to entry for anaerobic digestion in North America (Ostrem, 2004). Despite this, there has been renewed interest in anaerobic digestion, with feasibility studies being conducted in many states such as New York and California. The vast majority of anaerobic technologies have been developed and implemented in European countries such as Germany, Belgium and Finland, approximately 200 of these anaerobic digestion systems will be operational throughout Europe by the end of 2010 (Baere and Mattheeuws, 2010). The use of these systems to treat MSW is due to increasingly stringent environmental legislation put forward by the European Union (legislation requires a 65% reduction in biogenic wastes by 2016, 20% renewable energy consumption by 2020) as well as higher energy prices (Levis et al, 2010).

Anaerobic digesters are typically used in small scale applications in developing countries. By 2006 anaerobic digesters were installed in over 22 million rural households in China, and today, anaerobic digesters across all sectors produce 7-8 billion m^3 of biogas – saving almost 5 million tons of coal (He, 2010). With the annual waste generated expected to reach 210 million tons in 2015, the implementation of large scale anaerobic digestion plants is expected to signal major advances in renewable energy production (Cheng and Hu, 2009). An estimated 3.67 million household biogas units have been installed in India to provide heat and power to homes, also serving as sanitation in peri-urban areas (Sharholy et al, 2008). Pilot projects have also been launched to gain experience and provide preliminary information for implementing further anaerobic digestion plants using municipal, agricultural and industrial wastes (van Nes, 2006; Sharholy et al, 2008).

3.10 Case studies of anaerobic digestion facilities

3.10.1 Ieper Waste Facility (Belgium)

3.10.1.1 Introduction

Ieper is a Belgian city in the province of Flanders. Ieper covers an area of 130.61 km^2 with a population estimated to be 34, 897 (Tourism-ieper, 2010). Ieper waste facility comprises of an anaerobic digestion plant, two open window composting facilities and a fully operational enclosed chicken manure composting facility. The construction cost of the plant was approximately € 20 million. The information and statistics that follow were obtained from the article „*Open tunnel Composting'* by Blischke (2004).

Figure 3.3 – Ieper Municipality and Ieper Waste Facility

(Source: http://img.freebase.com, 2010 and Blischke, 2004)

3.10.1.2 Design and process technology

The plant capacity is 55,116 tons of biogenic waste per year and uses the German BTA technology. Source separated biogenic waste is collected from residential and commercial areas and transported to the waste facility. The bags of biogenic and green waste are transferred to a trommel screen, where the bulkier woody waste (approximated as 10% of waste received) is separated. Screen conveyers transfer the remaining waste into two 2,260 m^3 hydropulpers where the waste is crushed. Lightweight contaminants are raked out of the pulp mixture whilst heavy contaminants such as metal and glass are removed using a heavy fraction trap. Any subsequent fine contaminants that remain such as glass shards or fine sand are removed by the BTA grit removal system. A wet digestion process is adopted and recycled water from the process is used to produce an input feedstock mixture of 8 -10% TS. The biogenic waste suspension is transferred into the anaerobic digesters (660,500 m^3). The digesters are used in either a mesophilic single stage (process occurs simultaneously in both reactors) or multistage configuration illustrating the flexibility of the process. Biogas is injected throughout the length of the reactors as a mixing method, thus ensuring uniform distribution of micro-organisms and preventing heat gradients through the reactor. The remaining wastewater is treated to meet accepted discharge standards and is finally discharged into the nearby canal.

Figure 3.4 – Hydropulpers and dewatering equipment

(Source: Blischke, 2004)

3.10.1.3 Output products and post-treatment

Approximately 140 million ft^3 of biogas is generated annually with a 50-70% composition of methane. The electricity generated supplies the power required to run the entire facility, with more than 50% of the electricity produced being sold to the national energy grid. A CHP unit is installed comprising of four (300kW) 12 cylinder gas engines and electricity generator sets. These units are able to function together and singly to generate energy when waste input feedstock and consequently biogas is insufficient to warrant the operation of all four units at full capacity. The residual solid digestate from the reactors is pumped into a dewatering unit after 14 days. A flocculent emulsion is added to the digestate which is dewatered using a system of screw presses. The liquid from the digestate is either recycled back into hydropulper process, or treated as wastewater. The woody waste removed during mechanical treatment is crushed and rejoins this process line. Reverse operational screw presses break down the wood fibres to create an optimum substrate surface for micro-organisms during composting. The composting material comprises of processed woody waste and dewatered solid digestate. Composting is conducted in enclosed composting tunnels at thermophilic temperatures for effective pathogen elimination. The material is composted for 2-3 weeks after which it is transferred to a curing windrow area and left to mature for another six weeks. Approximately 18,740 tons of compost is produced annually.

3.10.2 South Shropshire Biowaste Digester

3.10.2.1 Introduction

The South Shropshire Biowaste Digester (shown in Figure 3.8) is a pilot project in Ludlow, South Shropshire. South Shropshire is considered a rural district with large areas of land comprising farmland and agricultural areas. The population of South Shropshire was 40,410 in 2001 according to the most recent UK census and the district spans over 1027 km^2 (UK National Statistics, 2010). The South Shropshire Biowaste Digester has been operational since June 2006. The plant is a pilot project and a demonstrative facility for the benefit of the public, with one of the primary objectives being to gain experience and knowledge through operational activities as many large scale plants are planned throughout the UK. Waste is obtained from restaurants, schools, hospitals and households through a kerbside collection program. Public participation is essential for the success of the plant, and a 78% compliance rate has been reported (Biogen Greenfinch, 2009).

Figure 3.5 – South Shropshire District and Biowaste Digester

(Source: Biogen Greenfinch, 2009; DEFRA, 2010)

3.10.2.2 Design and process technology

The plant comprises of a reception area, a waste storage tank, digester, and a digestate storage tank. Contaminants are removed and the remaining biogenic waste is then shredded during mechanical pre-treatment (Monson et al, 2007). Wastewater from the process is added to produce a TS content of 12%. A single stage wet digestion process at a mesophilic temperature (42°C) is utilised at the facility (Monson et al, 2007). The process occurs in a 900m^3 reactor which is continuously fed once every hour. A roller press separates the fibrous solid fraction of the digestate from the liquid fraction.

3.10.2.3 Output products and post-treatment

As of February 2009, the plant receives up to 4,000 tons of biogenic waste per annum and produces 160 kW of electrical output. An estimated 10% of the electricity generated is used for plant operations and the remaining energy is exported to the national energy grid (Biogen Greenfinch, 2009). Digestate (both liquid and solid fractions) is sold to the local agricultural sector.

3.10.3 Case study review

This case study researched two anaerobic digestion plants. The Ieper waste facility is an ideal example of an integrated and sustainable waste management system using zero waste strategies. Evidence of this includes the source separation of MSW, anaerobic treatment of biogenic wastes, the production of energy from waste and the aerobic treatment of digestate in composting tunnels which produces high quality compost (Blishke, 2004). The integration of anaerobic digestion with other waste management strategies results in an efficient system and generates income from the sale of electricity and compost. The flexibility of the process is also illustrated by the use of different reactor configurations, and CHP units.

The South Shropshire Biowaste Digester is currently operating below its capacity of 5,000 tons/annum, and experiences up to 10% of contaminants in collected „source separated' wastes. Initial problems experienced were the inclusion of garden waste in the input feedstock which resulted in greater operating costs for a lower biogas yield (Biogen Greenfinch, 2009). Problems such as this underline the purpose of the South Shropshire Biowaste Facility as a pilot project – to provide knowledge and experience for the eventual implementation of larger facilities. Smaller scale applications and pilot projects such the South Shropshire Biowaste Digester can therefore provide experience and knowledge with regard to operation and optimisation for anaerobic digestion of biogenic MSW. Smaller plants would especially benefit developing countries such as South Africa where experience in the field is lacking, and the financial requirements to construct and operate larger facilities may not be entirely feasible.

3.11 Summary

Anaerobic digestion is a biological process that treats biogenic waste and produces renewable energy that reduces dependency on energy derived from fossil fuels. This in itself is significant, as the goals of waste management are sustainability and environmental benefit and the focus of waste management views waste as a potential resource (Coulon, 2010). Whilst the energy generated from anaerobic digestion is hardly sufficient to power an entire municipality like eThekwini, it can be viewed as a supplementary green (renewable) energy source which is valuable with the current status of energy supply and demand in South Africa. Anaerobic digestion also diverts waste from landfill disposal, reducing ground contamination and odours, two of the most environmentally destructive characteristics of landfills (UK Environment Agency, 2002). Admittedly, anaerobic digestion facilities require significant capital investment, and landfilling is still considered the most cost effective method of disposal (Ostrem, 2004). Legislation and economic instruments need to put forward to make anaerobic digestion and biogas production an attractive alternative to landfilling (Monnet, 2003).

Research and pilot projects have been launched with the long term goal of implementing anaerobic digestion across the industrial, agricultural and waste sectors in some countries, while larger scale plants already operate at high efficiency throughout Europe (Monnet, 2003; Ostrem, 2004).

Anaerobic digestion cannot be viewed as the ultimate solution to disposal of biogenic waste; however it is a strategy with environmental and economic benefits. Capital investment needs to be weighed against the costs of the environmental damage of other options such as landfills, as this damage is usually not considered in economic analyses (Monnet, 2003). South Africa can learn from the experiences in other countries. Legislation, incentives, feasibility studies, innovative design and proper management of operations should result in a smoother transition to anaerobic digestion technology being utilised in the waste sector.

CHAPTER 4: AEROBIC COMPOSTING

4.1 Introduction and definition of aerobic composting

Aerobic composting refers to the biological degradation of biogenic wastes in the presence of oxygen, producing carbon dioxide, ammonia, water and humus or compost thus ensuring stabilisation of biogenic wastes. A suitable formal definition as stated by Saravannan et al (2003) refers to aerobic composting as:

"the biological decomposition and stabilisation of organic substrates under conditions that allow for development of thermophilic temperatures as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plant seeds and can be beneficially applied to land."

Aerobic composting has been the favoured treatment method for stabilisation of biogenic waste as the process is considered a more simplistic approach to biological treatment of waste (Polprasert, 1996). Polprasert (1996) also highlighted that the term aerobic simply implies that the predominant condition during biological metabolism is that of air or oxygen being present. A study comparing the impacts of landfilling and composting on GHG emissions by Lou and Nair (2009) similarly discussed the formation of „anaerobic pockets' and the resultant production in methane within compost piles due to the heterogeneous nature of biogenic MSW itself.

4.2 Biological process of composting

The biological process of aerobic composting consists of three stages: an initial stage where readily degradable waste is decomposed; a thermophilic stage characterised by high bio-oxidative activity; and finally a maturation/stabilisation stage in which humus is produced (Sharma et al, 1997). The following phases have been outlined by Polprasert (1996) using temperature ranges as defining characteristics.

i. Latent phase: this initial phase allows for micro-organism populations to grow and acclimatise to environmental conditions.
ii. Mesophilic growth phase: micro-organism populations continue to increase, as temperatures rise to the mesophilic range.
iii. Thermophilic phase: temperatures increase to the thermophilic temperature range resulting in waste stabilisation and effective pathogen destruction.

iv. Maturation phase: biological activity reduces and temperature decreases to the mesophilic range. The oxygen requirement is consequently lower and nitrification (conversion of ammonia into nitrates) and humification (production of humus) occur.

A schematic of the aerobic composting process is presented in Figure 4.1 and the overall biochemical conversion reaction for aerobic composting may be expressed as:

$(C_6H_{10}O_4)_x + 6.5\ O_2 \rightarrow (C_6H_{10}O_4)_{x-1} + 5\ H_20 + 6\ CO_2$ (van Haaren, 2009)

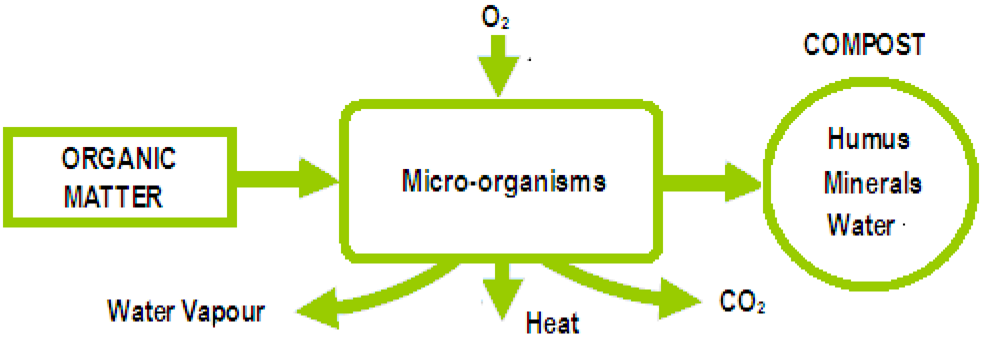


Figure 4.1 – Schematic of aerobic composting process

4.3 Composting systems and methods

4.3.1 Windrow composting and Dome Aeration Technology (DAT)

The windrow composting method comprises of an arrangement of compost piles, each 2-3 metres high with a length of up to 100 metres (van Haaren, 2009). These piles are arranged in rows and together are usually 4-5 metres wide. The arrangement of the compost pile into rows allows for good oxygen flow to the centre core as well as even temperature distribution (van Haaren, 2009). Mechanical windrow turners are used to turn piles allowing for air exposure thus preventing anaerobic conditions.

Dome Aeration Technology (DAT) is essentially a modification of the windrow composting method which does not require periodic turning. A system of thermally driven advection caused by temperature gradients between the windrow and the external environment provides a forced aeration mechanism as illustrated in Figure 4.2 (Griffith and Trois, 2006; Douglas, 2007; Trois et al, 2007). DAT composting is ideally suited for the treatment of biogenic wastes in South Africa due to the lower energy requirement, high efficiency and therefore lower operating costs (Griffith and Trois, 2006; Trois and Simelane, 2010).

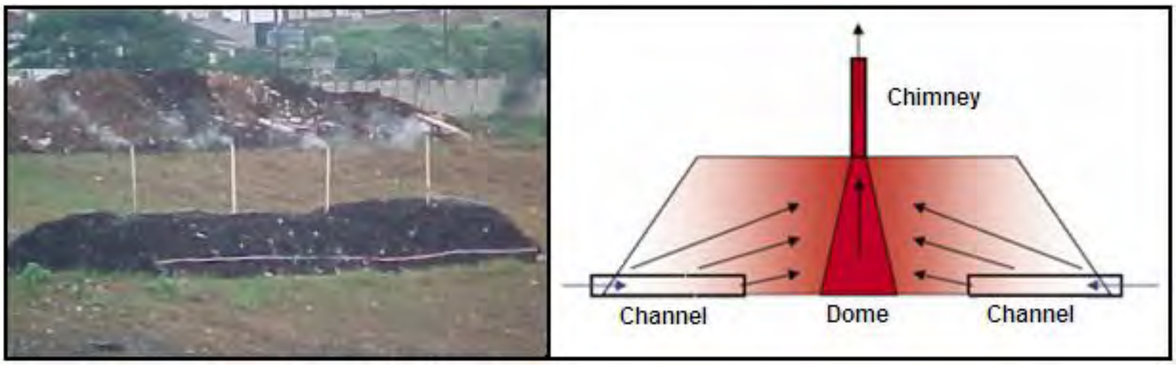


Figure 4.2 – DAT windrow with schematic representation

(Source: Griffith and Trois, 2006; Trois et al, 2007)

4.3.2 Static pile or forced aeration composting

This method of aerobic composting involves the use of ventilated floor systems which use perforated aeration tubes that allow for the circulation of air through the pile. The compost is piled on top of these specially designed floors. Mixing of the biogenic wastes is essential prior to loading onto the floor as no turning occurs during the process. The bottom layer of the compost pile usually consists of a mature compost layer about 10 centimetres thick, and has a total of height of 1-2 metres (Sharma et al, 1997). The piles may be covered using special membrane cloth, which allows for the diffusion of nitrogen, oxygen and carbon dioxide, without moisture and odours escaping (van Haaren, 2009).

4.3.3 Enclosed reactor (In Vessel) composting

Enclosed reactor composting systems allow for decomposition of biogenic wastes within a reactor. These reactors are designed to allow for a high degree of process control to optimise the composting process. Temperature, moisture content, pH and aeration parameters can be monitored and adjusted to optimum levels. A typical reactor system consists of a rotating drum (usually 3 metres in diameter), air blower (aeration mechanism) and air filtration (odour control) unit (van Haaren, 2009). The rotating action allows for efficient mixing ensuring even distribution of micro-organisms, heat and moisture.

4.4 Design and process considerations

Waste to be composted should be shredded to reduce particle size thus producing a relatively homogenous mixture of biogenic MSW thus preventing formation of „anaerobic pockets' as described by Lou and Nair (2009). The size reduction increases reaction rates, due to the greater surface area of individual substrates. Reducing the waste particle size allows micro-organisms to digest a greater amount of material, increase population growth rates and produce more heat, all of which improve the overall efficiency of the aerobic composting process. A particle size between 25-75 mm is considered optimal (Tchobanoglous et al, 1993).

Mixing or turning of the waste material is also essential as this action allows for even and uniform distribution of micro-organisms, moisture and nutrients (Tchobanoglous, et al 1993). Turning is also required depending on the type of composting system in place, to expose the waste to air thus minimising anaerobic reactions and the production of methane odours. Odours are also minimised by designing an efficient aeration mechanism, ensuring periodic turning of waste where required. The use of special membrane covers for static pile systems (forced aeration composting) serves to keep odours within the pile yet allow for diffusion of oxygen, carbon dioxide and nitrogen (van Haaren, 2009). Odours can also be effectively minimised by conducting the composting process in an enclosed building where biofilters are used to filter air (Ostrem, 2004).

4.5 Utilisation and Benefits of Compost

Compost can be utilised in a wide array of applications, the most common of which include the use as soil conditioner, landfill cover material and fertiliser for agricultural, landscaping and horticultural purposes. Polprasert (1996) confirms that:

"composts improve the physical properties of soils, as evidenced by increased water content and water retention; enhanced aggregation; increased soil aeration, soil permeability and water filtration; and decreased surface crusting".

Another major benefit to the environment is the reduction in the use of chemical fertilisers, and the reduction in soil erosion. The quality of the compost produced is measured by its content of essential plant nutrients such as nitrogen, potassium and phosphorus and depends greatly on process control. Screening of the matured compost is also required to remove contaminants such as plastic and metal.

4.6 Summary

Aside from the oxygen requirement, the primary difference between anaerobic digestion and aerobic composting lies in the objectives of each process, listed in Table 4.1. Although waste stabilisation is the desired result for treatment of the biogenic fraction of the MSW stream, and is achieved by both processes, the primary focus and main benefit of anaerobic digestion is the utilisation of biogas as a renewable energy source. With regard to GHG emissions, composting can be considered as being „carbon neutral' in the sense that biogenic CO_2 is the principal gas produced from the process itself, however, emissions from energy and fuel requirements should also be considered when comparing strategies. Composting could be considered as a less complex process that achieves the same goals of volume reduction and waste stabilisation (Polprasert, 1996). Although it is easier to implement and requires less capital investment depending on the system type adopted, it does not herald the same benefits in terms of energy production as with anaerobic digestion. The type of composting to be adopted is influenced ultimately by the quantity of waste to be composted. Technologies such as forced aeration and in-vessel systems are less likely to be implemented if sufficient input wastes are not available due to the higher capital investment as they are more technologically advanced; require electricity, and frequent monitoring and maintenance (van Haaren, 2009).

Table 4.1 – Comparison of aerobic composting and anaerobic digestion

(Source: Tchobanoglous et al, 1993)

Characteristic	Aerobic Composting	Anaerobic Digestion
End products	Compost, CO2, H2O	CH4, CO2, digestate
Volume reduction	Up to 50%	Up to 50%
Composting period	20-30 days	20-40 days
Primary goal	Volume reduction	Energy production
Secondary goal	Compost production	Volume reduction

CHAPTER 5: RECYCLING

5.1 Introduction and definitions of recycling

The International Solid Waste Association (1992) describes recycling as the reuse of materials not necessarily in their original forms, and documents that recycling may fall into any of the following classes:

i. The direct use of a product more than once for the same purpose for which it was originally designed.
ii. The use of a product in its original form but for another purpose.
iii. The return of production line process wastes into mainstream production line feedstock.
iv. The treatment and reconstitution of the materials from one product to produce secondary raw materials for other products.
v. The conversion of wastes into energy.
vi. The separation of wastes at the source, collection and transportation where applicable are regarded as part of recycling.

This broad definition encompasses many of the different forms of recycling and conveys the general meaning of recycling - the reprocessing or reuse of used/waste material into new materials/products. Applying this definition, many of the „zero waste strategies' discussed previously can be viewed as forms of recycling. Anaerobic digestion and composting may be viewed as „biogenic waste recycling' as biogenic waste is converted into energy and composting products. In the context of this study, recycling refers to the reprocessing of materials and products from the MSW stream. Thus an appropriate definition of recycling is:

"The process whereby discarded products and materials are reclaimed or recovered, refined or reprocessed, and converted into new or different products".

(DEAT, n.d)

Recycling processes may be considered to be either closed loop recycling or open loop recycling (DEAT, n.d). Closed loop recycling refers to the reprocessing of waste materials or products into input raw materials for use in the manufacturing of products of a similar nature as the original product for example, the reprocessing of glass cullet and bottles into new glass beverage bottles. Conversely, open loop recycling entails reprocessing of waste materials into entirely different products, for example the recycling of scrap metal into metal beverage cans (DEAT, n.d). In the context of both closed and open loop recycling, the United Nations (2007) definition of recycling seems most applicable:

"Any reintroduction of waste materials in a production process that diverts it from the waste stream. Both reprocessing as the same type of material and for different purposes are included".

5.2 Recycling and recovery methods

Recycling and recovery occurs via various methods and mechanisms in South Africa which include buy back and drop off centres, informal recycling and materials recycling facilities.

5.2.1 Buyback and drop off centres

Buyback centres purchase recyclables from waste collectors or informal recyclers and are typically operated by individuals/entrepreneurs. Buy back centres operate successfully if implemented in commercial/industrial areas where packaging wastes are readily available for collection. Ideally, buy back centres should be easily accessible to lower income groups which rely on these centres for income generation and usually do not have transportation to haul recyclable materials (DEAT, n.d). Drop off centres provide waste reclamation containers for the general public to deposit recyclable wastes. Drop off centres are usually located at central convenience points which are easily accessible to the public such as shopping centres, garden refuse sites, and schools (DEAT, n.d). Drop off centres rely on public participation, as no remuneration is awarded for recyclables and are therefore predominantly used by higher income groups.

5.2.2 Informal recycling

Informal recycling, also known as scavenging or waste picking refers to the collection and recovery of wastes from landfill sites, informal dumping sites, refuse bags and bins or any other public domain. Informal recycling is mainly practiced among low income groups to either reuse unwanted products for personal use, convert waste materials into useful items to be sold for income, or to sell recyclables to buy back centres (DEAT, n.d). This practice often poses a high degree of health and safety risks to scavengers, as they do not have personal protection equipment required for handling MSW such as gloves and masks. The operation of landfill machinery and vehicles also poses a health and safety risk for waste pickers.

5.2.3 Materials Recycling Facilities (MRF)

Materials recycling facilities are specially equipped facilities that sort and separate recyclable materials (Smith et al, 2001; Purchase, 2008). These facilities may employ manual separation of recyclable wastes, or the use of mechanical equipment and technologies such as magnetic separation of metals, screening of fines, air jet separation of shredded paper, and separation by density in water (as described in the BTA process in Chapter 3). MRF's are categorized according to the types of incoming wastes/waste streams by R.W Beck (2006) as follows:

- Multi-Stream MRF's: These MRF's sort and separate specific fractions from several streams of recyclable fractions that have been separated at the source, for example the separation of individual grades of plastics (PET, HDPE and so forth) from the plastic waste stream.
- Single Stream MRF's: The sorting and separation of recyclables that have been collected in a single stream at the source and subsequent sorting of specific recyclable fractions.
- Mixed Waste Processing Facilities (MWPF): Separate and sort recyclable materials from the MSW stream and referred to as "Dirty MRF's". Separation of wet and dry fractions, and sorting of specific recyclable fractions.

Although MRF's allow for recycling to be implemented on a much larger scale, both multi-stream and single stream MRF's rely heavily on public participation for initial separation of dry and wet fractions of wastes to avoid contamination of recyclables. An initiative by Durban based Tempo Recycling employing manual separation of wastes failed largely due to contamination of the waste stream by hazardous medical wastes which resulted in unacceptable health risks for workers (DEAT, n.d). Capital intensive MRF’s have also experienced failure through a lack of public participation and unstable market conditions for recycling (DEAT, n.d). The Mariannhill MRF located on the Mariannhill landfill site has operated successfully since 2007 and illustrates the potential positive impacts of MRF’s in terms of job creation, landfill space savings and environmental benefits (Purchase, 2008).

5.3 Recyclable components of the MSW stream

The recyclable fractions of the MSW stream selected for this study include glass, metals, paper, and plastic, as they form the majority of the recycling market, however other wastes such as electronic wastes, tyres, textiles, building and construction materials may also be recycled and reused (DEAT, n.d). In the following sections the recycling process, recovery rates, benefits and problems associated with each fraction or group will be discussed.

5.3.1 Overview of glass recycling

Raw materials required for the production of glass include quartz, lime, soda ash and sand (ICF, 2005). Recyclable glass or „cullet’ from the waste stream is introduced into the production process which accelerates melting and crystallization of these raw materials. The inclusion of cullet therefore makes the production process more efficient, lowering the melting point and reducing the energy input (ICF, 2005). Glass cullet is collected, separated into fractions by colour, and potential contaminants such as metal caps and cork fragments are removed. Almost all types of glass can be recycled with the exception of crystal, opaque, window and laminated glass (DEAT, n.d). The energy required to recycle glass is 9.23 GJ/ton in comparison with 14.1GJ/ton of energy input to produce glass from virgin materials (Matete, 2009). For every ton of cullet used, 1 ton of glass is produced, whereas 1.2 tons of virgin materials are required to produce the equivalent amount of glass (The Glass Recycling Company, 2010). Glass is considered to be infinitely recyclable as the recycling process does not result in any degradation in quality. The last recycling recovery rate reported was 24% in 2007 (The Glass Recycling Company, 2007).

5.3.2 Overview of metal recycling

The recyclable metal fraction of the MSW stream includes beverage cans, food tins, scrap metal and wire, and construction steel (USEPA, 2006). These fractions primarily consist of steel, aluminium and copper. The recycling process of recovered metals typically includes sorting, removal of contaminants that inhibit melting, shredding and heat treatment to remove paint and coatings and finally smelting and ingot casting (ICF Consulting, 2005). Metal wastes can be recycled repeatedly without losing quality or strength (Smith et al, 2001; ICF Consulting, 2005). The most commonly recovered metal group is that of beverage cans, which in South Africa are produced predominantly from steel, since aluminium can production ceased due to escalating production costs in South Africa. Aluminium cans are still present in the waste stream as imports from other countries (Berry, 2009). Aluminium is produced from metal ore called bauxite which is rich in alumina compounds. A powerful electric current is required to separate the aluminium from oxygen, making the production process energy intesive. For every ton of aluminium that is recycled, 6 tons of bauxite and 4 tons of chemical compounds are saved. Recycling aluminium requires 95% less energy than producing it from virgin materials (Waste Online, 2004). Steel is produced from iron ore, which like bauxite, must be stripped of oxygen and other compounds. Recycling one ton of steel saves 1.5 tons of iron ore and 0.5 tons of coal. The recycling process requires 60% less water and 75% of the total energy input required (Waste Online, 2004). Beverage can recovery rates in South Africa are among the highest in the world with the last reported figure of 69% reported by Collect-a-Can (2009), whilst The Metal Recyclers Association of South Africa (MRA) reports that 80% of ferrous and non-ferrous scrap metal is recovered for recycling (MRA, 2010).

5.3.3 Overview of paper recycling

Paper materials that can be recycled are extensive. The various classifications of paper include newspaper, cardboard, office paper and paper packaging. Virgin paper is generally produced from wood pulp; however materials such as grasses, sugar cane and straw may also be used for production (Waste Online, 2004). The general paper recycling process as described by Mondi Recycling (2010) includes cleaning processes to remove grit and ink, bleaching, and the addition of water and chemicals to produce a paper 'pulp'. Paper unlike glass, is not infinitely recyclable as the paper fibres become shorter and weaker after the recycling process and reduce quality. Recycling one ton of paper saves the equivalent of 17 trees, 54% of the process water required, 2.5 barrels of oil and 64% of the energy input (Recycling Revolution, 2010). The last reported paper recovery rate for the year 2009 in South Africa was approximately 43.56% (Paper Recycling Association of South Africa, 2009). A general trend in the paper recycling industry has been the increase in exporting of recovered paper to developing countries with limited forest resources and lower production costs such as China and other East Asian countries (WRAP, 2007). The United States exported more then 14 million tons of recovered paper in 2005, and this trend is expected to continue as developing countries increase their recycling capacity.

5.3.4 Overview of plastic recycling

Plastic post consumer waste may belong to one of seven plastic classification groups. These classifications (based on the particular resin code each of which have specific compositions and therefore melting points) make plastic recycling difficult in that products are required to be sorted into respective groups before recycling (Dahlbo and Korhonen, 2007). Recovery rates for plastics, as listed in Table 5.1, vary across the different plastic types, with the highest rate for LDPE plastic (26.7%). The recovery of PET plastic can be considered inadequate, as PET plastics arguably have the greatest potential for recycling in both closed and open loop recycling applications (Nahman, 2009).

Table 5.1 – Recovered Plastic Tonnages for South Africa

(Source: South African Plastic Recyclers Organisation, 2005)

Plastic Derivative	% Recovery Rate
PE-LD/LLD	26.70%
PE-HD	19.10%
PP	12.30%
PET	21.80%
PVC-P	14.40%
PVC-U	3.10%
PS	7.10%

5.4 Advantages and disadvantages of recycling

The advantages of recycling are numerous. Environmentally, recycling waste materials results in GHG and pollutant emission reductions (Blend and Elsaesser, 2004). These reductions are due to increased carbon sequestration (17 trees are saved for every ton of paper recycled); lower energy input required for recycling materials in comparison to producing new products from virgin materials and reduced emissions from the mining, collection and transportation of these virgin materials (US EPA, 2006). Recycling wastes into new products reduces the consumption of virgin materials and natural resources such as metal ores, timber, water and fossil fuels required for energy thus preserving natural resources and ecosystems. The diversion of waste from landfill disposal to recycling also results in landfill space savings which assist in meeting waste management legislation and targets (Polokwane declaration – zero waste to landfill by 2022).

The recycling market has the potential to generate economic benefits by creating jobs in both the public and private sectors. Many informal recyclers currently rely on the collection and selling of recyclables to buy back centres for their livelihood in order to provide for their families (DEAT, n.d). Recycling is therefore a source of income for many lower income groups, more so in developing countries (Bogner et al, 2008). An estimated 1.1 million jobs have been created in the United States from both public and private recycling and for every job collecting recyclables an estimated 26 more jobs are created for the processing and recycling of these recyclable materials (National Recycling Coalition, 2010).

Recycling wastes also produces social benefits such as improved health benefits due to pollution and emission reductions and improved aesthetics of public and recreational areas due to collection of wastes for recycling (Blend and Elsaesser, 2004). Recycling can be considered a powerful educational and information tool that promotes the principles of waste management and sustainability whilst instilling a sense of environmental awareness into those who practice recycling or are exposed to recycling concepts and initiatives.

The main challenges or disadvantages of recycling are:

- Inefficiency: Recycling processes may not always be energy efficient as in the case for recycling aluminium and glass. For example with some recyclable plastic groups, recycling one ton of plastic does not produce a greater or equivalent amount of new product (Haight, 2004).

- Public Participation: Recycling programs rely on high levels of public participation for instance, kerbside collection programs, at source separation of wastes and drop off centres are all dependent on high participation and compliance rates (Matete, 2009)

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- Market conditions: Recycling depends heavily on market availability, demand for recyclables and prices (Matete, 2009). The recycling market is ever changing due to price volatility for example the price of recyclable materials are directly affected by the prices of virgin materials, such as the oil price. Price variation therefore creates uncertainty in the recycling market and a sense of hesitancy amongst investors (Stromberg, 2004; Lavee et al, 2009).

- Financial capacity: Provision of recycling facilities, education and promotion of recycling initiatives and management of recycling programmes requires capital investment and resource allocation. Currently, an estimated 87% of municipalities in South Africa do not have the capacity to address recycling and other waste minimisation efforts (Oelofse, 2008).

5.5 Challenges in implementation

There are significant challenges with regard to the implementation of recycling. These challenges can be categorized into social, institutional and economical challenges. Social challenges include enlisting public support and increasing public participation rates in recycling initiatives. These social challenges can be addressed through recycling awareness campaigns, advertising through print and other media, and providing incentives for recycling. Social challenges also include providing safe and convenient methods for the public to engage in recycling – for example issuing protective gear to informal recyclers and the provision of recycling drop off centres or recycling banks in public areas. Economic challenges essentially comprise methods of improving price stability within the recycling market. Subsidising recycling initiatives would assist in keeping recycling prices constant (Nahman, 2009). Collect a can for example is subsidised by beverage drinks companies and is therefore able to offer a set price for recyclable cans to recyclers and waste collectors (DEAT, n.d). Similar efforts by producers – termed extended producer responsibility (the extension of a producer's responsibility for a product through to the post consumer stage of the product life cycle, including waste disposal) will assist in providing some stability to recycling prices in that recyclables can be bought at a set price despite changes in market prices (Nahman, 2009). Government subsidies would also have the same effect. Institutional challenges necessitate the formulation of specific legislation that governs and regulates recycling, provides incentives for recyclers, 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 as recycling is currently governed by municipality specific by-laws (DEAT, n.d). Setting recycling targets for households, businesses, and industry is integral for waste management as a whole.

5.6 Summary

Recycling has many advantages that include environmental, economic and social benefits, and has been recognized as the waste management strategy that results in the greatest benefit to the environment (WRAP, 2006). Recycling, however, cannot be treated as a universal solution to the management of the recyclable fraction (Matete, 2009). There are disadvantages to recycling as discussed in section 5.4 and other methods of waste management and emerging waste treatment technologies should not be disregarded without careful review. Recycling meets the current „needs’ of the waste sector in that it is a feasible and sustainable strategy that is able to divert a significant amount of waste from the MSW stream from landfill disposal – in accordance with the goals of the Polokwane declaration. Recycling is primarily conducted by the private sector throughout South African municipalities. Recycling can be more effective with the support of legislation and economic instruments and requires more incentives on the part of both consumers and producers to strengthen the recycling market (Nahman, 2009; Troschinetz and Mihelcic, 2009). One of the greatest barriers to achieving adequate recycling recovery rates is that of source separation. Often recyclables in the waste stream have a degree of contamination that significantly or completely reduces the potential monetary value, as seen in the fact that higher rates are paid for clean and uncontaminated recyclables. If and when source separation of waste can be achieved and recovery rates are improved, recycling has the potential to become even more of a viable industry.

CHAPTER 6: CASE STUDY DESCRIPTION – eTHEKWINI MUNICIPALITY

6.1 Introduction

The following case study within the eThekwini municipality focuses on municipal waste services, waste management systems and infrastructure currently in operation, with particular emphasis on the Mariannhill Landfill Site. As outlined in section 1.1, the municipality was selected for the study due to its representation of typical South African municipalities in terms of socio-economic factors, in major cities such as Cape Town, Johannesburg and Durban (Stotko, 2006). The eThekwini municipality is located on the eastern coastline of South Africa in the province of KwaZulu-Natal as illustrated in Figure 6.1. Sub-tropical climate conditions are pre-dominant in the coastal areas of eThekwini. The municipality covers a total area of 2297 km^2 and has an approximate population of 3.16 million people (Friedrich and Trois, 2010). Areas of eThekwini vary in socio-economic climate from well developed urban areas of the metropolitan to newly integrated rural areas with little service coverage and infrastructure (Couth and Trois, 2010). The socio-economic distribution consists of high, middle and low income groups in both urban and rural areas. Approximately 35% of the areas of the eThekwini municipality are considered urban, and 80% of the local population resides in these areas. Waste generation rates for the formal sector range from 0.4 - 0.8 kg per capita per day, and 0.18 kg per capita for the informal sector whilst the total waste landfilled per annum is approximately 1.15 million tons (SKC Engineers, 2004).

Figure 6.1 – eThekwini Municipality

(Source: Wikimedia Commons, 2010)

6.2 Municipal waste services

Matete (2009) highlights the inequitable waste service coverage in South Africa as a whole. The level or extent to which waste services are provided vary, with metropolitan municipalities and urban areas having higher levels of service (kerbside collection, better equipment, vehicles and facilities) on par with that of developed countries whilst some rural areas receive inadequate waste services, if any (Matete and Trois, 2008). Table 6.1 lists the percentage of households receiving a basic level of service in various South African municipalities and Table 6.2 highlights the type of waste service provision received by households within eThekwini. A study of waste service delivery in South Africa by Oelofse et al (2009) lists the root causes of inadequate and inequitable waste service coverage as the lack of financial resources, equipment and trained/skilled human capital as well as poor access to service areas. Furthermore service charges often do not reflect the actual cost of the service provided, and lower fees affect the quality and level of service of waste services being provided (DEAT, 2000; Matete, 2009).

Table 6.1 – Municipal levels of service in South Africa

(Source: DEAT, 2007)

Category	Description	Level of Service
A	Metropolitan	80%
B1	Municipalities with the largest budgets	61%
B2	Municipalities with large town 'cores'	60%
B3	Municipalities with small populations and a high portion of urban areas	55%
B4	Rural municipalities with a few small towns	20%

Table 6.2 – Waste service provision by household in the eThekwini Municipality

(Statistics South Africa, 2005)

eThekwini Municipality	No. of Households
Removed by local authority at least once a week	706,113
Removed by local authority less often	7,042 `
Communal refuse dump	4,469
Own refuse dump	91,819
No rubbish disposal	14,818
Not applicable	111

The continual increase in population, urbanization and development contributing to annually increasing waste generation requires improved and efficient waste service coverage and provision of waste management systems. Currently the scope to address waste services includes the provision of free basic waste removal and collection services specifically targeting poor communities and undeveloped areas (Oelofse, 2009). Municipal waste services in the eThekwini municipality such as the collection, transportation, storage and treatment of municipal wastes as well as domestic and street cleaning services are provided by Durban Solid Waste (DSW). Private contracting companies and community based contractors are also operational in some areas of Durban.

6.3 Waste Collection

Municipal waste is either collected by municipal service providers or self hauled to waste disposal sites. Household waste receptors or collection mechanisms include black refuse bags for general household wastes, green refuse bags for garden refuse and green wheeled container bins as illustrated in Figure 6.2.

Figure 6.2 – Refuse collection bags/bins and a typical DSW collection vehicle
(Source: Durban Solid Waste, 2010; www.ett.co.za, 2010)

The wheeled container bins are popular in high density multi-dwelling units such as apartment complexes and flat clusters and other commercial properties due to the reduced space required (Gaillot et al, 2005). The new orange refuse bags were implemented in residential areas as part of a paper recycling project in conjunction with Mondi. Residents are meant to separate paper waste materials into the orange refuse bags, which are then collected separately on waste collection days. Informal areas that limit access of waste collection trucks are provided with communal skips, where refuse bags of waste are discarded, and collected by either municipal waste service providers or community based contractors. Waste collection services are provided weekly for residential areas and daily to once a week in business and commercial areas by a fleet of 264 vehicles (eThekwini Municipality, n.d).

6.4 eThekwini landfill sites

There are currently three engineered landfills being operated by Durban Solid Waste in the eThekwini municipality. These are the Bisasar Road, Mariannhill and Buffelsdraai landfill sites as illustrated in Figure 6.3. The Bisasar Road landfill is the oldest of the active landfills, and began operating in 1980. The Buffelsdraai landfill site serves the area north of the Umgeni River, and began operating in 2006. The Mariannhill landfill site is considered a conservancy site due to its naturalistic, efficient design and environmentally sustainable rehabilitation techniques employed. The landfill site includes a leachate treatment plant, materials recycling facility and landfill gas recovery project.

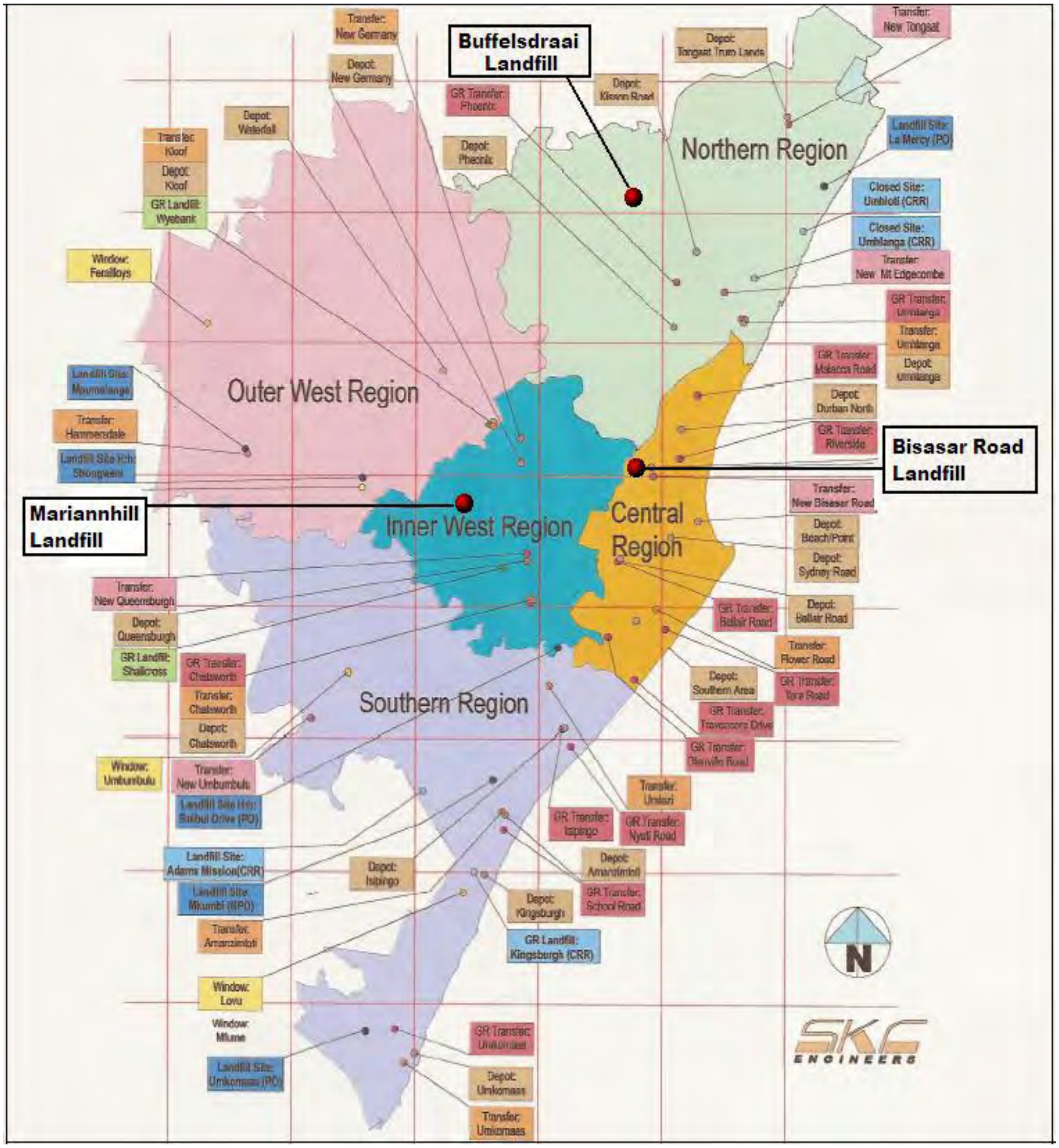


Figure 6.3 – Municipal landfill sites in eThekwini

(Source: SKC Engineers, 2002)

6.5 Mariannhill landfill site

The Mariannhill landfill is located in the western region of eThekwini, in what is considered to be a peri-urban area. The landfill site has been operational since 1997, and has an approximate incoming waste stream of 550-700 tons per day (Couth et al, 2010). The landfill covers approximately 33 hectares, has a capacity of 5 million m^3 and an average depth of 18 m. 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.

Figure 6.4 – Aerial view of Mariannhill landfill site
(Strachan et al, 2004)

6.5.1 Plant Rescue Unit (PRUNIT) and Leachate Treatment Plant

The plant rescue unit was initiated as part of the unique rehabilitation methods employed on the Mariannhill landfill site. The original soil profile and indigenous vegetation to the area is not removed, but rescued and temporarily stored in a large holding nursery. This vegetation is then used to rehabilitate areas both on and off site. As each cell is closed, it is rehabilitated. This 'phased' rehabilitation method has made landfilling in the area environmentally sustainable as it minimises biodiversity loss; is more socially acceptable, and is also a more financially attractive option as it produces greater long term savings than a single rehabilitation phase upon closure of the landfill site (Strachan and Bowers, n.d).

Landfill leachate refers to the liquid produced or 'leached' from landfill waste through the percolation of water. The practice of disposing landfill leachate as wastewater to the sewer system has been replaced by the on-site treatment of leachate on the Mariannhill landfill site. The 50 m^3/day plant was constructed in 2004 after trial testing during a pilot project and consists of a sequencing batch reactor, equalisation tank and a reedbed for final polishing treatment (Strachan et al, 2004). Treated leachate is used on site for either irrigation purposes or dust suppression (eThekwini Municipality, n.d).

6.5.2 Materials Recycling Facility (MRF)

The Mariannhill MRF was implemented in 2007 after initial sampling analyses of waste composition, and waste types through to assess feasibility of the facility (Purchase, 2008). The MRF is operated by recycling company Re-ethical Environmental Re-Engineering and reported recovery rates of recyclables range between 9-13% (Refer to Appendix B, Table B2). 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 job creation and landfill space savings, however, problems have been experienced with regard to contamination of recyclable wastes by garden refuse and medical wastes (Purchase, 2008). Figure 6.5 presents elements of the recovery process.

Figure 6.5 – Mechanical pre-treatment and pre-sorting line and initial sampling phase
(Source: Re-ethical Environmental Re-engineering, 2009)

6.6 Bisasar landfill Site

The Bisasar landfill site (shown in Figure 6.6 below) is situated approximately 7 km from the central business district. The surrounding area is considered urban, comprising residential areas well as commercial and industrial districts; however a large number of informal settlements are also present. This variation in municipal waste sources or activities is characteristic of South Africa's socio-economic conditions (Matete, 2009). The landfill covers approximately 44 hectares, has an average depth of 40 m and a total capacity of 21 million m^3 (Couth et al, 2010). The average incoming waste stream is approximately 3,000 tons per day, peaking at 5,200 tons per day (Strachan et al, 2003). Currently, leachate is collected and discharged for treatment at the Northern Wastewater Treatment Works (Moodley, 2010). The site receives domestic MSW, garden refuse, commercial and industrial waste and approximately 40% of the waste stream comprises inert wastes (SKC Engineers, 2004). The closure date for the Bisasar landfill is expected to be in 2013 (Couth et al, 2010).

Figure 6.6 – Aerial view of Bisasar landfill

(Source: Google earth, 2008)

6.7 Buffelsdraai landfill site

The Buffelsdraai landfill is located approximately 8 km west of Verulam, and serves the northern region of the eThekwini Municipality. The lifespan of the landfill is estimated at 50-70 years and the waste stream comprises of general municipal solid waste. The current incoming waste stream is approximately 400 tons per day and is expected to increase to 1,500 tons of per day upon closure of the Bisasar landfill site (Payne, 2005). The landfill covers an area of 100 hectares and has an approximate airspace of 45 million m^3. Figure 6.7 presents an aerial and plan view of the Buffelsdraai landfill.

Figure 6.7 – Buffelsdraai landfill site

(Source: Payne, 2005; Google Earth, 2010)

6.8 Landfill gas recovery and CDM projects

Landfill gas recovery projects have been implemented at the Bisasar Road and Mariannhill landfill sites in the eThekwini municipality under the 'Clean Development Mechanism' (CDM). The Clean Development Mechanism (CDM) is one of three structures (the Emission Trading System (ETS); the Joint Implementation (JI) mechanism between developed countries and the CDM itself) put in place by the Kyoto Protocol. CDM projects that reduce carbon emissions and produce certified emissions reductions (CER's) may be implemented in developing countries such as South Africa. One CER is equivalent to one ton of carbon dioxide equivalents (1 tCO_2eq). These CER's are then sold to and used by developed countries that are committed to reducing carbon footprint/greenhouse gas emissions under the Kyoto Protocol. The CDM therefore serves a dual benefit in that developed countries are able to reduce emissions and implement sustainable projects/new technologies that promote economic growth, job creation and skills development. Although the carbon market is variable, CER prices are in the order of between US$ 11 and US$ 16 per CER (Couth et al, 2010).

The landfill gas CDM project was initiated by DSW in 2002 in partnership with the University of KwaZulu-Natal, and originally included the La Mercy landfill site, which has since closed in 2006. Component one comprised both the La Mercy and Mariannhill landfill sites and an Emissions Trading Purchasing Agreement with the World Bank and Prototype Carbon Fund (PCF) for a total of US$ 3.95 per CER. Despite landfill gas pumping trials not being performed at La Mercy landfill raising uncertainty of the quality and quantity of landfill gas produced, the project went ahead with the intention of eventually transferring the generator to Bisasar Road landfill. Figure 6.8 shows the Mariannhill landfill gas generation system.

Figure 6.8 – Mariannhill landfill gas generation system

(Source: Douglas, 2007)

Component two includes the Bisasar Road landfill gas to electricity project, and an Emissions Trading Purchasing Agreement with Trading Emissions Plc (TEP). The CER price in the agreement is confidential as per the agreement with TEP; however it is regarded to be profitable considering price volatility associated with the carbon market. Combustion of landfill gas has been employed at both Bisasar Road and Mariannhill landfill sites since 1996 and 2001 respectively (Couth et al, 2010). Project specifications of both components of the landfill gas CDM projects are listed in Table 6.3.

Table 6.3 – Summary of eThekwini landfill gas CDM projects

(Source: Couth et al, 2010)

Component	Project Specifications	Current Status
1 La Mercy Landfill	Installation of 16 wells in total, blower and 1000 Nm^3/hour flare. 0.5 MW generator.	Landfill Closed Project Abandoned
1 Mariannhill Landfill	Installation of 7 new wells and pipe-work to existing wells. 1000 Nm^3/hour flare. 1 MW generator.	350 m^3/hour of gas extracted 0.6 MW 16,000 CER's/year
2 Bisasar Road Landfill	Installation 50 new wells (115 vertical wells in total) and pipework. Two 2500 Nm^3/hour blowers. 2000 Nm^3/hour flare. Capacity for 8 MW generator, with 3 MW installed.	4000 m^3/hour of gas extracted. 6.5 MW. 218,000 CER's/year

6.9 Garden refuse disposal

Garden refuse sites are located throughout eThekwini, either as individual sites or as part of transfer stations. Currently, aerobic composting and other waste management methods for treatment of garden refuse is not undertaken by municipal waste service providers.

CHAPTER 7: DESCRIPTION OF CASE STUDY – uMgungundlovu DM

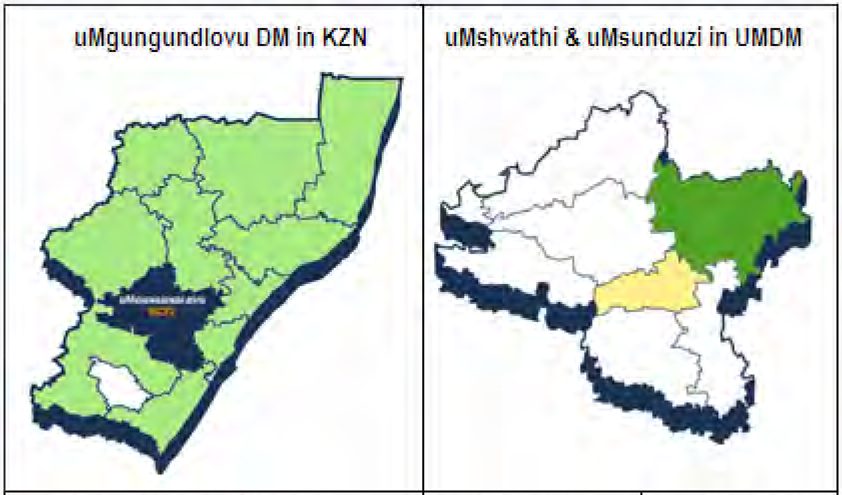
7.1 Introduction

This chapter describes the case study of the uMgungundlovu Municipality (UMDM). The UMDM is representative of South African municipalities due to the socio-economic differences among the local municipalities within the UMDM, inequitable service delivery, and current and future projects that are being planned for long term growth and sustainability with regard to waste management. Two of the largest local municipalities (uMsunduzi and uMshwathi) were selected for the study, due to the lack of data and infrastructure at waste landfill sites of other Local Municipalities (LM).

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 km^2 and encompasses areas of varying socio-economic conditions – from urban residential and commercial/industrial areas, to informal areas/shack settlements and rural, traditional areas (UMDM Corporate Profile, n.d). These areas, similar to the eThekwini municipality, have varying levels of municipal service provision. Although the UMDM has the fastest growing economy in KZN, this economic growth is largely limited to the urban areas (UMDM Corporate Profile, n.d).

7.2 Selected Local Municipalities for study: uMshwathi and uMsunduzi LM

The uMgungundlovu Municipality further comprises of 7 Local Municipalities. The municipalities chosen for the WSA are the uMsunduzi LM and uMshwathi LM which together account for approximately 71.27% of the total population of the uMgungundlovu District Municipality after the institution of new demarcation boundaries in 2005. Together uMsunduzi and uMshwathi LM comprise the majority of the UMDM population, and it is for this reason that the results of the WSA are considered representative of the UMDM as a whole. uMshwathi LM is the largest local municipality within uMgungundlovu DM and is based in New Hanover. The climatic conditions inherent to uMshwathi make it suitable for farming and agriculture, and uMshwathi contributes to 40% of the sugar cane and maize production in uMgungundlovu DM (UMDM Corporate Profile, n.d). Other contributors and activities to agricultural and industrial sector include sugar mills, nurseries and timber processing plants and tea cultivation. uMsunduzi LM, based in the city of Pietermaritzburg, is a centre for industry and manufacturing. The tourism sector contributes greatly to the economy, as the city plays host sporting events such as the Comrades Marathon and the Midmar Mile.



District/Local Municipality	Households	Population
■ uMgungundlovu DM	234 781	927 845
🟩 uMshwathi LM	27 327	108 422
🟨 uMsunduzi LM	135 329	552 835

Figure 7.1 – Location and population of UMDM, uMsunduzi and uMshwathi LM

(Source: UMDM Corporate Profile, n.d; Statistics South Africa, 2005)

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 provision of municipal waste collection services varies depending on the area. This is clearly evident from data in Table 7.1 overleaf: approximately 60% of urban (uMsunduzi) households receive waste collection services, in comparison with only 17.6% of rural households. This result once again highlights inequitable service delivery. Undercharging of municipal waste services, area accessibility (largely rural setting), aging fleets and equipment have been cited as major problems by the UMDM (Jogiat, 2010). These issues can be considered as a general characteristic in most South African municipalities, along with the lack of technical resources, human capital and restricted funding (Couth and Trois, 2011).

Table 7.1 – Household waste service provision for uMsunduzi and uMshwathi LM

(Source: Statistics South Africa, 2005).

uMshwathi Local Municipality	**No. of Households**
Removed by local authority at least once a week	4020
Removed by local authority less often	792
Communal refuse dump	647
Own refuse dump	17662
No rubbish disposal	4206
Not applicable	0
uMsunduzi Local Municipality	**No. of Households**
Removed by local authority at least once a week	80529
Removed by local authority less often	1686
Communal refuse dump	1272
Own refuse dump	47582
No rubbish disposal	4253
Not applicable	7

7.3 New England Road landfill and other UMDM landfill sites

The majority of municipal landfill sites in the UMDM do not have permits, or infrastructure such as weighbridges, and therefore information and waste data is not available. The lack of data and equipment 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. Landfill sites currently operating are listed in Table 7.2. Consequently, weighbridge data is only available for the New England Road Landfill Site in uMsunduzi.

Table 7.2 – uMgungundlovu landfill sites

(Source: Hydroplan, Aurecon, 2010)

uMgungundlovu Landfill Sites	Local Municipality Served	Remaining Lifespan (years)	Waste Disposed (tons/annum)
New England Road Landfill	uMsunduzi, uMshwathi and Mkhambathini	5	183,531
Richmond Landfill	Richmond	4	1,960
Impendle Landfill	Impendle	3	46
Mooi River Landfill	Mooi River	0	3,152
Curry's Post Landfill	uMngeni	10	10,881

The New England landfill was opened in 1950 as an open dump site, and was upgraded to an engineered landfill site in the 1980’s, in accordance with the National Environment Act (Naidoo, 2010). The New England Road landfill receives waste from both the uMsunduzi area and neighbouring municipalities of uMshwathi and Mkhambathini which do not have their own landfill sites. Waste from other municipalities is recorded as „industrial’ waste as the domestic waste category is reserved strictly for material collected from uMsunduzi (UMDM, 2009). This may lead to discrepancies in the actual quantities of domestic and industrial wastes when compared to recorded data. The landfill receives an annual average of 183,531 tons of waste in total which is equivalent to approximately 700 tons of waste per day. Approximately 250,000 m^3 of compacted waste is landfilled every year (UMDM, 2009). An aerial view of the site is presented in Figure 7.2.

Figure 7.2 – Aerial view of the New England landfill site

(Source: uMgungundlovu District Municipality, 2010)

7.4 Objectives of the Waste Stream Analysis

The waste stream analysis for the uMgungundlovu District Municipality was conducted as part of a feasibility study for an Integrated Solid Waste Management System, requested by the uMgungundlovu District Municipality Solid Waste Management Unit and the German Development Bank (Entwicklungsbank). The study was undertaken by GreenEng

Environmental Engineering at the request of the Aurecon group. GreenEng, in collaboration with the University of KwaZulu-Natal (UKZN) conducted the waste stream analysis over a two week period (19 July to 27 July 2010) at the New England Road landfill site. The primary objective of the study was to ascertain the composition of the waste stream entering the landfill and generate a general waste profile for the UMDM as this data is required to estimate annual quantities of each fraction (recyclables, biogenic, and inert wastes) which will in turn be used as input data for the carbon emissions reduction potential of various strategies in the UMDM.

7.5 Selection of waste streams and focus areas

The following waste streams/source categories were sampled and characterised:

- URBAN: High, medium and low income residential waste stream; commercial and industrial waste streams.
- RURAL: High, medium and low income residential waste stream; and commercial and industrial waste streams

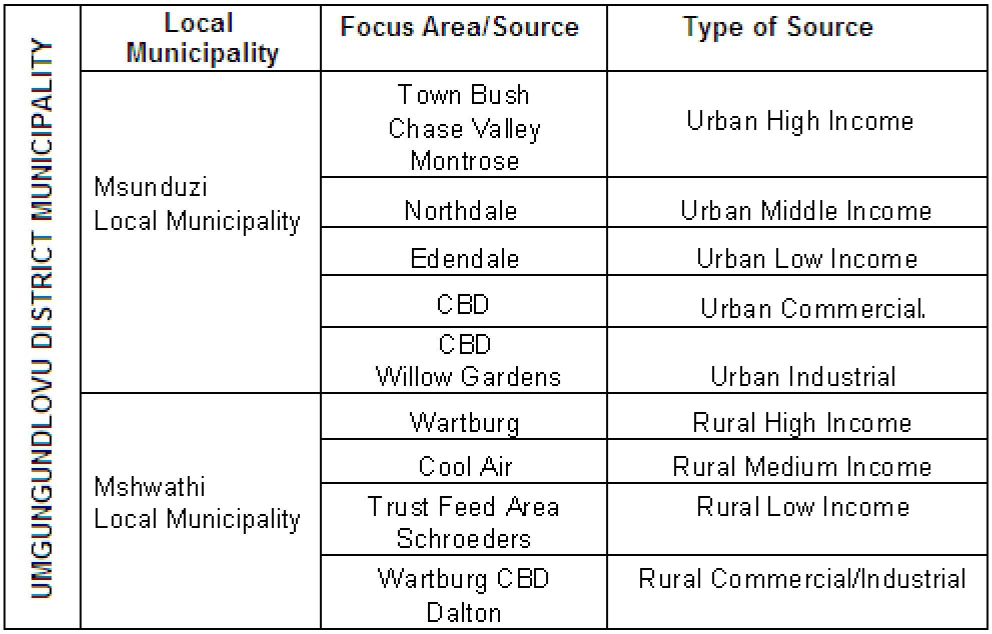
These waste streams were classified using three strata:

i. The type of waste source or activity that MSW originates from: Residential/Household, commercial and industrial waste.
ii. Area classification: Rural or urban settings.
iii. Income group (in the case of residential/household waste): low, medium and high income groups.

Residential waste comprises all municipal solid waste originating from households. Commercial waste refers to waste generated through commercial activities from businesses, shopping centres, restaurants and other similar sources. Industrial waste comprises all waste from light industrial activities such as goods manufacturing. The focus areas, listed in Table 7.3, from which loads were sampled, were selected after consultation with landfill managers, as being representative of the waste streams required to be characterised. The focus areas were then classified on the basis of monthly average income per household as per the UMDM Integrated Waste Management Plan Review

(2009): R 801-R3,200 /month (low income); R3,201-12,800/month (medium income) and upward of R12,800/month (high income).

Table 7.3 – Focus areas and source classification



UMGUNGUNDLOVU DISTRICT MUNICIPALITY	**Local Municipality**	**Focus Area/Source**	**Type of Source**
	Msunduzi Local Municipality	Town Bush Chase Valley Montrose	Urban High Income
		Northdale	Urban Middle Income
		Edendale	Urban Low Income
		CBD	Urban Commercial.
		CBD Willow Gardens	Urban Industrial
	Mshwathi Local Municipality	Wartburg	Rural High Income
		Cool Air	Rural Medium Income
		Trust Feed Area Schroeders	Rural Low Income
		Wartburg CBD Dalton	Rural Commercial/Industrial

7.6 Summary

This chapter outlined the case study area of the uMgungundlovu District Municipality. It has been established that the UMDM has varying levels of service with regard to municipal waste services, and that the New England landfill site receives an incoming waste stream generated by approximately 70% of the UMDM population. The New England Landfill site was selected for the waste characterisation study due to it being the largest landfill, and having the necessary infrastructure and data records. The complete methodological approach to both the WSA and the rest of the study is discussed in the following chapter.

CHAPTER 8: METHODOLOGY

8.1 Introduction

The primary objective of this research is to quantify environmental impacts of zero waste strategies that exclusively target specific fractions of the MSW stream of two local landfill sites: the Mariannhill landfill and the New England landfill. The methodological approach adopted in achieving this and other objectives outlined in the Introduction comprises of the following components:

i. Development of the zero waste model: the selection of zero waste strategies suitable for MSW management in South Africa and the development of possible waste management scenarios incorporating these strategies.
ii. Waste Stream Analysis (WSA): an assessment of the quality and quantity of the MSW streams of both the Mariannhill and New England landfills.
iii. Greenhouse Gas Modelling: The GHG impacts of every scenario were estimated using emissions factors and the development of a GHG quantification model/tool.
iv. Landfill space savings resulting from each scenario.
v. The potential income, capital and operating costs produced by each strategy.

The following sections detail the development of the zero waste model and the various models, methods and tools considered for the final selection of the methodological approach for each of the above components.

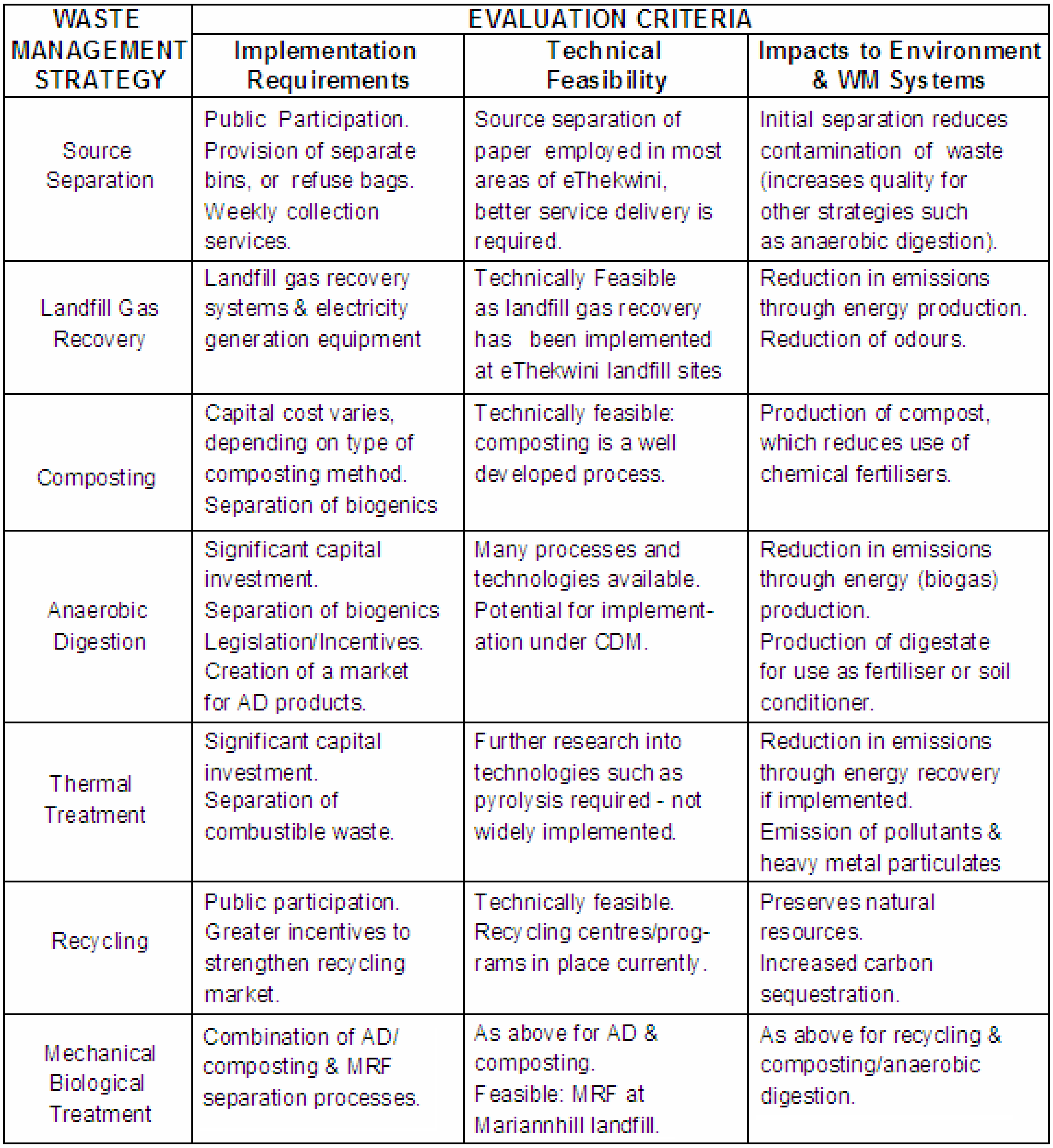
8.2 Development of the zero waste model

The zero waste model was developed exclusively on the premise of a dry-wet waste diversion model. The model simulates several scenarios that may be implemented or are currently implemented at municipal level for effective waste diversion from landfill disposal

8.2.1 Selection of MSW strategies

A desktop study of waste management methods and technologies was undertaken to identify potential zero waste strategies to be evaluated in various waste management scenarios. The selection criteria for this initial assessment of strategies, presented in Table 8.1, were the implementation requirements, technical feasibility, and impacts to the environment and waste management systems.

Table 8.1 – Assessment of waste management alternatives



WASTE MANAGEMENT STRATEGY	EVALUATION CRITERIA		
	Implementation Requirements	Technical Feasibility	Impacts to Environment & WM Systems
Source Separation	Public Participation. Provision of separate bins, or refuse bags. Weekly collection services.	Source separation of paper employed in most areas of eThekwini, better service delivery is required.	Initial separation reduces contamination of waste (increases quality for other strategies such as anaerobic digestion).
Landfill Gas Recovery	Landfill gas recovery systems & electricity generation equipment	Technically Feasible as landfill gas recovery has been implemented at eThekwini landfill sites	Reduction in emissions through energy production. Reduction of odours.
Composting	Capital cost varies, depending on type of composting method. Separation of biogenics	Technically feasible: composting is a well developed process.	Production of compost, which reduces use of chemical fertilisers.
Anaerobic Digestion	Significant capital investment. Separation of biogenics Legislation/Incentives. Creation of a market for AD products.	Many processes and technologies available. Potential for implement-ation under CDM.	Reduction in emissions through energy (biogas) production. Production of digestate for use as fertiliser or soil conditioner.
Thermal Treatment	Significant capital investment. Separation of combustible waste.	Further research into technologies such as pyrolysis required - not widely implemented.	Reduction in emissions through energy recovery if implemented. Emission of pollutants & heavy metal particulates
Recycling	Public participation. Greater incentives to strengthen recycling market.	Technically feasible. Recycling centres/prog-rams in place currently.	Preserves natural resources. Increased carbon sequestration.
Mechanical Biological Treatment	Combination of AD/ composting & MRF separation processes.	As above for AD & composting. Feasible: MRF at Mariannhill landfill.	As above for recycling & composting/anaerobic digestion.

The above assessment was based on the following sources: Smith et al (2001); Monnet (2003); Ostrem (2004); US EPA (2006) WRAP (2006); Douglas (2007); Oelofse (2009); van Haaren (2009); Matete (2009); and Trois and Simelane (2010). The strategies that formed the basis of the model were selected using the assessment in Table 8.1. These strategies were:

i. Mechanical pre-treatment of unsorted, untreated MSW through an MRF.
ii. Recycling of the recyclable dry fraction.
iii. Biological treatment: composting/anaerobic digestion of the wet biogenic fraction.
iv. Landfilling of all waste or residual wastes, with landfill gas recovery.

Source separation was not considered in the model as source separation in South African municipalities is not financially feasible (Douglas, 2007). Thermal treatment of MSW was not selected due to the uncertainties with new technologies and the pollutants produced through treatment of MSW (Smith et al, 2001).

8.2.2 Rationale for selection of landfill sites

As discussed in Chapter 1, 6 and 7, the eThekwini municipality and the UMDM were selected due to their representation of other South African municipalities in terms of socio-economic parameters, MSW service delivery and current and future projects planned for development of MSW management systems. The Mariannhill landfill was selected from the three eThekwini landfills due to the facilities and projects implemented on site, specifically, the MRF and landfill gas recovery system. The site is therefore somewhat representative of an integrated waste management approach and the analysis assesses the current environmental benefits of MRF operations and recycling recovery rates. The New England Road landfill was selected for the UMDM case study, as it is the largest landfill and serves approximately 71.27% of the total UMDM population as highlighted in Chapter 7. The WSA of the New England Road landfill can therefore be considered as representative of the UMDM waste stream as a whole. Both the Mariannhill (160,373 tons/annum) and New England landfill (183,531 tons/annum) waste streams are also of comparable size.

8.2.3 Simulated waste management scenarios

The scenarios for assessment reflect different combinations of waste diversion strategies or treatment methods that include elements of current waste disposal in South African municipalities (landfilling and landfill gas recovery) as well as potential waste management strategies as previously outlined (recycling, anaerobic digestion and aerobic composting). Each scenario is applied at municipal level, to the incoming waste streams of the Mariannhill and the New England Road landfills. The objective of conducting a CER assessment that reflects current operations at both landfill sites is essential to determine the performance of the current waste management system and comparing the status quo with other potential waste management strategies. A summary of each scenario and the waste management strategies evaluated is presented in Table 8.2 below and detailed definitions are discussed in the sections thereafter.

Table 8.2 – Summary of waste management scenarios

SCENARIO	**Waste Management Strategy**				
	Landfill Disposal	Landfill Gas Recovery	Anaerobic Digestion	Aerobic Composting	Recycling MRF
1*	✓				
2	✓	✓			
3**	✓	✓			✓
4	✓	✓	✓		✓
5	✓	✓		✓	✓
* Status Quo of New England Road Landfill ** Status Quo of Mariannhill Landfill					

8.2.3.1 Scenario one: Landfill disposal of unsorted, untreated MSW

This scenario evaluates landfill disposal of all incoming MSW at both landfill sites, as is the status quo at most municipal landfill sites in South Africa. Although the Mariannhill landfill site has both an MRF and landfill gas recovery systems in place, scenario one is included to provide a baseline for comparing the efficiency of landfill gas capture and the current MRF recovery/diversion rate of recyclables to landfilling. There is currently no other waste diversion/treatment method or landfill gas recovery employed at the New England Landfill site, and thus scenario one reflects the status quo of waste disposal in the UMDM.

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

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 scenario is intended to assess the efficiency of the landfill gas recovery with energy generation in comparison with biological treatment options for the biogenic fraction.

8.2.3.3 Scenario three: MPT, Recycling and landfill gas recovery

Scenario three comprises of mechanical pre-treatment, landfilling of the biogenic and residual waste while recyclables are sorted, baled and sold to local private recycling companies. Landfill gas is recovered and converted into electricity. This scenario represents the status quo of the Mariannhill landfill that currently has both an MRF and a landfill gas recovery system thus diverting recyclables from landfill disposal and capturing methane gas produced through degradation of biogenic waste. Currently, the Mariannhill MRF recovers between 9-13% of recyclables (DSW, 2010). Both the current rate (9.82%) and a 40% recovery rate were considered for the eThekwini Municipality to provide a comparison between the current and potential rates that can be targeted through various initiatives such as increased public awareness and participation with regard to separation of garden refuse from household waste to prevent contamination and the identification and diversion of loads that yield high recyclables (in particular commercial and industrial loads). A 40% recovery rate was considered for the New England waste stream, as well as all further scenarios considering recycling for both municipalities. This recovery rate is in accordance with the targets of the Polokwane declaration (an increase of 30% in recycling) (Austin and Gets, 2009).

8.2.3.4 Scenario four: MBT – anaerobic digestion and recycling

This scenario evaluates the mechanical separation and pre-treatment of both biogenic and recyclable fractions through an MRF facility. The recyclable fraction is sorted, baled and sold to local private recycling companies, while the biogenic fraction of the waste stream is anaerobically digested to produce biogas electricity. All residual inert waste is landfilled. Biological treatment of biogenic waste also falls under possible projects that can be implemented under the CDM.

8.2.3.5 Scenario five: MBT – aerobic composting and recycling

This scenario evaluates mechanical separation and pre-treatment of biogenic and recyclable fractions through an MRF. The recyclable fraction is sorted, baled and sold to private recycling companies and the biogenic fraction is composted. The DAT composting method was selected as the most appropriate technology to be applied within the waste management structure of South African municipalities in terms of cost and efficiency (Trois and Simelane, 2010).

Figure 8.1 illustrates a schematic of all scenarios and strategies.

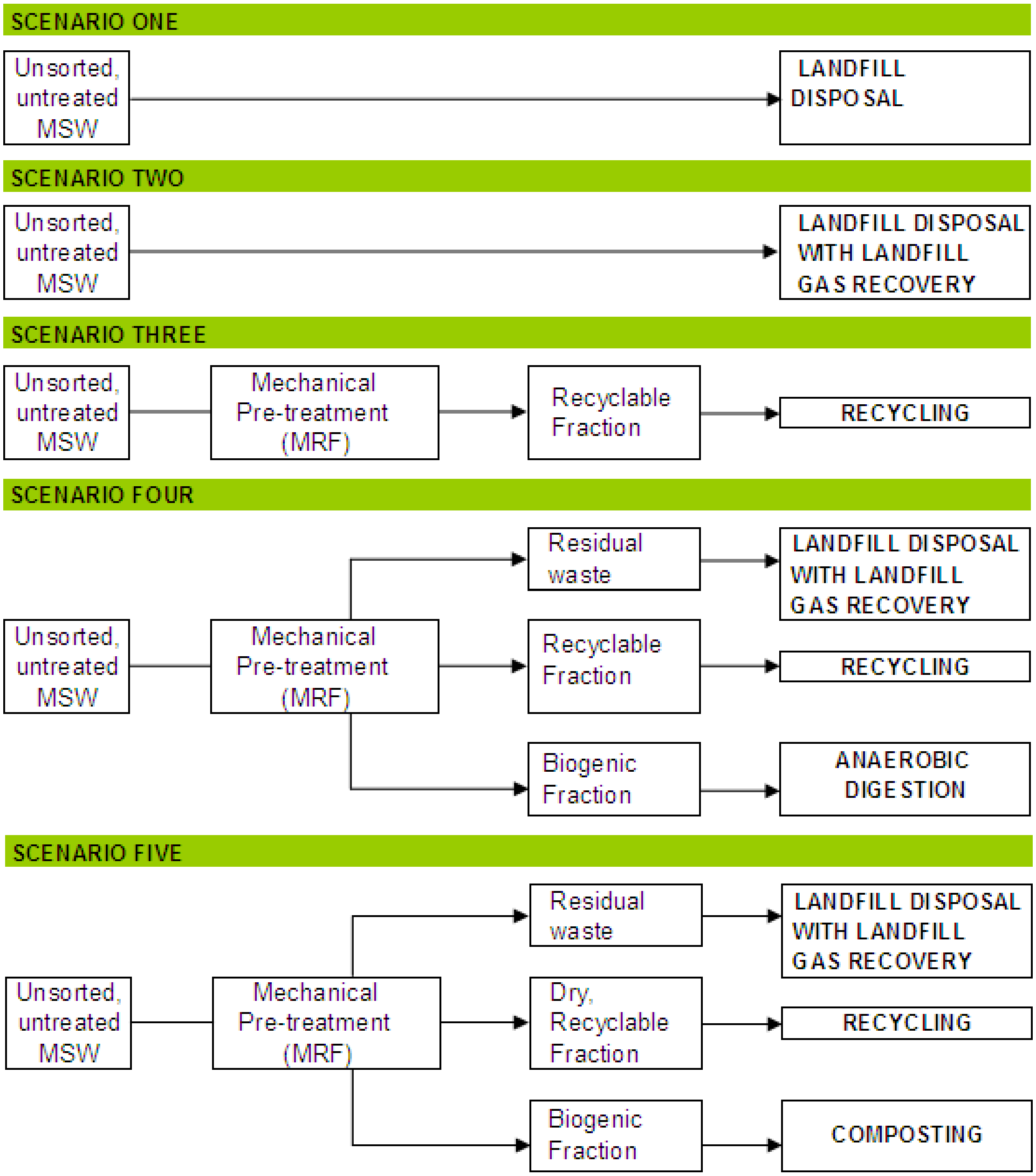


Figure 8.1 – Schematic summary of scenarios

8.3 Waste Stream Analysis approach

8.3.1 Introduction and objectives

A waste stream analysis determines the composition and the nature of the waste stream in a particular area or region. This information is essential in designing an integrated waste management system as it:

i. Determines and classifies the specific fractions of the MSW stream and therefore the types of strategies that should be considered in the planning of waste management systems (Cascadia, 2009).
ii. Determines the quantity of waste and individual fractions allowing waste managers to assess the feasibility of implementing waste management strategies such as recycling. The implementation of recycling schemes, anaerobic digestion and other treatment methods is dependent on the quantity and quality of each fraction of waste to be treated (Gaillot et al, 2005).
iii. Determines the size and capacity of infrastructure required for particular waste management strategies, for instance, the size of an anaerobic digestion plant is determined by the annual tonnage of biogenic wastes (Reinhart and McCauley-Bell, 1996).
iv. Produces data for statistics reporting and waste information systems for use in research, modelling, and future projects (Purnell, 2009).
v. Assesses the performance of current waste management strategies and programs such as recycling centres, by determining the fraction of recyclables that is being landfilled rather than recycled (Purnell, 2009).

WSA is therefore necessary for the planning and design of waste management systems, the subsequent assessment of the efficiency of such systems and for information and statistics reporting which is especially lacking in developing countries as far as current and up to date data is concerned.

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 implementation of a standardized WSA methodology will assist in determining the composition of waste generated.

8.3.2 Waste Stream Analysis methodology selection

There are currently two approaches to WSA, namely, a materials flow approach, and a site specific study or output approach (Reinhart and McCauley-Bell, 1996). The materials flow approach generates waste composition data based on the expected life cycle of products that end up in the waste stream. Production data of materials and products as well as import and export data is reviewed to produce waste composition of waste streams (US EPA, n.d). This approach is preferred for waste characterisation on a regional or national level, as information on a macro-scale is easily available. The materials flow approach does not take into account wastes and materials that are not manufactured, such as garden refuse (Reinhart and McCauley-Bell, 1996).

Site specific waste analysis is a direct approach to waste characterisation and involves the sampling, sorting and weighing of individual waste stream material/product categories (Tchobanoglous et al, 1993). The site specific approach is well suited to determining the composition and quantities of waste in local waste streams, as there is less chance of waste categories being excluded (US EPA, n.d). Careful planning and design of the sampling procedures is required in order to produce valid results that are representative of the actual waste stream.

The site specific method is ideal for achieving the study objectives as it includes all waste categories (greater level of accuracy in assessing waste composition) and also due to the fact that the study is localised – limited to local landfill sites.

8.3.3 Reviewed site specific/output studies and methodologies

Site specific waste stream analysis or waste characterisation studies conducted around the world were reviewed during the literature survey of methodologies in preparation for the design and planning of the sampling methodologies. These studies are listed in Table 8.3.

Table 8.3 - Waste characterisation studies reviewed

Reference	Country	Year	Waste Quant.	Waste Comp.	Level of Sampling	Approach
Gaillot et al *Environmental Protection Agency. Program for Municipal Waste Characterisation Surveys*	Ireland	2005	✓	✓	Households Businesses Waste collection bins Refuse collection vehicles	Sample size and units selected Local survey areas selected on basis of urbanisation level and waste collection system Selection of waste sampling areas Planning of survey and waste sampling schedules Statistical analysis and scaling up methodology applied to generate national waste profile.
Sky Valley Associates and Cascadia *Waste Stream Analysis: Clark County*	Washington, USA	2003	✓	✓	Households Refuse collection vehicles Self haul vehicles	Sub streams of waste defined (residential, commercial and self haul wastes) Planning of surveys, sampling areas and schedules Sample collection and sorting Statistical analysis and waste profiling
Purdy and Sabugal *Waste Composition Study for the City of Davao*	Mindanao, Philippines	1999		✓	Refuse collection vehicles Self haul vehicles	Landfill specific study Random collection trucks selected for sampling Number of truck recorded for geographic purposes to determine the area the waste was collected from Sampling of wastes Data processing (no statistical analysis)
Cascadia *California Statewide Waste Characterisation Study*	California, USA	2009	✓	✓	Households Refuse collection vehicles Self haul vehicles Businesses	Sub streams of waste defined (residential, commercial and self haul wastes) Selection and recruitment of sites Planning of survey and site scheduling and logistics Sample collection and sorting Statistical analysis and scaling up methodology applied to generate state waste profile.

Study	Country	Year	Waste Quant.	Waste Comp.	Level of Sampling	Approach
Cascadia and DSM. *DSWA Statewide Waste Characterisation Study*	Delaware, USA	2007	✓	✓	Households Refuse collection vehicles Self haul vehicles Businesses	Sub streams of waste defined (residential, commercial and self haul wastes) Selection of waste sampling areas (Landfill sites and transfer stations specified in brief) Planning of survey and sampling methods Sampling over a 12 month period Statistical analysis and scaling up methodology applied to generate state waste profile.
Cascadia *Wisconsin Statewide Waste Characterisation Study*	Wisconsin USA	2003	✓	✓	Refuse collection vehicles Self haul vehicles	Sub streams of waste defined (commercial and self haul) Sampling Allocation to various waste disposal facilities Planning of survey and waste sampling schedules Sample collection and sorting over two 14 day periods in summer and winter Statistical analysis and scaling up methodology applied to generate state waste profile.
Ojeda-Benitez et al. *Characterisation and Quantification of Household Wastes in a Mexican City*	Mexicali, Baja California Mexico	1999/ 2000	✓	✓	Households	114 households randomly sampled (total of 1598 in Mexicali) over a 16 week period. Sampling and weighing of wastes Statistical analysis
City of Toronto Policy Planning Group. *Waste Composition Study of Multi-Family Households Receiving Collection of Source Separated Organics*	Toronto Canada	2003	✓	✓	Households	246 households receiving source separated waste collection services over a two week period. Sampling and weighing of wastes Statistical analysis

A general trend among larger scale solid waste stream analysis studies was the identification of strata for waste characterisation (Gaillot et al, 2005; Cascadia, 2009). The categories for waste composition were defined using these strata, and included:

- Level of urbanisation in area (urban, rural area).
- Waste collection type (single or multiple bins, refuse bags, self hauled waste).
- Waste sub-stream or sub-sector (residential, commercial, industrial, or self hauled).

With regard to actual sampling methods, trends noted were the selection of the „n$^{\text{th}}$' refuse vehicle for sampling (Gaillot et al, 2005; Cascadia, 2009). This method of „systematic sampling' ensures random sampling, and is determined by the total number of refuse vehicle loads expected in a single day divided by the total number of samples required per day. Refuse vehicle drivers and workers are interviewed as they are most likely to be able to determine „abnormal' or unusual loads, which are not sampled due to variability. Waste loads are laid out on designated areas of the landfill/waste disposal facility, separated into categories and weighed. Each sample is approximately 200 pounds (90kg). Waste surveys are also conducted with self haul vehicles entering waste disposal sites and commercial and industrial sector waste surveys are carried out through restaurants, retail stores, supermarkets, businesses and factories. The data collected is used to generate waste composition profiles by sector, which in turn is used to produce annual tonnages of waste. The sampling periods in the literature survey reviewed varied between 2-3 weeks and year long surveys, where sampling occurs on selected days during each season to account for seasonal variations. The site specific methodology adopted for the waste stream analysis of the New England landfill is discussed fully in section 8.4.

8.4 Waste Stream Analysis Methodology

8.4.1 Planning and design of Waste Stream Analysis

The methodological approach toward the WSA of the New England Road MSW stream was researched extensively after which a „site specific' approach was selected. This approach entails physical sampling, sorting and characterisation of waste streams from the selected focus areas. The principal fractions of the waste stream that were focused on where „recyclables' and „biogenic' wastes, as these fractions present greatest potential for recovery, re-use, and waste to energy strategies. The WSA was planned and designed with the assistance of landfill and waste managers from both the uMshwathi and uMsunduzi LM. A schedule of the number and type of loads and the respective collection areas was drawn up with the assistance of municipal managers for each sampling day of the 2 week study period (19 July – 01 August 2010). The sampling of loads was conducted by a team of „waste recovery pickers’. The team comprised of 3 supervisors/trained staff from the Mariannhill Materials Recycling Facility. Several local waste pickers were employed for assistance during the study period, and were trained and instructed on how to recognize, classify and separate recyclables and other waste fractions.

8.4.2 Waste classification categories

The waste classification system (shown in Table 8.4) used in the sorting and separation of the samples was based on guidelines given by the Integrated Waste Management Plan (IWMP) guidelines (eThekwini IWMP, 2004; City of Cape Town IWMP, 2004). The main categories under which waste was classified were Paper and Cardboard, Plastic, Glass, Metals and Biogenic waste. These waste groups were considered „priority wastes’ due to the potential for recycling, anaerobic digestion and aerobic composting.

Table 8.4 – Waste classification utilised during sampling

(Source: Adapted from eThekwini IWMP, 2004 and City of Cape Town IWMP, 2004)

Paper and Cardboard		
Newspaper	Heavy Letter 1 (HL1: Clean White Paper)	
Common Mixed Waste	Scrap Boxes and Cardboard - K4	
(CMW: General mixed paper)	Tetra Pak (Juice/Milk Cartons)	
Plastic		
Low density polyethylene	(LDPE: Packaging films; shrink wrap)	
High density polyethylene	(HDPE: juice bottles; vest shopping bags)	
Polyethylene-terephthalate	(PET: Clear soda/drinks bottles)	
Polypropylene	(PP: Yoghurt; margarine, icecream containers)	
Polyvinyl chloride	(PVC: Sewage pipes; cable insulation)	
Polystyrene	(PS: Packaging; take away cutlery, crockery)	
Glass	**Metals**	
Green glass bottles and containers	Cans (Steel/Tin)	
Brown glass bottles and containers	Beverage cans (Aluminium)	
Clear glass bottles and containers	Other metals (Scrap metal; copper wire)	
Biogenic Wastes	**Other Wastes**	
Organic food wastes (Putrescibles)	Wood waste	Electronic waste
Garden refuse: green waste	Tyres	Batteries
Garden refuse: woody waste	Textiles, Cloths	

8.4.3 Equipment and materials

The equipment and tools used (shown in Figure 8.2) for safe and efficient handling and separation of waste included:

- Spades, pitch forks, brooms and picking tools
- Buckets/plastic containers for collecting and weighing separated wastes.
- Digital scale for weighing individual samples and waste fractions.
- Cleaning materials: buckets, liquid soap and scrubbing brushes for daily cleaning of tools, Tables and work surfaces.
- Health and safety personal protective equipment (PPE). Each team member was issued with a PPE kit which included reflective jackets, protective gloves and masks. In addition, the team was briefed on the use of equipment and the protective measures that should be taken to ensure their safety when handling waste.

Figure 8.2 – Equipment/materials used and truck drivers being interviewed

8.4.4 Sampling methodology

Designated waste truck loads were assigned to the research team by the landfill manager daily and were diverted to a demarcated area on site. The trucks would empty loads, and drivers would be consulted regarding waste collection areas, and any unusual and unrepresentative loads collected.

Loads were sampled using a „quarters' approach (Tchobanoglous et al, 1993). Each load to be sampled is quartered after which one of the „quarters' is quartered, and so on until a sample size of approximately 200 kg was produced. This approach is regarded as a random method of sampling (Tchobanoglous et al, 1993). Once the samples were acquired the team set about sorting and separating recyclables, biogenic wastes and other predetermined waste fractions. A typical waste sample is presented in Figure 8.3.

Figure 8.3 – A typical 200 kg waste sample

Figure 8.4 overleaf presents some of the waste fractions identified from sampling the MSW stream. The fractions were then weighed and individual fraction weights recorded.

Polystyrene
Textiles
HDPE plastics
Newspaper
PET plastics
Glass (green)
Beverage cans
Scrap boxes (K4)
Batteries

Figure 8.4 – Specific waste fractions identified during sampling

Residual (indeterminable waste remaining waste after recyclables and other large items were removed) waste that could not be separated consisted of contaminated paper, mixed plastics, fine organics, soil and other inert materials. The residual waste was characterised by a residual waste analysis. This approach was adopted due to time constraints, as sorting of residual waste required an excessive amount of time as determined on the first day of sampling. A random sample (75 litres) was selected from the residual waste, weighed, and then sorted into individual fractions of plastic, paper and cardboard, glass, food waste, and garden refuse. These fractions were weighed and the fraction percentage of each of the categories was then calculated. This percentage was then used to determine the fraction composition of the residual waste, and the overall contribution to the

200 kg sample. The residual waste analysis was considered the most accurate approach in the characterisation of the residual waste and therefore the entire sample as a whole. All data was recorded and electronically transferred. The overall approach to sampling is illustrated in Figure 8.5.

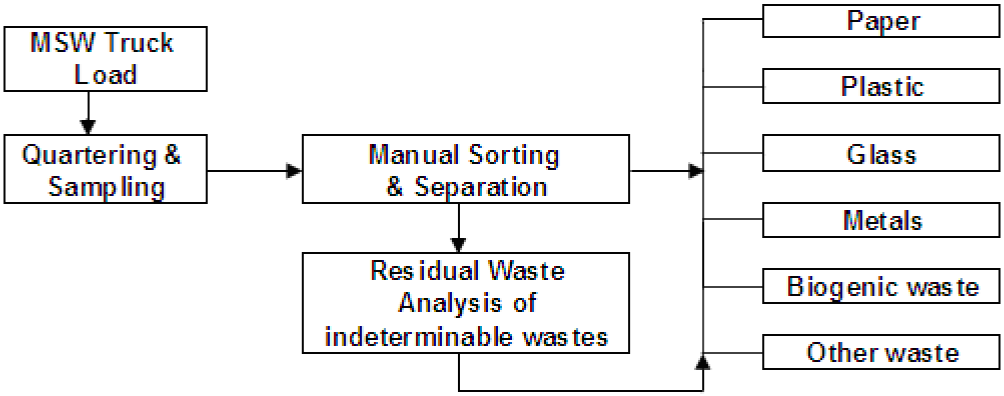


Figure 8.5 – Schematic of sampling procedure

Once all the designated loads were sampled, all equipment was cleaned and stored in preparation for the next day of sampling. The sorted waste was then cleared and removed as per arrangement with the landfill manager, illustrated in Figure 8.6.

Figure 8.6 – Waste removal from demarcated work area after sampling

8.4.5 Approach to data analysis

The studies reviewed in section 8.3.2 were conducted on a much larger scale (nation wide waste characterisation) and therefore more than one waste facility/landfill site was selected for sampling, obviously producing a greater number of samples. The samples (a total of 74) that were categorised in the UMDM WSA are, however, are believed to be representative of the incoming landfill MSW waste stream as generally consistent results were obtained from the random sampling of waste loads from the same area. The composition for each fraction of the MSW stream for each component sub-stream (urban high income, rural low income, rural commercial and so forth) was obtained by summing the total fraction composition weight for an individual fraction across all samples for the particular waste sub-stream and dividing by the total weight of all samples from the waste sub-stream, as per the methodology used in the California Statewide 2009 Waste Characterisation Study (Cascadia, 2009). The equation is presented below:

$$r_j = \frac{\sum_i c_{ij}}{\sum_i w_i} \quad \text{X} \quad 100\%$$

Where C_{ij} = individual fraction weight

W_i = sample weight

i = 1 to n where n = number of samples

j = 1 to m where m = number of individual fractions

Once the overall percentage compositions of each specific fraction of the waste stream was calculated, the data was presented in the form of pie charts illustrating the general fractions (recyclables, biogenic and other waste), the specific fractions (K4, HL1, LDPE etc.) and finally an overall waste profile (Plastic, Paper and Cardboard, Glass, Metals, Biogenic and Other waste fractions) for each waste stream characterised. The compositions were then applied to waste generation data from the UMDM IWMP Terms of Reference Report (2009) in order to calculate annual quantities of waste fractions generated in the UMDM.

8.5 Carbon emissions/reduction assessment

GHG emissions are measured in metric tons of carbon dioxide equivalents ($MTCO_2eq$). GHG emissions of other gases are converted into $MTCO_2$ by multiplying by the GWP of the particular gas. The challenge in GHG accounting is making assumptions based on various factors and conditions that affect both emissions and reductions throughout the life cycle of discarded waste. Many countries such as Australia, United States of America and Canada have formulated emissions databases and factors for material groups and specific waste management methods that quantify emissions/reductions (Smith et al, 2001). A wide range of GHG accounting and modelling software has also been developed for this purpose. Many of these models use Life Cycle Assessment (LCA) principles to quantify emissions generated throughout a product or materials life span (Friedrich and Trois, 2010). Life Cycle Assessment (LCA) is a methodology or tool used to evaluate and analyse environmental impacts of products, processes or systems. The scope of activities may include acquisition of virgin materials, manufacturing processes, transportation and distribution through to product use and disposal by the user (Craighill and Powell, 1996). LCA is used to identify environmentally friendly processes and products, evaluate operational systems, design choices and associated environmental impacts (Craighill and Powell, 1996). Environmental impacts may include a range of categories such as global warming impacts, acidification, eutrophication, and toxicity.

The models that were identified and evaluated for use in this study were:

- Municipal Solid Waste Decision Support Tool (MSW-DST)
- Waste and Resources Assessment Tool for the Environment (WRATE)
- Waste Reduction Model (WARM)
- Environmental Assessment of Solid Waste systems and Technologies Model (EASEWASTE)
- Integrated Waste Management Model (IWM)

8.5.1 Methodology alternatives

Each of the approaches to GHG quantification was evaluated before selecting the approach most appropriate for this study.

8.5.1.1 Municipal Solid Waste Decision Support Tool (MSW-DST)

The Municipal Solid Waste Decision Support Tool was developed by the United States Environmental Protection Agency (US EPA) with the intention of modelling both costs and environmental impacts of waste management activities using life cycle inventories (US EPA, 2006). These activities include waste generation, collection, transfer, separation, composting, thermal treatment and landfill disposal. The model divides MSW generated by sector, thus the total quantity of waste from each sector is required as input data. The MSW-DST is used fundamentally as a decision making tool that assists in evaluating costs; calculating reductions in GHG emissions and pollutants (Thornloe et al, 2001).

8.5.1.2 Waste and Resources Assessment Tool for the Environment (WRATE)

The WRATE model uses a life cycle analysis approach to evaluate environmental impacts of various waste management scenarios and includes waste management activities such as, collection, transport and disposal. The model employs a „gate to the grave' LCA analysis, where the life cycle of the waste product begins when the waste is discarded by the user and ends at its final point of recovery or disposal (Environment Agency Wales, 2009). This approach simplifies the process by only modelling impacts that arise as a result of waste management activities specifically. These impacts include acidification, eutrophication, global warming, resource depletion, human toxicity and aquatic toxicity.

8.5.1.3 Waste Reduction Model (WARM)

The Waste Reduction Model was created by the US EPA with the aim of calculating the benefits of alternative waste management strategies such as recycling, incineration, composting, source reduction and landfill disposal (US EPA, 2006). I. The model is intended to assist waste managers and organisations providing a comparative analysis of various waste management strategies against a baseline scenario (US EPA, 2006). WARM uses emission factors researched and continuously updated by the US EPA. These emission factors were determined using life cycle inventory for material production, transport, treatment and disposal.

8.5.1.4 Environmental Assessment of Solid Waste systems and Technologies Model (EASEWASTE)

The Easewaste model was developed by the Technical University of Denmark. The model uses material flows and life cycle inventory to evaluate environmental impacts (emissions to soil, air and water sources) of waste management activities including biogas production from anaerobic digestion of biogenic wastes.

8.5.1.5 Integrated Waste Management model (IWM)

The Integrated Waste Management model was developed with the intention of providing a tool that assesses environmental impacts and economic implications of waste management activities for municipalities. The model consists of two modules: a life cycle inventory module and an economic analysis module (Haight, 2004). Although the IWM model is calibrated for Canadian use, it is still widely used as it is made freely available by its developers (Environment and Plastics Industry Council, Environment Canada and Corporations Supporting Recycling).

8.5.2 Selection of GHG quantification method:

The main criteria for the evaluation of the methods included the following:

- Availability: the terms and conditions required to be met by users, and whether models are freely available for public use.
- Scope of the model: the specific waste management options/strategies and individual waste streams evaluated.
- User friendliness: provision of detailed instruction manuals, online or other user support, knowledge/skills required to operate model.
- Transparency of the models calculations, emissions factors and other parameters used to quantify GHG emissions.

The results of this evaluation follow in Table 8.5 overleaf.

Table 8.5 – Evaluation of GHG quantification models

Model/Software	**Developer**	**Availability**	**Scope**	**User Friendliness**	**General**
Municipal Solid Waste Decision Support Tool	RTI International	Not freely available	Anaerobic digestion not evaluated	MS Excel spreadsheet	Peer reviewed Uses US emissions data
Waste and Resources Assessment Tool for the Environment (WRATE)	UK Environment Agency	Subscription required for access	Anaerobic digestion not evaluated	Technical support available User manual available	Peer reviewed UK and European emissions data used in model
Integrated Waste Management Model (IWM)	University of Waterloo EPIC CSR	Freely available Registration online	All major waste management strategies evaluated	MS Excel spreadsheet User manual and online support available	Peer reviewed Developed for municipalities Canadian, US and European data used in model
Waste Reduction Model (WARM)	United States Environmental Protection Agency (US EPA)	Freely available from US EPA website	Anaerobic digestion not evaluated	MS Excel spreadsheet User manual and online support available	Only model that evaluates source reduction Uses US emissions data
Environmental Assessment of Solid Waste Systems and Technologies Model	Technical University of Denmark	Not freely available	All major waste management strategies evaluated	No information available regarding format User manual available	Peer reviewed Uses Danish emissions data

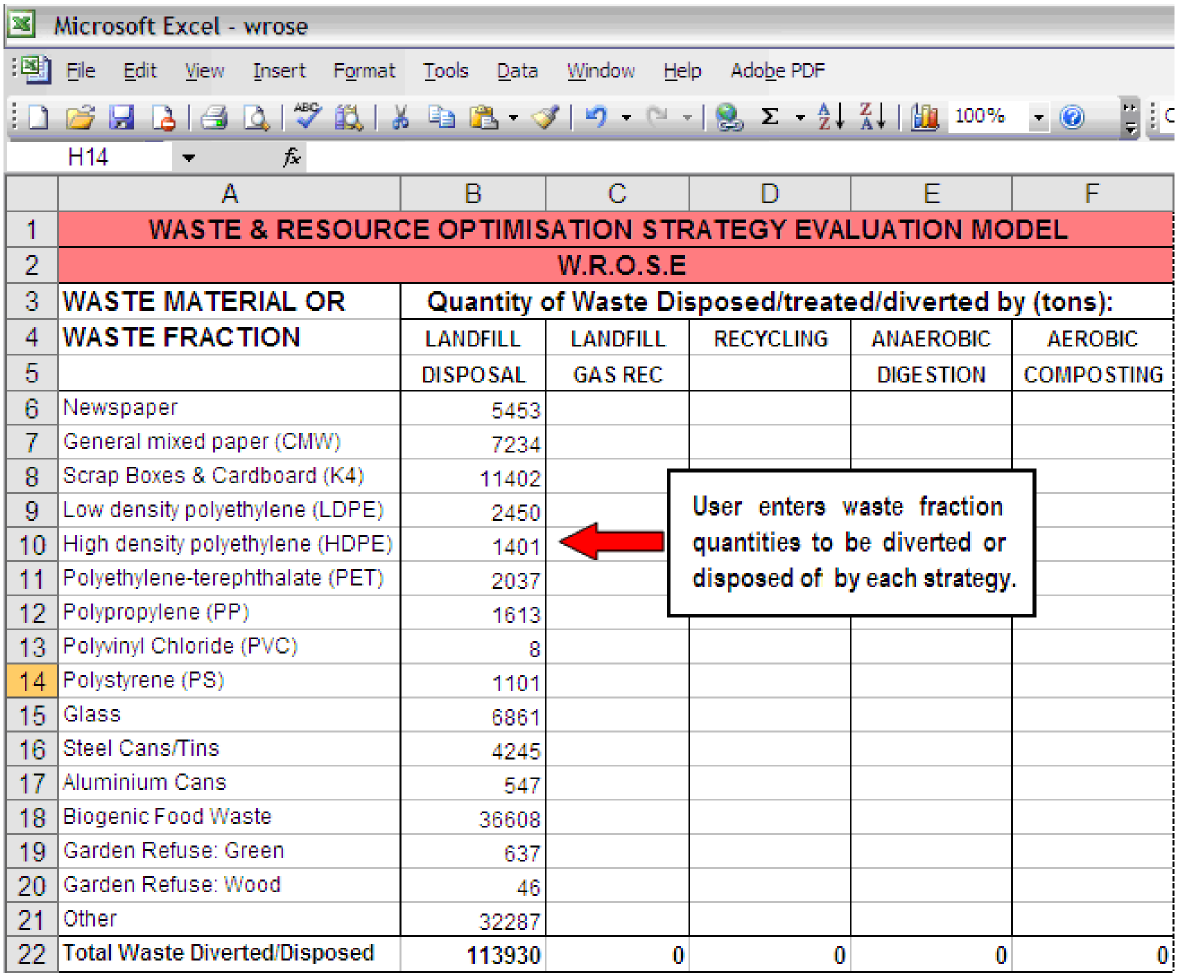
In some cases, models could not be obtained freely, and thus criteria such as user friendliness were evaluated based on available reviews and literature. From the methods and models reviewed the most appropriate models are the EASEWASTE model and IWM model as these take into account the environmental impacts of anaerobic digestion. The EASEWASTE model is well documented but not freely available. The model is administered by the Technical University of Denmark, and authorisation for use of the model requires training at the university itself. Due to these constraints, the EASEWASTE model could not be used.

The IWM model was also considered a suitable model, as it is freely available and the scope of the model extends to modelling environmental impacts including GHG emissions, and pollutants of all waste management strategies considered in the study. The single limiting factor in using the IWM model was the lack of transparency – the user isn't able to determine the emissions calculation process with certainty, and while the model manual supplies information concerning the system boundaries and impacts considered for each strategy it fails to provide the user with an exact methodology of how emissions are calculated. A trial analysis (refer to Appendix E, Table E7) conducted using the IWM model, showed that landfilling produces fewer emissions than landfilling with landfill gas recovery (with energy generation) of the very same input waste quantity and composition – which is an incorrect result. Another study by Mohareb et al (2008) also found that the model underestimated GHG reductions from electricity generation through biogas, and therefore does not fully account all the benefits of anaerobic digestion. Inconsistencies such as the global warming potential of N_2O being considered as 331 by the model, when IPCC GHG accounting methodology considers the value to be 310 also make the model less favourable (Mohareb et al, 2008).

Due to the evident limitations, a unique approach was required to quantify the emissions from each scenario. The emission factors developed by the US EPA for landfilling, landfill gas recovery, recycling and composting, and together with an estimated emission factor for anaerobic digestion were used to produce a spreadsheet model called the Waste and Resource Optimisation Scenario Evaluation (WROSE) model. The model views waste as a potential „resource' and evaluates the GHG emission reductions due to the products (recycled products, energy and compost) produced or harnessed from applying waste diversion strategies to the MSW stream. Although the emissions factors have been obtained from two different sources, they have been determined using the same principles of life cycle analysis, and IPCC guidelines for GHG accounting. For the objective of the study, which is, to provide a comparative assessment of various waste management scenarios, the model is considered a suitable methodology for carbon emissions/reductions assessment. A conservative approach was adopted in the determination of this factor for anaerobic digestion.

8.5.3 The Waste and Resource Optimisation (WROSE) Model

The Waste and Resource Optimisation Scenario Evaluation model developed in this study evaluates GHG emissions from various waste management strategies including landfilling, landfill gas recovery, recycling, anaerobic digestion and aerobic composting. The WROSE input screen uses a Microsoft Excel spreadsheet interface as shown in Figure 8.7.



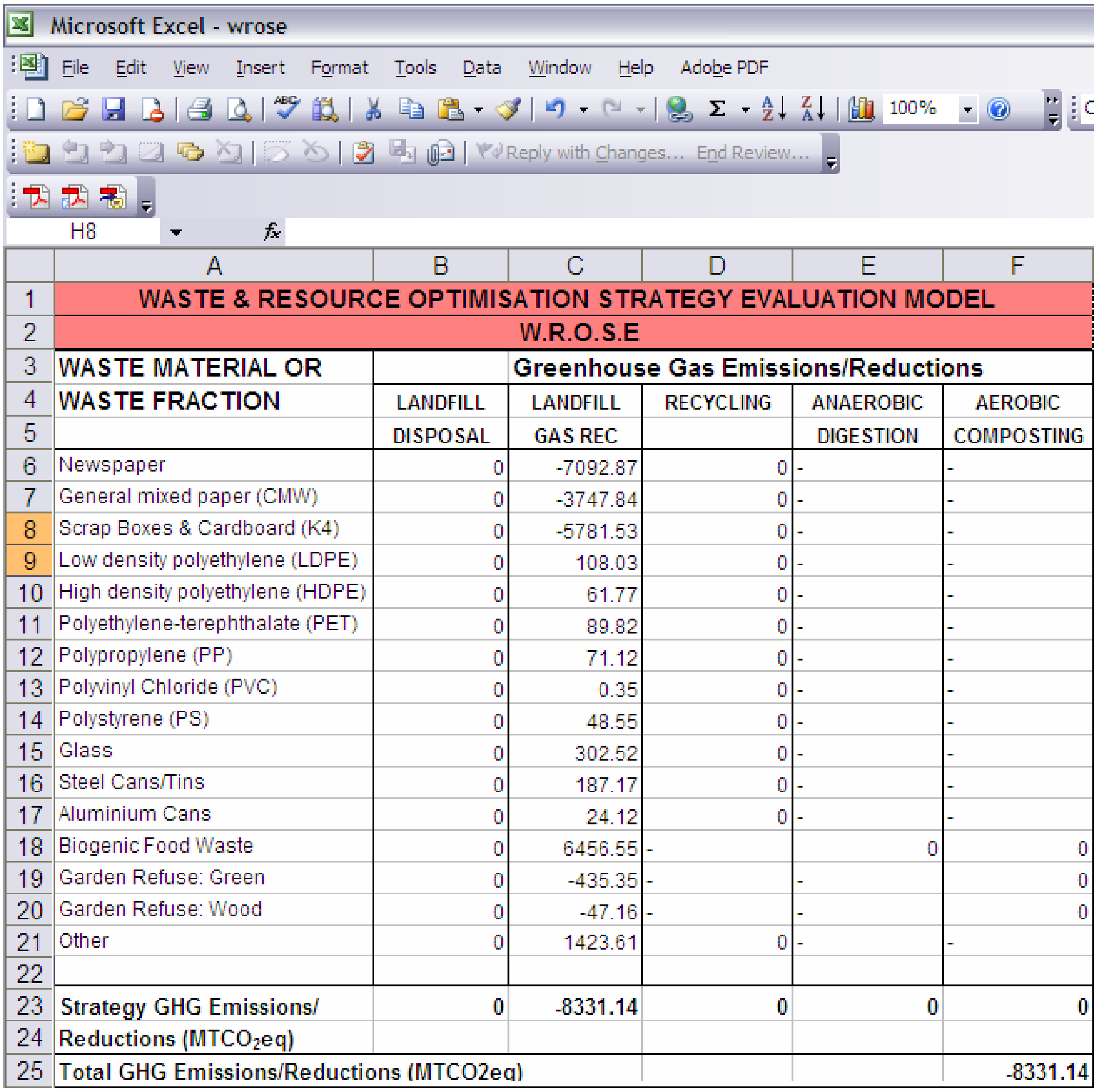
	A	B	C	D	E	F
1	WASTE & RESOURCE OPTIMISATION STRATEGY EVALUATION MODEL					
2	W.R.O.S.E					
3	WASTE MATERIAL OR	Quantity of Waste Disposed/treated/diverted by (tons):				
4	WASTE FRACTION	LANDFILL	LANDFILL	RECYCLING	ANAEROBIC	AEROBIC
5		DISPOSAL	GAS REC		DIGESTION	COMPOSTING
6	Newspaper	5453				
7	General mixed paper (CMW)	7234				
8	Scrap Boxes & Cardboard (K4)	11402				
9	Low density polyethylene (LDPE)	2450				
10	High density polyethylene (HDPE)	1401				
11	Polyethylene-terephthalate (PET)	2037				
12	Polypropylene (PP)	1613				
13	Polyvinyl Chloride (PVC)	8				
14	Polystyrene (PS)	1101				
15	Glass	6861				
16	Steel Cans/Tins	4245				
17	Aluminium Cans	547				
18	Biogenic Food Waste	36608				
19	Garden Refuse: Green	637				
20	Garden Refuse: Wood	46				
21	Other	32287				
22	Total Waste Diverted/Disposed	113930	0	0	0	0

User enters waste fraction quantities to be diverted or disposed of by each strategy.

Figure 8.7 – WROSE Model input data screen

The user enters input values of the amount of waste disposed or diverted by each strategy (in metric tons) for the scenario being evaluated. The GHG emissions or reductions are then automatically generated as shown in Figure 8.8 in the output screen, in metric tons of carbon dioxide equivalents (MTCO$_2$eq). These emissions or reductions are calculated by the following equation:

Carbon Emissions/Reductions = Emission Factor (MTCO$_2$eq/ton) x Quantity of Waste (tons)



	A	B	C	D	E	F
1	WASTE & RESOURCE OPTIMISATION STRATEGY EVALUATION MODEL					
2	W.R.O.S.E					
3	WASTE MATERIAL OR		Greenhouse Gas Emissions/Reductions			
4	WASTE FRACTION	LANDFILL	LANDFILL	RECYCLING	ANAEROBIC	AEROBIC
5		DISPOSAL	GAS REC		DIGESTION	COMPOSTING
6	Newspaper	0	-7092.87	0	-	-
7	General mixed paper (CMW)	0	-3747.84	0	-	-
8	Scrap Boxes & Cardboard (K4)	0	-5781.53	0	-	-
9	Low density polyethylene (LDPE)	0	108.03	0	-	-
10	High density polyethylene (HDPE)	0	61.77	0	-	-
11	Polyethylene-terephthalate (PET)	0	89.82	0	-	-
12	Polypropylene (PP)	0	71.12	0	-	-
13	Polyvinyl Chloride (PVC)	0	0.35	0	-	-
14	Polystyrene (PS)	0	48.55	0	-	-
15	Glass	0	302.52	0	-	-
16	Steel Cans/Tins	0	187.17	0	-	-
17	Aluminium Cans	0	24.12	0	-	-
18	Biogenic Food Waste	0	6456.55	-	0	0
19	Garden Refuse: Green	0	-435.35	-	-	0
20	Garden Refuse: Wood	0	-47.16	-	-	0
21	Other	0	1423.61	0	-	-
22						
23	Strategy GHG Emissions/	0	-8331.14	0	0	0
24	Reductions (MTCO$_2$eq)					
25	Total GHG Emissions/Reductions (MTCO2eq)					-8331.14

Figure 8.8 – WROSE Model results output screen

8.5.4 GHG emissions sources and sinks evaluated

The US EPA emission factors and the methodology used in the development of these factors are listed and discussed in detail in the US EPA publication „Solid Waste Management and "Greenhouse Gases: A Life Cycle Assessment of Emissions and Sinks" (2006). GHG emissions from solid waste management can be characterised as:

i. Direct Process Emissions: all emissions directly released through the waste treatment or disposal process itself, for instance the production of landfill gas; the production of carbon dioxide through aerobic composting and so forth.

ii. Transportation emissions: all emissions resulting from the supply and combustion of fuel for the transportation of MSW (Møller et al, 2009).

iii. Energy emissions: all emissions resulting from the acquisition and production of electricity such as the mining of coal and operation of power stations and GHG reductions from the generation of renewable energy/electricity from waste.

iv. Virgin material acquisition or displacement emissions: all emissions resulting from the extraction of raw virgin materials such as the mining of minerals, and forestry to produce timber. The collection and transportation of virgin materials during production processes are also included. These emissions are considered wherever there is a substitute for materials or products produced from virgin materials, such as the use of recycled materials in production processes, or the substitution of compost from composting for inorganic chemical fertilisers (US EPA, 2006).

v. Carbon sequestration: refers to any process, resulting from natural or anthropogenic activity that removes carbon from the atmosphere and stores it for long periods of time (US EPA, 2006). Carbon sequestration includes storage of carbon in landfills and the removal of CO_2 from the atmosphere by trees.

GHG sources produce positive emissions, while GHG sinks result in negative emissions (emission reductions). GHG sources and sinks evaluated for the development of the US EPA emissions factors are illustrated in Figure 8.9 overleaf.

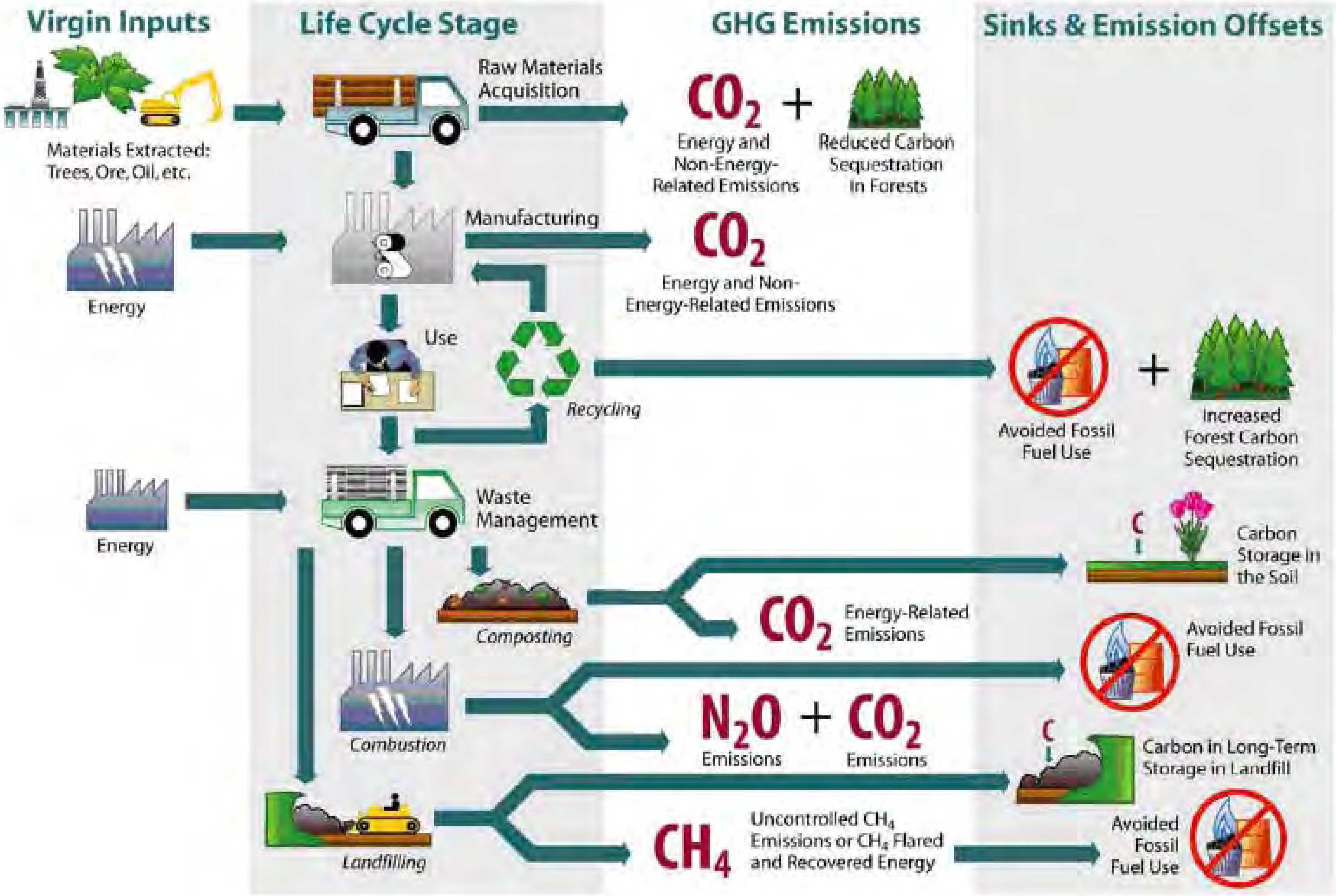


Figure 8.9 – GHG sources and sinks evaluated by US EPA emission factors

(Source: US EPA, 2006)

8.5.5 US Emission factors used in WROSE model

The emission factors used in the WROSE model are those derived by the United States Environmental Protection Agency using IPCC guidelines and were considered as the most „transparent' approach to modelling the GHG emissions or reductions. A streamlined LCA approach is 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. The factors for the waste fractions considered in eThekwini and uMgungundlovu Municipality case studies are listed in Table 8.6.

Table 8.6 – US EPA GHG emission factors

(Source: US EPA, 2006)

	Emission Factor (MTCO$_2$eq/ton)			
Waste Material/Fraction	**LANDFILL DISPOSAL**	**LANDFILL GAS REC**	**RECYCLING**	**AEROBIC COMPOSTING**
Newspaper	0.48	-1.18	-2.8	N/A
General mixed paper (CMW)	1.35	-0.47	-3.54	N/A
Scrap Boxes and Cardboard (K4)	1.49	-0.46	-3.11	N/A
Low density polyethylene (LDPE)	0.04	0.04	-1.71	N/A
High density polyethylene (HDPE)	0.04	0.04	-1.4	N/A
Polyethylene-terephthalate (PET)	0.04	0.04	-1.55	N/A
Polypropylene (PP)	0.04	0.04	-1.52	N/A
Polyvinyl Chloride (PVC)	0.04	0.04	-1.52	N/A
Polystyrene (PS)	0.04	0.04	-1.52	N/A
Glass	0.04	0.04	-0.28	N/A
Steel Cans/Tins	0.04	0.04	-1.8	N/A
Aluminium Cans	0.04	0.04	-13.67	N/A
Biogenic Food Waste	1.43	0.16	N/A	-0.2
Garden Refuse: Green	0.06	-0.62	N/A	-0.2
Garden Refuse: Wood	0.07	-0.93		-0.2
Tyres	0.04	0.04	-1.84	N/A
**** A negative emissions factor indicates a net reduction*** ***A positive emissions factor indicates a net emission***				

These factors apply to waste quantities in short tons (1 short ton = 1.1 metric tons), however these are converted for compatibility with metric units of measurements by the WROSE model. A typical landfill gas recovery efficiency (75%) was chosen (Barton, 2009). It should be noted that biogenic carbon dioxide emissions from biogenic wastes are not considered as contributing to GHG impacts, and are rather considered as the final step in the carbon cycle, as the CO_2 is simply returned to the atmosphere replacing the CO_2 originally removed by photosynthesis processes (US EPA, 2006). This principle applies to landfilling, aerobic composting and anaerobic digestion of biogenic MSW. Methane produced from „anaerobic pockets' in compost piles is considered to be fully oxidised into CO_2 before it escapes into the atmosphere (Smith et al, 2001; US EPA, 2006). Composting is therefore considered to be carbon neutral, with the only emissions occurring from transportation of waste and energy requirements for the composting process itself. Composting is also a sink in CO_2 emissions, from carbon storage due to the application of compost. This reduction has been estimated to be approximately 0.183 $MTCO_2eq$/ton of wet waste compost feedstock (US EPA, 2006).

8.5.6 Development of anaerobic digestion emissions factor

The emissions factor for the anaerobic digestion of biogenic MSW was developed using the same streamlined life cycle analysis approach as the development of the USEPA factors (on a wet weight basis) and considered the following emissions and reductions:

i. Direct emissions from the anaerobic digestion process.
ii. Energy emissions from the energy requirement of the anaerobic digestion process.
iii. Energy reductions from substitution of fossil fuel energy due to energy recovery and electricity generation from waste.
iv. Transportation emissions from the collection and transportation of MSW.
v. Emissions from digestate application and emissions reduction from substitution of inorganic chemical fertiliser by compost produced from digestate.

The emissions and reductions are discussed further in the following sections.

8.5.6.1 Direct process emissions

Direct process emissions were determined as shown in Table 8.7, using the IPCC GHG inventory guidelines (IPCC, 2006). The tier 1 approach was adopted, as 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 (IPCC, 2006). Nitrous oxide emissions are assumed to be negligible (IPCC, 2006).

Table 8.7 – Calculation of direct emissions factor

Direct Emission Factor Calculation	**Source, Reference or Conversion**
1g CH_4 / kg of wet waste	IPCC guidelines for National Greenhouse Gas Inventories (2006)
Conversion to $MTCO_2$ = 0.021 $MTCO_2$	Multiply by CH_4 GWP (21)
Assume 95 % of methane is recovered for energy generation.	Average fugitive losses = 3% Møller et al (2009) Assume 5% - conservative approach.
Direct Emission EF = +0.00105 $MTCO_2$eq/ton	5% of methane produced

8.5.6.2 Energy emission factor

Energy emissions consist of emissions from the combustion of methane to produce energy; emission reductions from electricity generation and emissions from energy consumption. 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 the 2009 study by Møller et al. An average biogas yield of 110Nm^3/ton of waste digested and a 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.

Finally, an average emission 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 disparity is likely due to the highly carbon intensive electricity grid in South Africa comprising of approximately 91.7% coal generated electricity (Department of Energy - SA, 2010). Emission reductions from the substitution of electricity amounted to -0.23397 $MTCO_2$eq/ton, producing an overall energy emissions factor of -0.23157 $MTCO_2$eq/ton of wet waste, as shown in Table 8.8.

Table 8.8 – Calculation of energy emission factor

Energy Emissions Factor Calculation	Source, Reference or Conversion
Combustion of Biogas: Assume biogas yield is between 80-130Nm^3/ton Average CH_4 emissions factor = 20 kgCO_2/ton Average N_20 emissions factor = 0.4 kg CO_2/ton Combustion Emissions = +0.0024 MTCO_2/ton	 Møller et al (2009) Møller et al (2009)
Energy Generation: Assume biogas yield = 110 Nm^3/ton waste Calorific value of biogas = 23 MJ/Nm^3 Total energy generated = 2,530 MJ/ton Assume an energy recovery efficiency of 40% Total energy recovered = 1012 MJ/ton Assume the average energy consumption for the anaerobic digestion process = 18% Net energy recovered = 829.84MJ/ton Net power generated = 230.51 kWh/ton Average emissions/kWh from energy production in South Africa = 1.015 kg CO_2eq/kWh Energy EF = 230.51 kWh/ton x 1.015kg CO_2eq/kWh = 233.97 kg CO_2eq/ton Energy EF = - 0.23397 MTCO_2eq/ton **Net Energy EF = -0.23157 MTCO_2/ton**	 Møller et al (2009) Møller et al (2009) Assumed - DiStefano (2009) 18% energy recovered = 182.16 MJ/ton 1 kWh = 3.6 MJ UCT Energy Research Centre (2009)

8.5.6.3 Transportation emission factor

Transportation emissions were calculated using a similar methodology used by Møller et al (2009). The fuel efficiency of waste collection trucks over a 20 mile distance was determined, assuming a typical value of 0.03 L/ton/km. A 20 mile travelling distance was assumed to maintain consistency with the US EPA emissions factors.

Total emissions from transportation of waste amount to approximately +0.0029794 MTCO_2eq/ton as calculated in Table 8.9 overleaf.

Table 8.9 – Calculation of transport emissions factor

Transportation Emissions Factor Calculation	Source, Reference or Conversion
Assume average distance to the AD facility 20 miles facility (to maintain consistency with US EPA factors.	
Assume collection truck fuel efficiency: 0.03 L/ton/km Fuel efficiency = 0.03L/ton/km x 32.1868 km = 0.9656 L/ton	Møller et al (2009)
Emissions from provision of diesel = 0.4kg CO_2eq/L	Fruergaard et al (2009)
Emissions from fuel combustion = 2.6855kg CO_2eq/L	Durban Industry Climate Change Project
Transportation EF = (0.4+2.7) x (0.9656L/ton) = +2.9794 kg CO_2eq/ton **Transportation EF = 0.0029794 MTCO_2/ton**	

8.5.6.4 Digestate emission factor

Emissions from the use of digestate as an organic fertiliser were approximated from other studies, based on European data 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, as shown in Table 8.10.

Table 8.10 – Calculation of emissions from digestate

Digestate Emissions Factor Calculation	Source, Reference or Conversion
Digestate application = 1.5kg CO_2eq/ton	
Average soil carbon storage = -25.8 kg CO_2eq/ton	Range: 6.6-45 kgCO_2eq/ton Møller et al (2009)
Fertiliser substitution emissions = -20kg CO_2eq/ton	20-28 CO_2eq/ton Boldrin et al (2009)
Digestate EF = (1.5- 20- 25.8) kg CO_2eq/ton **Digestate EF = -0.0443 MTCO_2/ton**	

8.5.6.5 Resultant anaerobic digestion emission factor

The resultant emission factor for anaerobic digestion is obtained by adding the factors calculated from direct, energy, transportation and digestate emission factors, as shown in Table 8.11.

Table 8.11 – Resultant anaerobic digestion emission factor

Parameter	Calculated factor (MTCO$_2$eq)
Direct emissions	0.0011
Energy emissions	-0.23157
Transportation emission factor	0.0030
Digestate emission factor	-0.0443
Resultant emission factor	**-0.2718**

The anaerobic digestion emission factor amounts to approximately -0.2718 MTCO$_2$eq/ton of wet waste which is high due to the recovery of methane which prevents the emissions from the process being released into the atmosphere as well as the production of electricity and substitution of fossil fuels energy in South Africa's carbon intensive energy supply. The emission factor for anaerobic digestion 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, from which the total amount of water required is calculated using the density (1000 kg/m^3) of water (White, 2000).

Typical anaerobic digestion emissions factors derived from four different studies (Smith et al, 2001; ICF; 2005; Warnken, 2007; and Møller et al, 2009) are listed in Table 8.12 were compared with the calculated factor. The factors were calculated using data from four different regions or countries – Denmark, Australia, Canada and Europe respectively. The average emissions factor from these four estimates was -0.38065 MTCO$_2$eq/ton. The calculated emission factor of -0.2718 MTCO$_2$eq/ton therefore falls within the range of values, and could be considered conservative when compared to the average value of emission factors listed in Table 8.12.

Table 8.12 – Anaerobic Digestion Emissions Factors

Source		Emission Factor ($MTCO_2eq/ton$)
Anaerobic Digestion and Digestate Use: Accounting of Greenhouse Gases and Global Warming Contribution	Møller et al -2009	-0.375
Potential for GHG Abatement from Waste Management and Resource Recovery Activities in Australia.	Warnken ISE 2007	-0.8856
Determination of the impact of Waste Management Activities on Greenhouse Gas Emissions	ICF Consulting 2005	-0.1
Waste Management Options and Climate Change	Smith et al 2001	-0.165

8.6 Landfill space savings methodology

The estimation of landfill space savings from the diversion of waste 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 therefore based on three different methodologies to produce both a range of expected landfill space savings and an average LSS value for each scenario.

i. Mixed MSW Density Methodology: This approach was also used by Matete (2009) to calculate LSS for various zero waste scenarios. The total amount of waste in tons is divided by the average compacted density of MSW to yield the total landfill space savings as per the following equation :

$$\text{LSS } (m^3) = \frac{\text{Total Waste Quantity Diverted (tons)}}{\text{Compacted Density of Mixed MSW (tons/}m^3\text{)}}$$

The value used for the compacted density of MSW 1200kg/m^3 (1.2 tons/m^3) in accordance with the eThekwini Integrated Waste Management Plan (SKC Engineers, 2004).

ii. Environmental Benefits of Recycling Calculator (EBRC): This tool was developed by the Department of Environment and Conservation of Western Australia, and estimates the total LSS based on empirical parameters. The tool is in the form of a Microsoft Excel Spreadsheet. The LSS factors, listed in Table 8.13, are simply multiplied by the quantity of each waste fraction diverted from landfill disposal to yield total landfill space savings. The EBRC does not take into account LSS from the diversion of biogenic wastes and thus average values were assumed from the densities of these wastes (Tchobanoglous et al, 1993).

Table 8.13 – Landfill Space Savings factors

(Source: Department of Environment and Conservation of Western Australia, 2008)

Waste Fraction	**LSS Factor (m^3/ton)**
Paper and Card	2.84
Glass	4.36
PET	6.39
HDPE	5.47
PVC	10.77
PP	10.77
Al	4.93
Steel	2.15
*Food waste (890kg/m^3)	1.12
*Garden refuse (890kg/m^3)	1.12

iii. United States Environmental Protection Agency (US EPA) Landfill Density Factors: This methodology uses values for the landfill density of various waste fractions and materials. The factors, listed in Table 8.14 overleaf, constitute a wide range of waste materials and specific fractions that can be diverted from landfill disposal unlike the Environmental Benefits of Recycling Calculator, which employs a more generalized or holistic approach. Factors from the EBRC are applied for general fractions in some cases – modelling LSS for „Paper and Cardboard' rather than the group's individual constituents. Specific waste fractions such as polystyrene (PS) and LDPE are also excluded in the EBRC.

Table 8.14 –US EPA landfill space savings factors

(Source: United States Environmental Protection Agency, 1995)

Waste Fraction	**LSS Factor *(lb/cu yard)**
Paper and Cardboard	800
LDPE	670
HDPE	355
PET	355
PP	355
PVC	185
PS	1015
Glass	2800
Steel	560
Aluminium	250
Food	2000
garden refuse	1500
*Unit Conversion: 1 kg/m^3 =1.685554936 lb/cu yard	

8.7 Potential cost and income analysis

A simple approach toward assessing the potential costs and income generated from each scenario was adopted, as the objective of the analysis is to provide a general overview of the economic implications from the simulated zero waste strategies. Capital costs include planning, design and development, site preparation, construction, materials, and equipment. Operational costs include waste pre-treatment, labour, management, maintenance, electricity and water utilities. 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, and compost are discussed in the following sections. These parameters are based on research reports, journal publications, feasibility studies for local projects, and international projects where data is 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.

8.7.1 Landfill disposal and gas recovery

Landfill disposal costs vary with the amount of waste being disposed. Currently landfilling remains the least expensive method of MSW disposal (Smith et al, 2001; Ostrem, 2004). Annual operating costs for the Mariannhill landfill modelled for the year June 09-July 10 are approximately R 100.24/m^3 of waste landfilled, for an annual tonnage of 120,349 tons (SKC Engineers, 2002). This is equivalent to R 83.53/ton of waste landfilled. The actual cost of landfill disposal currently ranges between R 150-180/m^3 which is equivalent to an average cost of R 138/ton. This cost was used for the New England Road Landfill as no data was available. The capital cost of the eThekwini landfill gas to energy project for Mariannhill (0.5 MW) was used as an estimate for the analysis. Income from landfill gas recovery projects includes the sale of certified emissions reductions under the CDM and the sale of electricity.

8.7.2 Materials Recovery Facility (MRF) and recycling

The Mariannhill MRF currently has a throughput capacity of 80,000 tons per year (GreenEng, 2010). 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. A 40% recovery rate of recyclables has been assumed. Both operational and capital costs were approximated using a study by Chang et al (2005) which approximated a linear relationship between capital and operating costs and design capacity as shown in Figure 8.10. The total capital cost for mechanical pre-treatment and materials recovery therefore amounts to approximately US$ 33.8 million (R 231 million) while the total annual operational cost is US$ 9.9 million/year (R 68 million/year).

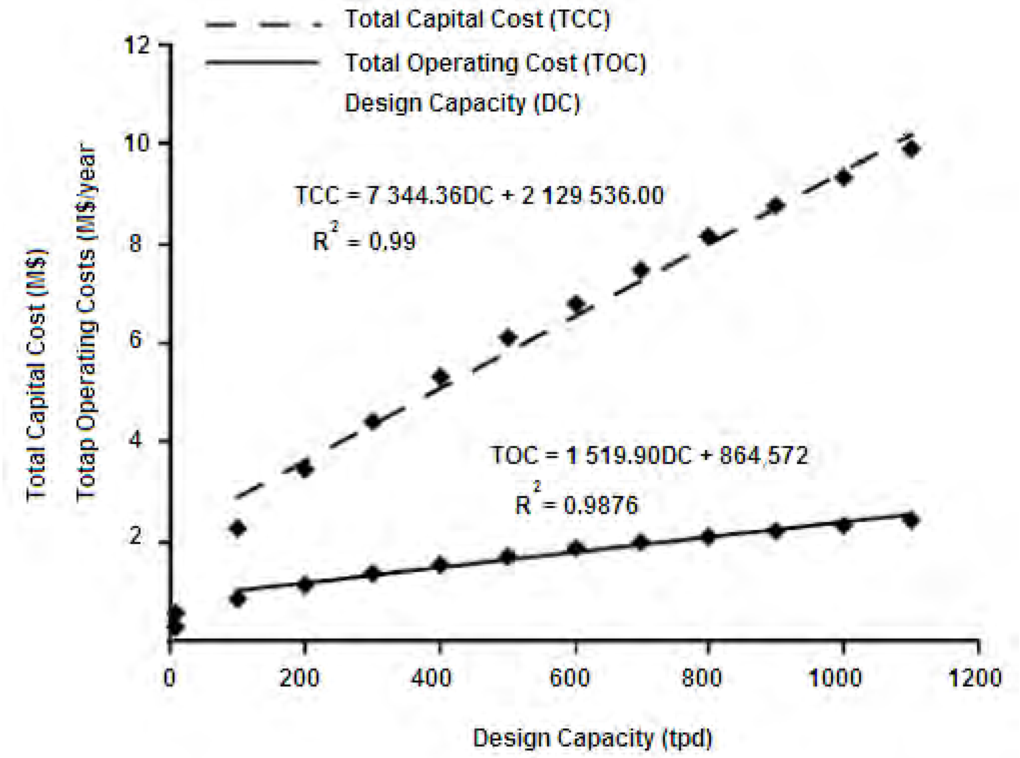


Figure 8.10 – Capital and operational cost data for MRF's
(Chang et al, 2005)

Recycling prices have been sourced from two local studies: GreenEng (2010) and 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, therefore reducing the demand for recyclables and directly affecting the recycling market (Stromberg, 2004; Matete and Trois, 2008; Lavee et al, 2009).

8.7.3 Anaerobic digestion

Although some estimates regarding the costs of anaerobic digestion plants are available, these represent a wide range of plant capacities and input feedstock tonnages making it difficult to approximate the potential costs to meet specific requirements. There is a general lack of data concerning detailed capital and operating costs of anaerobic digestion plants, however several studies have attempted to correlate these expenses with plant capacity. One such study by Tsilemou et al (2006) evaluated the capital and operating costs of 16 anaerobic digestion plants. The cost curves illustrated in Figure 8.11 and 8.12 were produced from this data by Rapport et al (2008) in a study reviewing anaerobic digestion as a treatment technology for biogenic MSW). The study also produced cost curves for data from Clarke (2000), however this data was not adjusted for consistency and therefore the cost curve based on Tsilemou et al (2006) was used in approximating costs.

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.

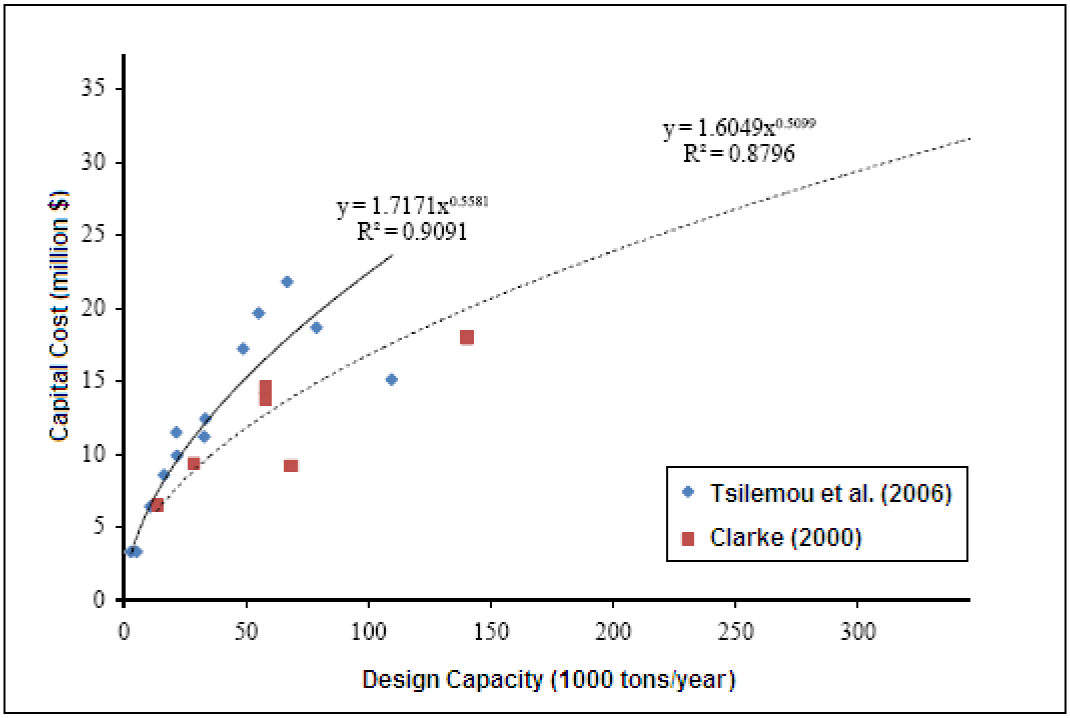


Figure 8.11 – Capital cost curve for anaerobic digestion plants

(Source: Rapport et al, 2008)

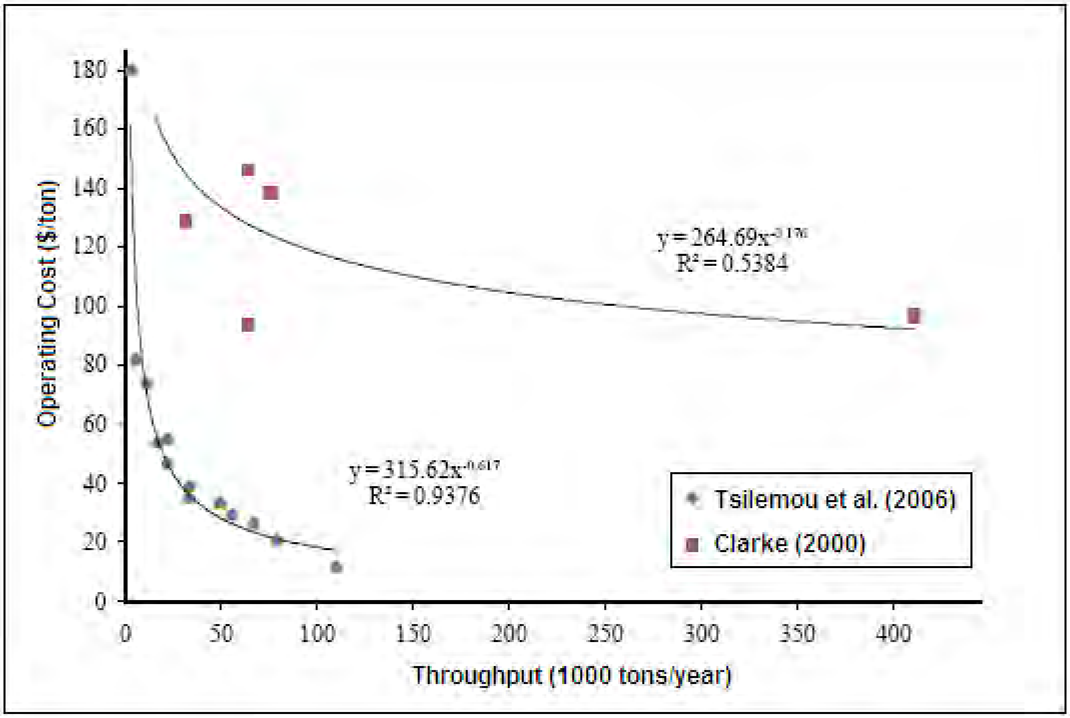


Figure 8.12 – Operating cost curve for anaerobic digestion plants

(Source: Rapport et al, 2008)

A degradation factor of 0.6 was used to determine the amount of digestate/compost produced from the anaerobic digestion process.

8.7.4 Aerobic composting

The capital and operating expenses for the implementation of DAT composting plants have been determined at local level as R 150-170 per ton of input waste (Moodley, 2010). A value of R 152.05 /ton was used in the cost analysis (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 R 2,400,000 (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).

8.7.5 Adjustment of Cost Data for Inflation

Inflation refers to the general rise in prices of goods and services (Olivier, 2000). Inflations is measure by the Consumer Price Index (CPI) and/or the Producer Price Index (PPI). These indices are used to adjust prices and costs from previous years, to reflect actual costs including inflation. The CPI and PPI cover a very broad range of items such as fuel, labour, plant and machinery, food, and so forth. This said, the operating costs and capital costs associated with implementing zero waste strategies are complex, and comprise of many different facets. For example, the operating costs of an anaerobic digestion plant would include, electricity, fuel and transportation, labour, energy and digestate treatment. These costs are not specifically covered by the PPI, and therefore the indices are too broad to adjust for inflation (Hart, 2011). The adjustment of the economic analyses is considered to complex a process to attempt at this level, and is believed to have no significant effect on the overall results of the analyses. To elaborate, the operating costs of an anaerobic digestion plant will still be greater than that of a composting facility, after adjusting for inflation. Because the objective of the analysis is to compare the feasibility of each strategy on an economic level, the methodology and consequently the results obtained are considered accurate in this respect.

Table 8.15 overleaf lists all relevant parameters, data and assumptions used in the cost analysis.

Table 8.15 – Economic parameters used in cost and income analysis

PARAMETER	UNIT	VALUE	SOURCE
Landfill Disposal and Landfill Gas Recovery			
Landfill Operating Cost	R/ton	138	SKC Engineers (2002)
Average Landfill Airspace Cost	R/m^3	62.5	City of Cape Town IWMP (2004); Parkin (2007)
Landfill Gas Recovery System (0.5MW)	$	1,100,000	Couth et al (2010)
Operating Cost of LFG Recovery and Electricity Generation	$/kWh	0.018	SCS Engineers (2005)
MRF Costs and Recyclable Selling Prices			
Materials Recycling Facility Capital Cost	$ million	4.957	Chang et al (2005)
Materials Recycling Facility Operating Cost	$million/year	1.4497	Chang et al (2005)
Newspaper and Common Mixed Waste	R/kg	0.50	City of Cape Town IWMP (2004)
HL1	R/kg	1.80	Green Engineering (2010)
Tetrapak	R/kg	0.50	Green Engineering (2010)
Scrap Boxes and Cardboard (K4)	R/kg	0.60	Green Engineering (2010)
Low density polyethylene (LDPE)	R/kg	1.50	Green Engineering (2010)
High density polyethylene (HDPE)	R/kg	2.70	Green Engineering (2010)
Polyethylene-terephthalate (PET)	R/kg	2.50	Green Engineering (2010)
Polypropylene (PP)	R/kg	2.00	City of Cape Town IWMP (2004)
Glass	R/kg	0.38	Green Engineering (2010)
Cans	R/kg	1.06	Green Engineering (2010)
Aerobic Composting			
Composting Facility Capital Cost	R/180tpd	2400000	Moodley (2007)
Composting Facility Operating Cost	R/ton	152.05	Moodley (2007)
Compost Selling Price	R/ton	250	City of Cape Town IWMP (2004)
Compost Degradation Factor		0.75	Douglas (2007)
Anaerobic Digestion			
Anaerobic Digestion Plant Capital Cost (Mariannhill)	$ million	15.24	Rapport (2008)
Anaerobic Digestion Plant Capital Cost (NER)	$ million	13.46	Rapport (2008)
Anaerobic Digestion Plant Operating Cost (Mariannhill)	$/ton	28.2	Rapport (2008)
Anaerobic Digestion Plant Operating Cost (NER)	$/ton	32.4	Rapport (2008)
Other			
Electricity Tariff	$/kWh	0.047	Couth et al (2010)
Selling Price: Certified Emissions Reductions	$/MTCO$_2$e	14	Couth et al (2010)
US Dollar/ZA Rand Exchange Rate (08-11-2010)	$	6.83	JSE (2010)

CHAPTER 9 – RESULTS AND ANALYSIS

9.1 Waste Stream Analysis: uMgungundlovu District Municipality

9.1.1 Introduction

Data is presented for each of the nine waste streams defined in section 7.5 in three ways:

- Firstly a waste profile of the general fractions of the waste streams (recyclables; biogenic and other waste) to immediately differentiate between the proportions of dry, wet and residual waste fractions.
- A pie chart of general waste fractions is then presented to ascertain the contribution of the individual recyclable waste material groups – „Paper and cardboard'; „Glass'; „Metals' and „Plastic'.
- Finally, the specific fractions of each waste material group as defined in the waste classification system in Table 8.4 are presented.

The interpretation of the results obtained from the waste stream analysis notes any trends, inconsistencies, and correlation with expected results. The waste streams are compared on the basis of the originating source/activity of waste generation, income groups and type of area. The composition of the waste streams are then applied to average weighbridge data for the New England Road Landfill to obtain average annual quantities of each waste fraction, used as input data for both the GHG modelling and the cost and income analysis.

9.1.2 Rural High Income (RHI) waste stream

The general and specific waste profiles for the RHI waste stream are presented in Figure 9.1. Recyclables form a significant fraction of the total waste stream (40.39%), followed by biogenic waste (35.08%). The glass (14.31%) and paper (12.61%) fractions were the highest contributors to the recyclable fraction.

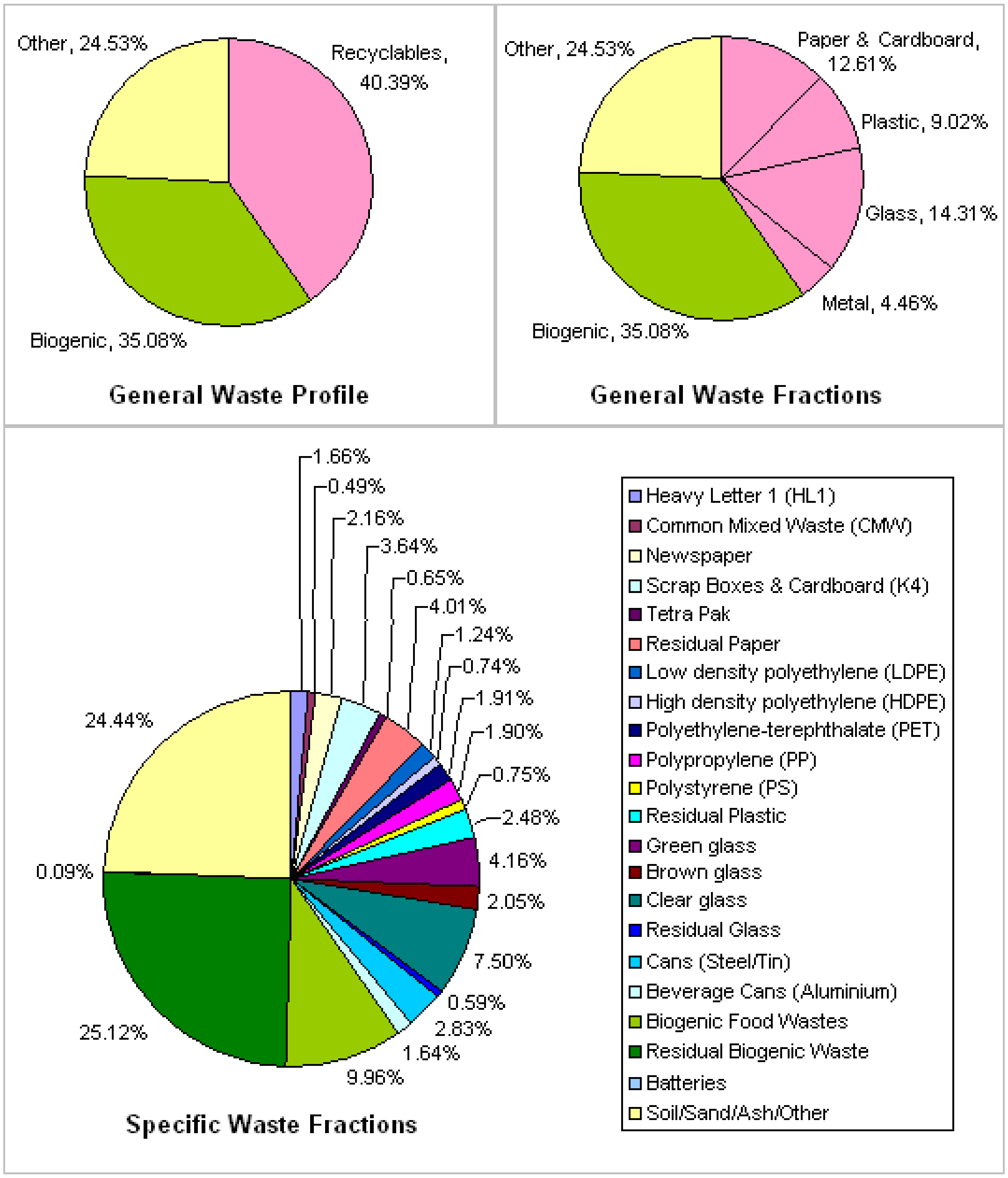


Figure 9.1 – Rural high income: general waste profile and specific fractions

9.1.3 Rural Medium Income (RMI) waste stream

The general and specific waste profiles for the RMI waste stream are presented in Figure 9.2. A high percentage of biogenic waste (43.64%) is present in the waste stream while the recyclable fraction (29.56%) is considerably less than the RHI waste stream. Paper (12.78%) and plastic (8.81%) are the most prevalent recyclables in the RMI waste stream.

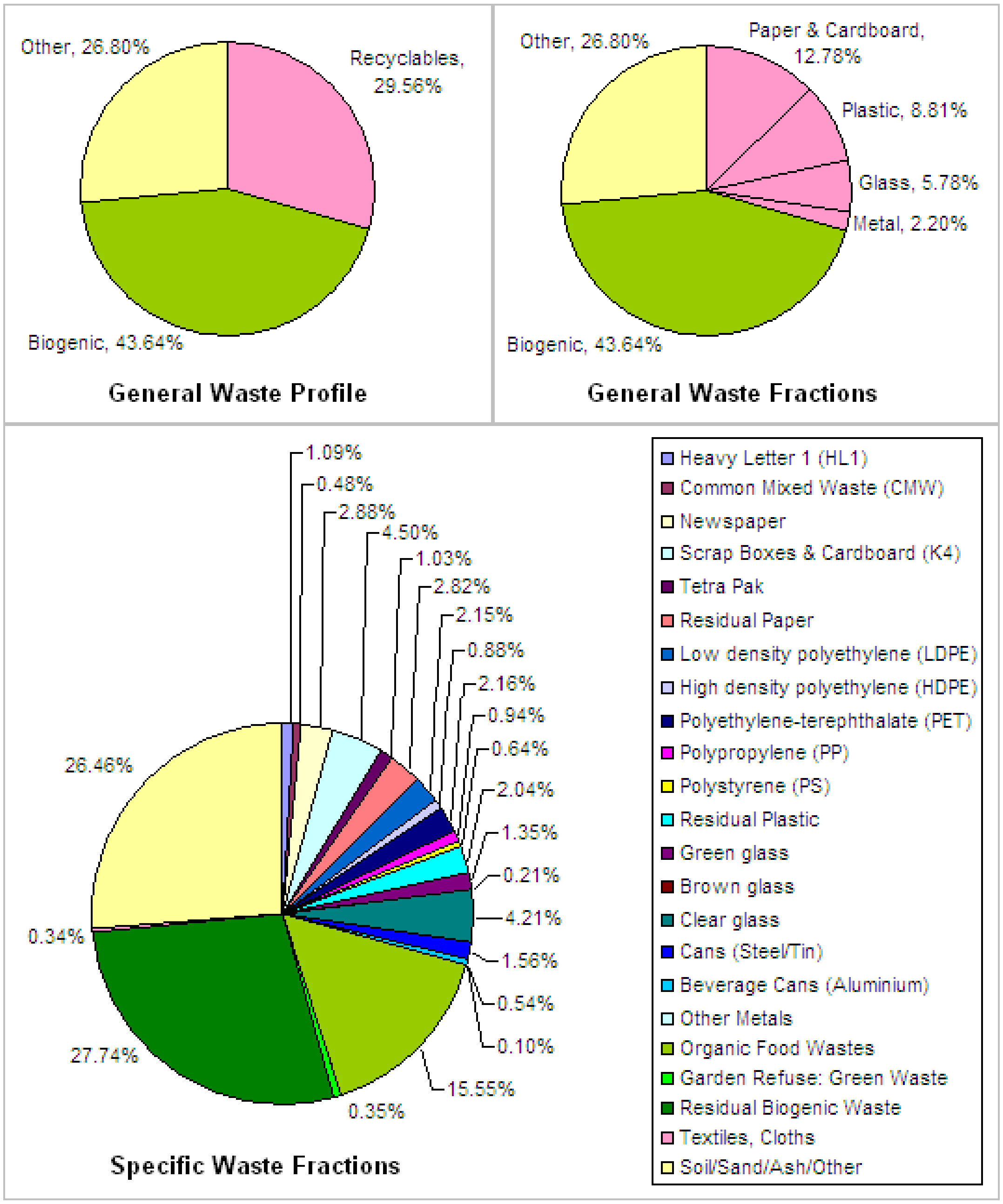


Figure 9.2 - Rural medium income: general waste profile and specific fractions

9.1.4 Rural Low Income (RLI) waste stream

The general and specific waste profiles for the RLI waste stream are presented in Figure 9.3. The RLI waste stream has the highest recyclable fraction (43.53%) amongst all the rural waste streams, with high percentages of glass (14.71%) and metals (12.11%). The biogenic fraction is approximately 32.62%.

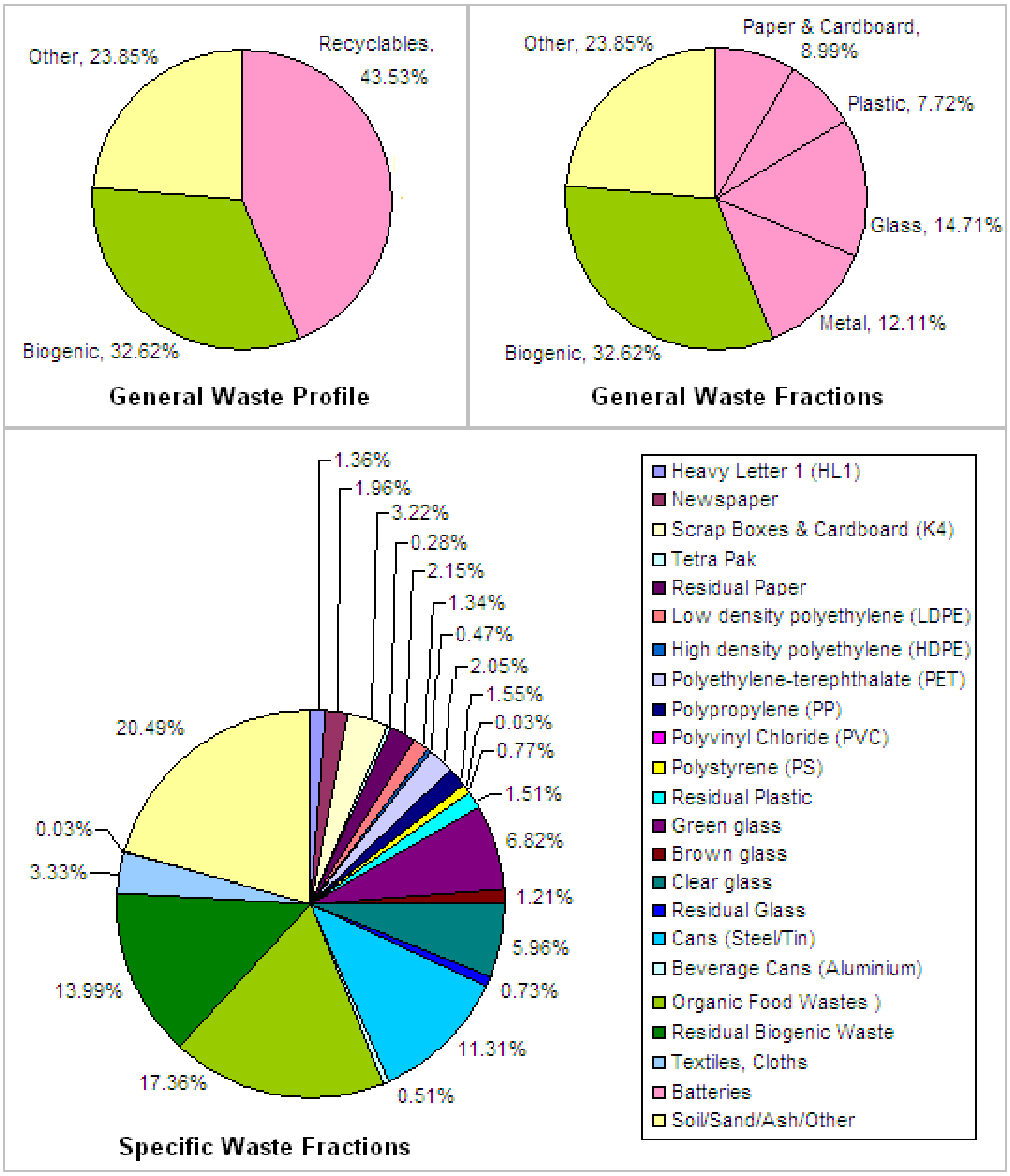


Figure 9.3 – Rural low income: general waste profile and specific fractions

9.1.5 Rural Commercial (RC) waste stream

The general and specific waste profiles for the RC waste stream are presented in Figure 9.4. The RC waste stream is characterised by significantly high fraction of biogenic waste (49.76%). The waste stream also contains a high proportion of recyclables (36.88%) and paper (14.72%) and plastic (13.49%) are the most prevalent recyclables.

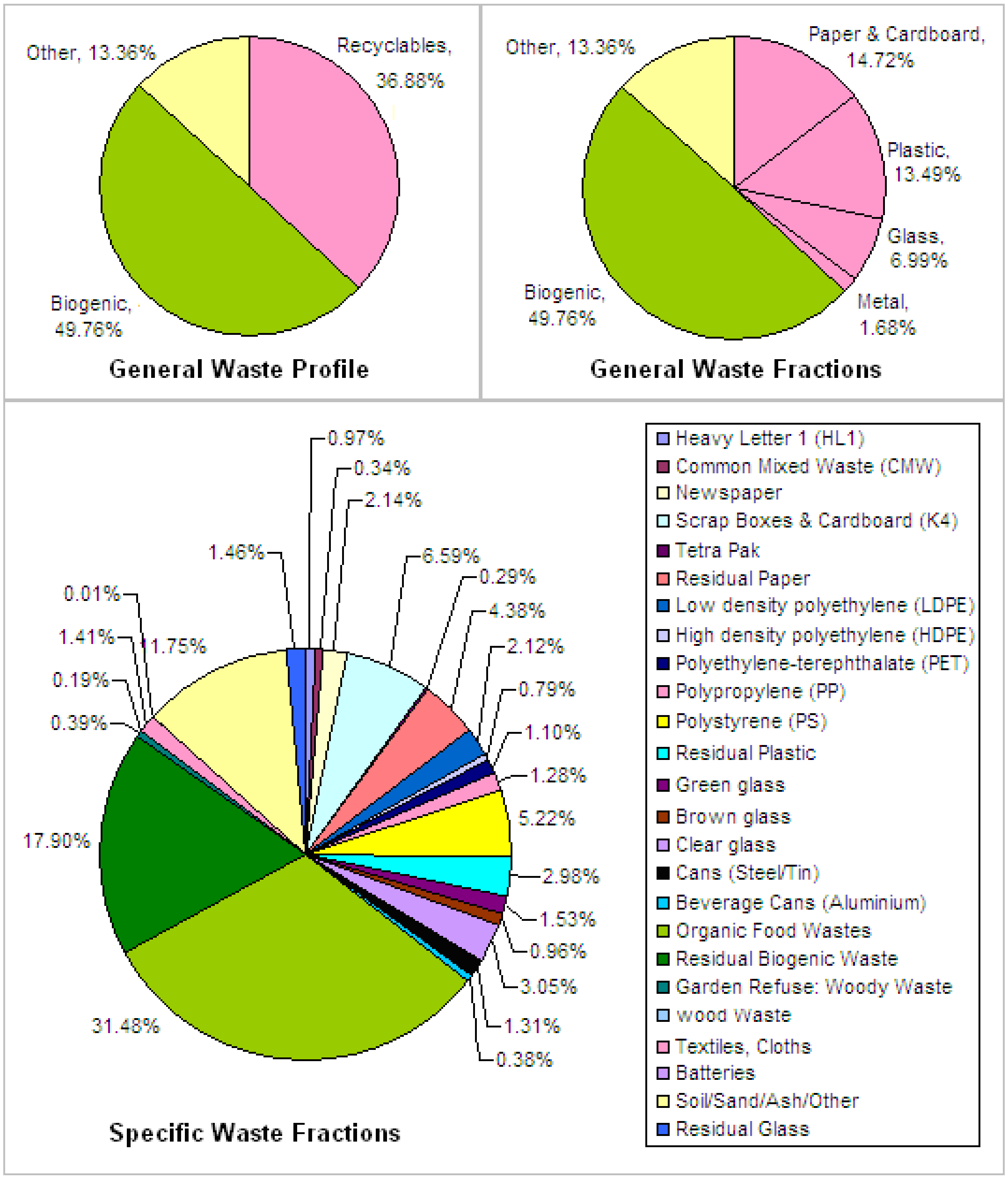


Figure 9.4 – Rural commercial: general waste profile and specific fractions

9.1.6 Urban High Income (UHI) waste stream

The general and specific waste profiles of the UHI waste stream are presented in Figure 9.5. The UHI waste stream comprises of 40.19% recyclables, and 36.58% biogenic waste. The most prevalent recyclables present in the waste stream are paper and cardboard (16.48%) and plastic (12.54%).

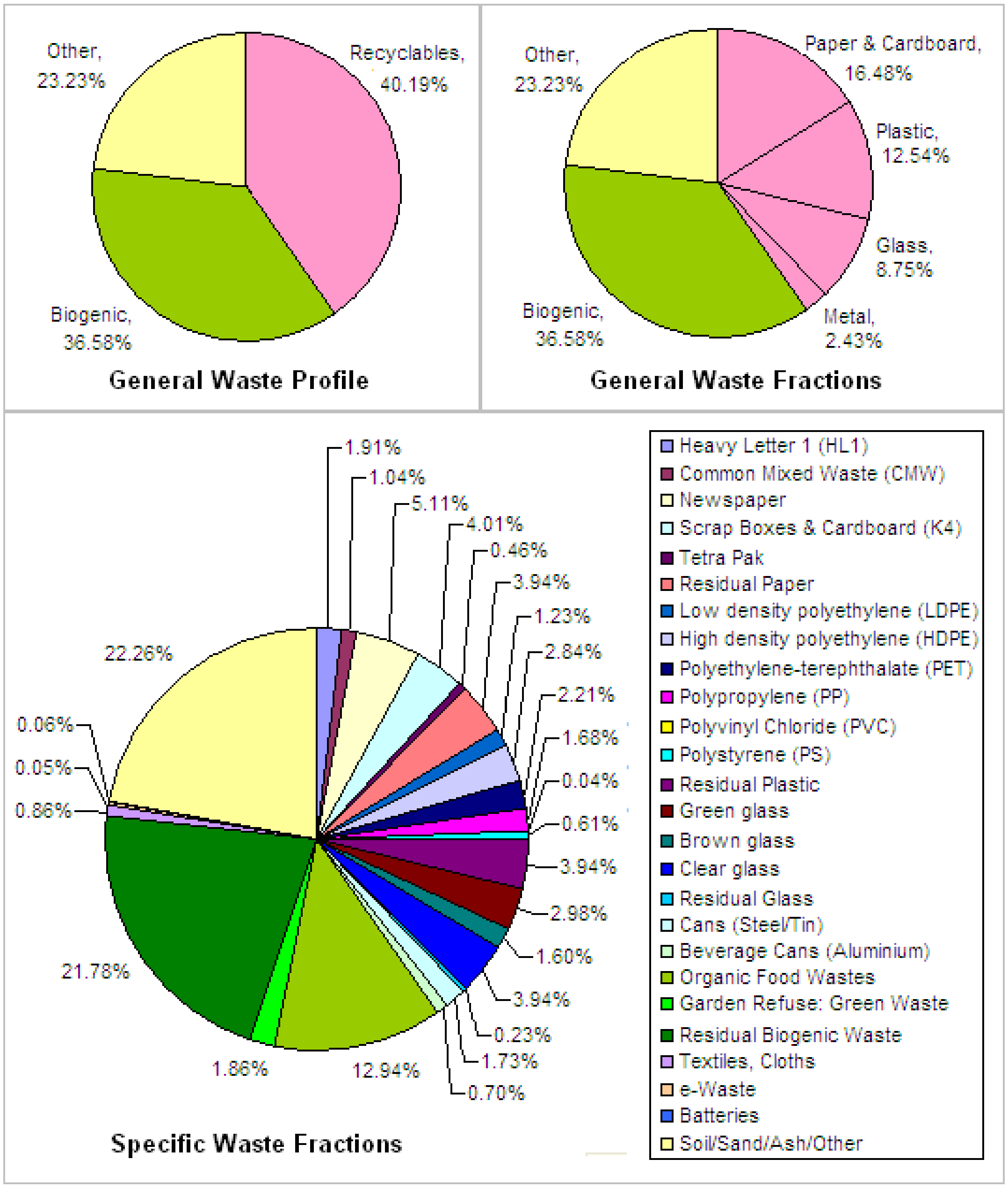


Figure 9.5 – Urban high income: general waste profile and specific fractions

9.1.7 Urban medium income (UMI) waste stream

The general and specific waste profiles of the UMI waste stream are presented in Figure 9.6. The UMI waste stream comprises of 33.73% recyclables and 37.68% biogenic wastes. The most prevalent recyclables in the UMI waste stream are paper and cardboard (16.23%) and plastic (9.88%).

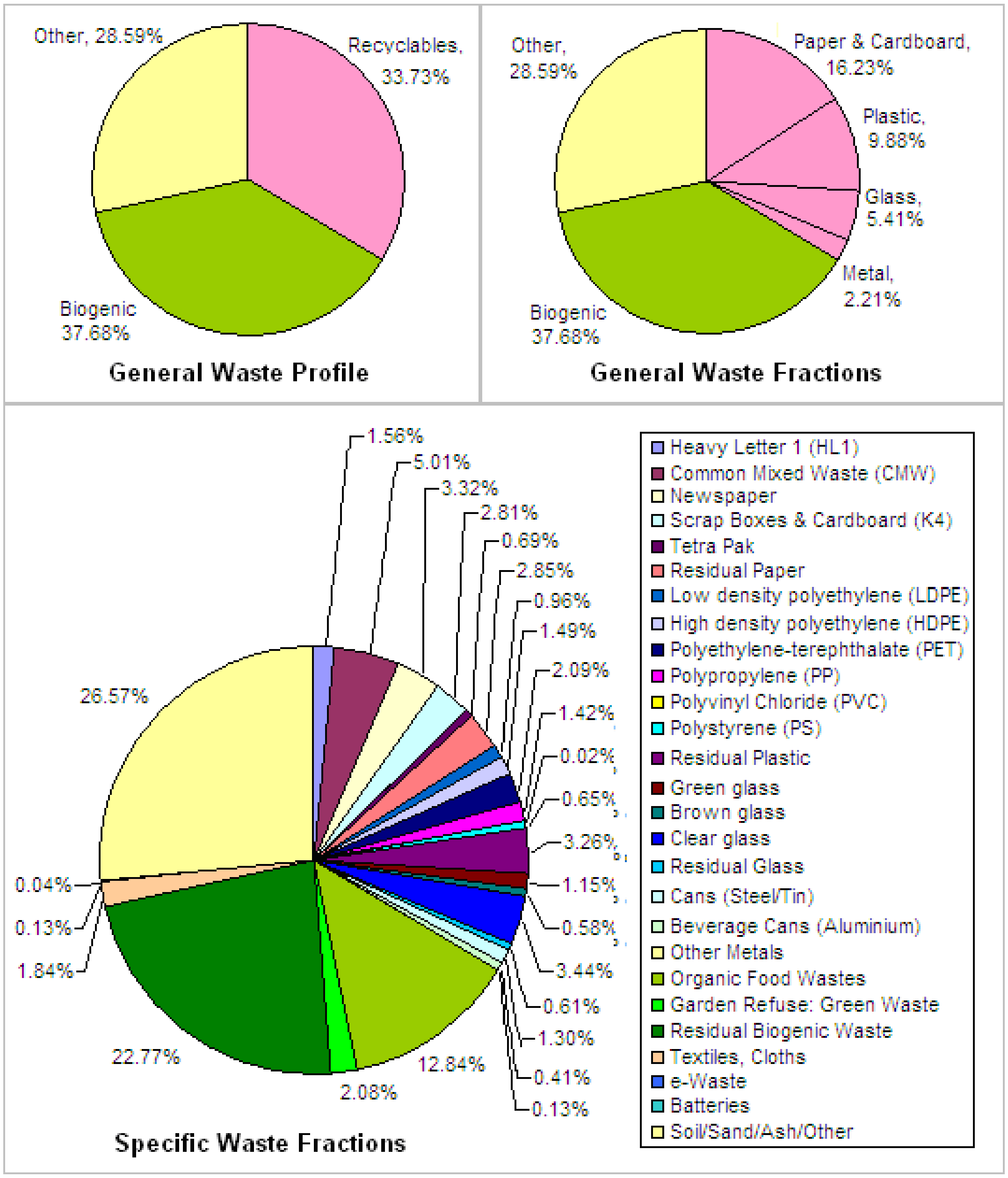


Figure 9.6 – Urban medium income: general waste profile and specific fractions

9.1.8 Urban Low Income (ULI) waste stream

The general and specific waste profiles of the ULI waste stream are presented in Figure 9.7. The ULI waste stream comprises of 32.35% recyclables and 34.04% biogenic waste. The most prevalent recyclables in the ULI waste stream are paper and cardboard (17.15%) and plastic (8.66%).

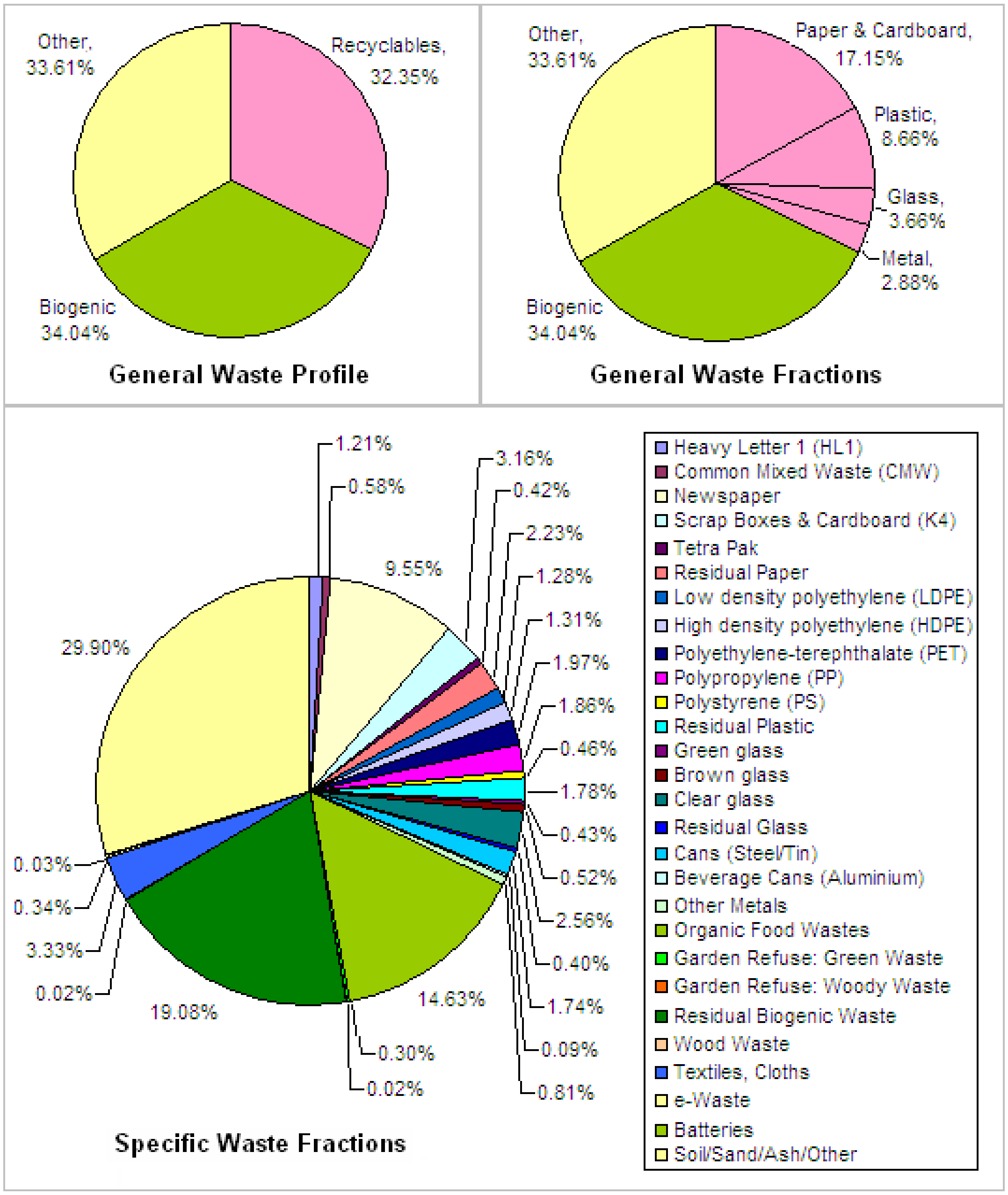


Figure 9.7 – Urban low income: general waste profile and specific waste fractions

9.1.9 Urban Commercial (UC) waste

The general and specific waste profiles for the UC waste stream are presented in Figure 9.8. The UC waste stream comprises of 46.81% recyclables, with a significantly high percentage of paper and cardboard (27.91%). The biogenic fraction of the UC waste stream amounts to 28.36%.

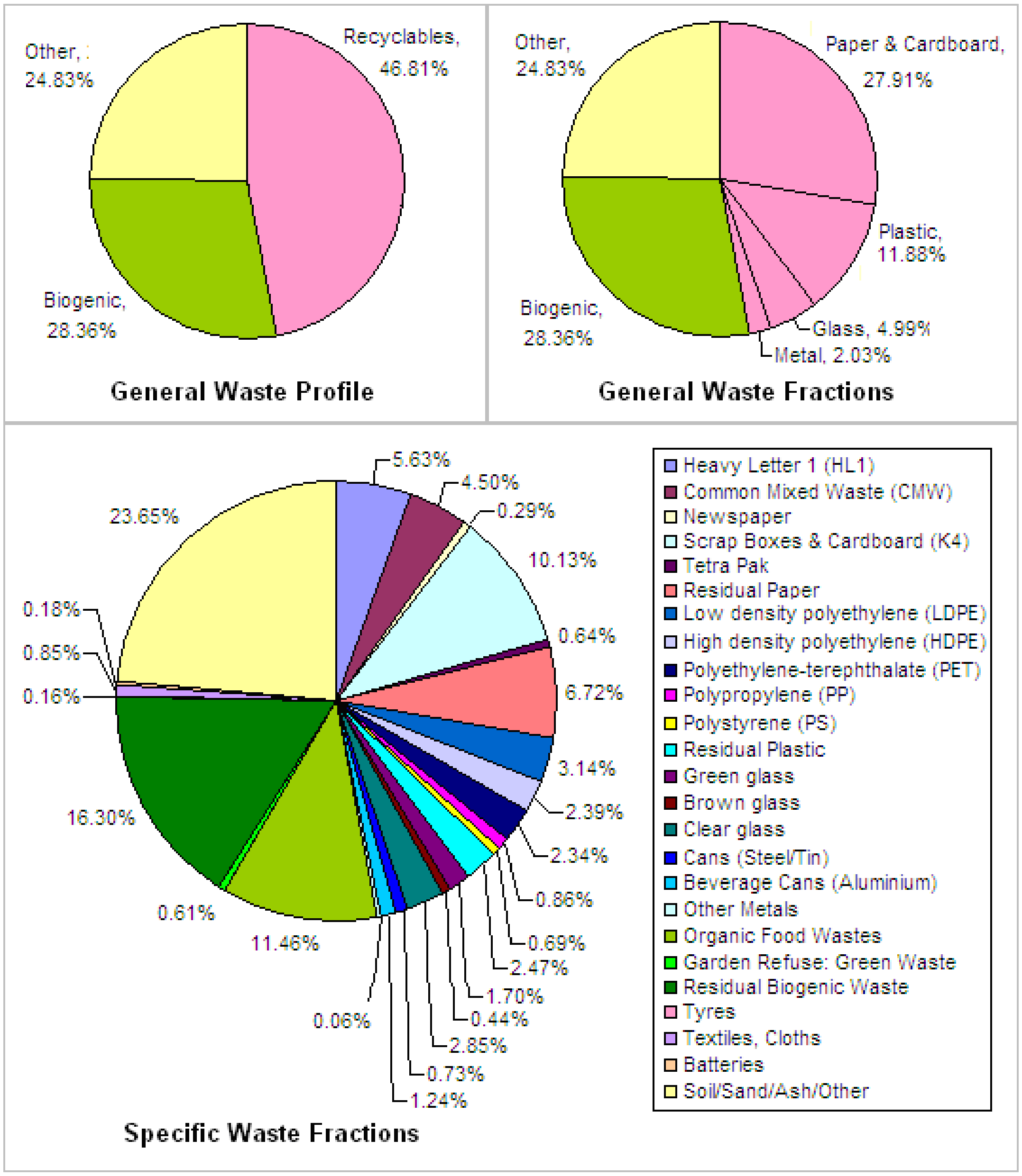


Figure 9.8 – Commercial waste: general waste profile and specific fractions

9.1.10 Urban Industrial (UI) waste stream

The general and specific waste profiles for the UI waste stream are presented in Figure 9.9. The UC waste stream comprises of 64.54% recyclables, with a significantly high percentage of paper and cardboard (50.14%). The biogenic fraction of the UC waste stream amounts to 17.91%.

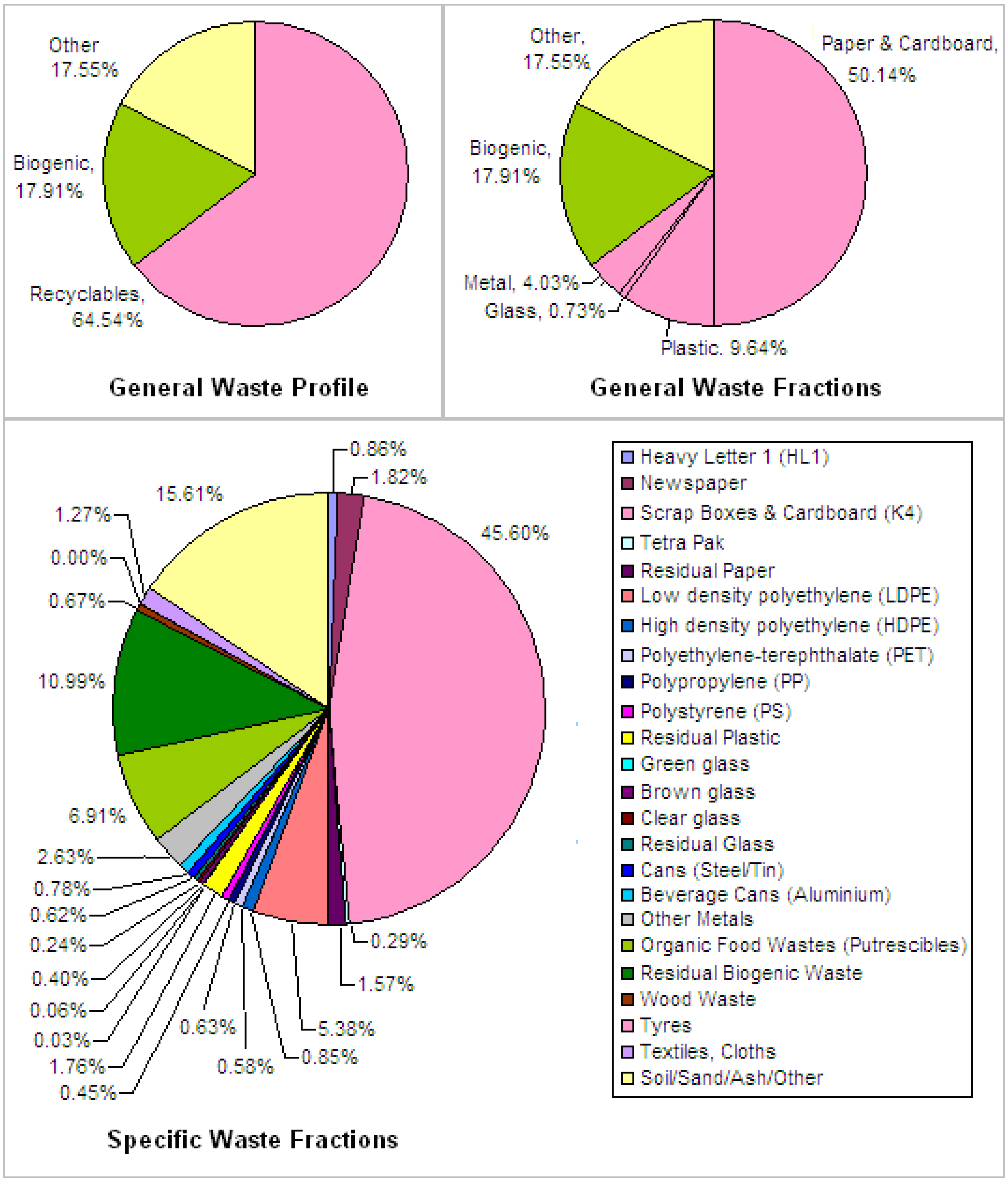


Figure 9.9 – Urban industrial: general waste profile and specific fractions

9.1.11 Interpretation of waste stream analysis results

A summary of the results obtained from the waste stream analysis of the New England Road landfill waste stream is presented in Table 9.1.

Table 9.1 – Summary of WSA results

Individual Waste Stream	Waste Fraction (%)						
	Biogenic	**Other**	**Recyclables**	**Paper**	**Plastics**	**Glass**	**Metal**
Rural High	35.08%	24.53%	40.39%	12.61%	9.02%	14.31%	4.46%
Rural Medium	43.64%	26.80%	29.56%	12.78%	8.81%	5.78%	2.20%
Rural Low	32.62%	23.85%	43.53%	8.99%	7.72%	14.71%	12.11%
Rural Commercial	49.76%	13.36%	36.88%	14.72%	13.49%	6.99%	1.68%
Urban High	36.58%	23.23%	40.19%	16.48%	12.54%	8.75%	2.43%
Urban Medium	37.68%	28.59%	33.73%	16.23%	9.88%	5.41%	2.21%
Urban Low	34.04%	33.61%	32.35%	17.15%	8.66%	3.66%	2.88%
Urban Commercial	28.36%	24.83%	46.81%	27.91%	11.88%	4.99%	2.03%
Urban Industrial	17.91%	17.55%	64.54%	50.14%	9.64%	0.73%	4.03%

9.1.11.1 General household waste stream

The proportions of the principle residential/household waste stream fractions (recyclables, biogenic and other waste) are generally consistent across all income groups for both rural and urban areas, with the exception of the rural and urban low income waste streams. The overall results suggest that waste composition does not differ greatly on the basis of the type of source/area, but rather varies across income groups. This result is expected as the quality or composition of waste differs by income group. Waste generation is related to a number of socio-economic factors such as spending and consumption habits, education and level of environmental awareness, which are all in turn related to income groups (Gaillot et al, 2005)

In both rural and urban areas, high income groups produce a significantly higher percentage of recyclable waste (40.19% and 40.39% respectively). This result is expected, as generally consumption habits of high income groups include the purchasing of pre-prepared, packaged, take-away and convenience foods producing more packaging wastes such as paper, plastic and glass, which all contribute considerably to the recyclable fraction of both rural and urban high income waste streams (Gaillot et al, 2005). Higher levels of recycling are common among lower income groups than high income groups as recycling is used as a source of income (Bogner et al, 2008). This result is only reflected across the urban low income waste stream. The urban low income waste stream comprises 32.35% recyclable materials in comparison with 43.53% for the low income waste stream. This could be due to greater participation in recycling schemes by urban low income groups, as well as closer proximity to recycling and buyback centres and not just a lack of interest or indifference on the part of rural low income groups. Surveys to gauge attitudes and the willingness to recycle in rural areas should be taken to confirm this conclusion. Among the recyclable fractions, paper and cardboard comprised between 8-16%; plastic 7-12%; glass 5-14% and metals 2-4%.

Items such as electronic wastes were more prevalent in urban waste streams, albeit contributing to a small percentage of the overall waste stream. This suggests that electronic wastes are either stored by the owners or perhaps recycled through specialist „e-waste' recycling schemes. Both metal food and beverage cans contribute between 0-2% of the waste stream across all income groups. This result could be attributed to high recovery rates of aluminium and steel cans by the national recycler Collect-a-Can (approximately 70% recovery rate).

Proportions of biogenic waste across all residential/household waste streams were consistently over 30% and in some cases as much as 43.64% (Rural medium income waste stream). The percentages of „Other wastes' (textiles, rubble, soil and other inert and indeterminable materials) was consistent at between 24-30% across all waste streams.

The majority of the loads sampled contained very little, if any garden refuse. This was an expected result as initial consultation with municipal waste managers revealed that independent private garden services were usually employed for both garden services and garden refuse removal, therefore explaining the lack of garden refuse in MSW loads sampled (Jogiat, 2010). A significant quantity of garden refuse could therefore be self hauled by waste generators or garden services and the overall waste steam composition could be greater than the results indicate. The low composition could also be explained by seasonal variation, as sampling took place during the winter season, and very little garden waste would be generated in colder months. Generally garden refuse can be expected from urban high-medium income groups (single households/plots of land with gardens/grassed areas). This expectation was reflected in the results with only 1-2% of garden refuse from both urban high and medium income groups.

9.1.11.2 Commercial and industrial waste streams

Proportions of biogenics, recyclables and other wastes differed greatly in both rural and urban commercial waste streams. This is likely due to the type of commercial activities associated with each area. Urban commercial waste contained as much as 46.81% of recyclables compared with 36.88% for the rural commercial waste stream. This difference is due to the paper and cardboard contribution – almost twice as high for urban commercial waste at 27.91%. This was an anticipated result due to the concentration of businesses and offices in urban commercial areas, where larger quantities of office and graphic paper are used or consumed. High percentages of biogenic wastes can be attributed to green grocers and fresh produce stores, as well as take-away and fast food outlets – evident in sampling of commercial waste loads.

The urban industrial waste stream largely comprises of recyclable waste material (64.54%) with a significant percentage of waste from the paper and cardboard waste group (50.14%). Industrial activities and sources include manufacturing and packaging of goods, as well as industrial complexes/offices. The main industrial activities include manufacturing of aluminium and leather products, chemicals, food and furniture (UMDM, 2009).

9.1.12 Calculated Annual Quantities of Waste Fractions

9.1.12.1 General household waste profile for New England

Table 9.2 lists the average annual quantity of waste generated per income group. This data was used to calculate the average quantity of each waste fraction (listed in Table 9.3) produced by both the uMsunduzi and uMshwathi LM, by multiplying the quantity of waste produced by a specific income group with the average composition as determined by the WSA.

Table 9.2 – Average annual quantities of household waste per income group

(Source: GreenEng, 2010)

Local (tons)	**Urban**			**Rural**		
Municipality	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
uMshwathi	1798	243	97	7277	983	369
uMsunduzi	41649	5625	2113	11811	1595	599
TOTAL	43447	5868	2204	19088	2578	968

Table 9.3 – Calculated average annual quantities of household waste: specific fractions

Waste Fraction	**Quantity (tons)**
Heavy Letter 1 (HL1) (Clean White Paper)	962
Common Mixed Waste (CMW)	591
Newspaper	4926
Scrap Boxes and Cardboard (K4)	2392
Tetrapak	319
Residual Paper	1746
Low density polyethylene (LDPE)	965
High density polyethylene (HDPE)	838
Polyethylene-terephthalate (PET)	1492
Polypropylene (PP)	1265
Polyvinyl Chloride (PVC)	8
Polystyrene (PS)	423
Residual Plastic	1416
Green glass bottles and containers	1696
Brown glass bottles and containers	551
Clear glass bottles and containers	2718
Residual Glass	357
Cans (Steel/Tin)	3095
Beverage Cans (Aluminium)	207
Other Metals	416
Organic Food Wastes (Putrescibles)	11208
Garden Refuse: Green Waste	546
Garden Refuse: Woody Waste	8
Residual Biogenic Waste	13735
Wood Waste	7
Textiles, Cloths	2216
e-Waste	158
Batteries	22
Soil/Sand/Ash/Other	19869
TOTAL	**74161**

The general household waste profile of the New England Road waste stream (illustrated in Figure 9.10 overleaf) was generated by calculating the overall percentage composition of each fraction in the waste stream. The overall household waste stream comprises of approximately 35.58% recyclables and 34.38% biogenic waste. The most prevalent recyclable fraction present in the household waste stream is paper and cardboard (14.75%). Both the recyclable and biogenic fractions and quantities (listed in Table 9.3) are significant enough to warrant investigation into alternate methods of waste management and treatment.

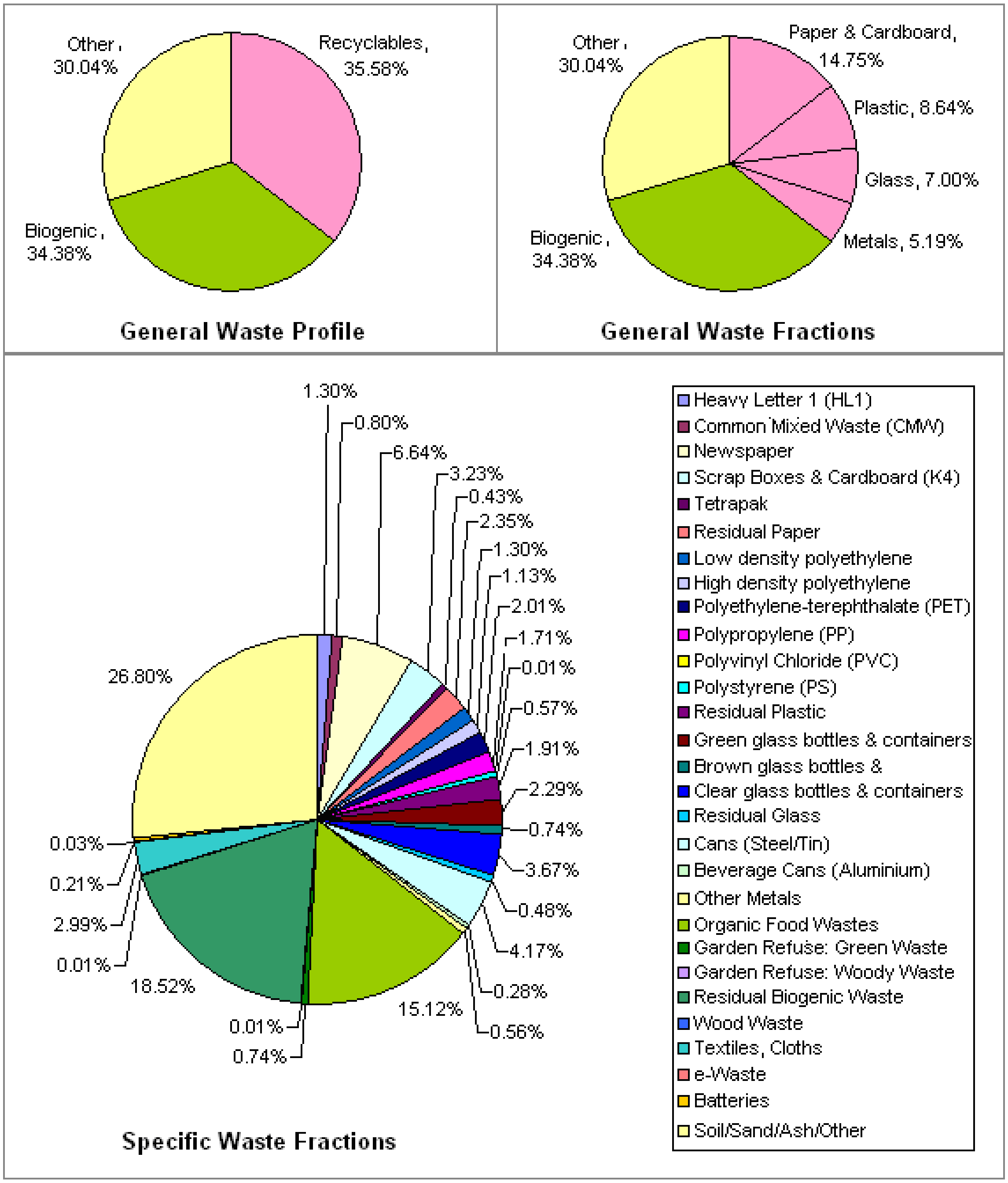


Figure 9.10 – General household waste profile for New England Road waste stream

9.1.12.2 Commercial/industrial waste profile

The commercial waste profile of the New England Road landfill waste stream was produced by applying the average sample compositions from the WSA to the average quantity of rural and urban industrial/commercial waste generated by each local municipality, as listed in Table 9.4 (UMDM, 2009). The percentage distribution of rural and urban developments was used to calculate the average quantity of rural and urban commercial/industrial waste generated by each local municipality.

Table 9.4 – Average annual quantity of industrial/commercial waste generated

Local Municipality	Average Quantity of Ind/Comm Waste (tons)	% Rural	% Urban	Rural Quantity (tons)	Urban Quantity (tons)
uMshwathi	1641	80.19	19.81	1316	325
uMsunduzi	38128	22.09	77.91	8422	29706
TOTAL	**39769**			**9738**	**30031**

Table 9.5 – Calculated average annual quantities of commercial waste: specific fractions

Waste Material	Quantity (tons)
Heavy Letter 1 (HL1)	1069
Common Mixed Waste (CMW)	709
Newspaper	527
Scrap Boxes and Cardboard (K4)	9010
Tetra Pak	167
Residual Paper	1671
Low density polyethylene (LDPE)	1485
High density polyethylene (HDPE)	563
Polyethylene-terephthalate (PET)	545
Polypropylene (PP)	348
Polystyrene (PS)	678
Residual Plastic	925
Green glass	408
Brown glass	168
Clear glass	786
Residual Glass	177
Cans (Steel/Tin)	330
Beverage Cans (Aluminium)	340
Other Metals	404
Organic Food Wastes	5824
Garden Refuse: Green Waste	91
Garden Refuse: Woody Waste	38
Residual Biogenic Waste	5841
Wood Waste	118
Tyres	23
Textiles, Clothes	456
Batteries	27
Soil/Sand/Ash/Other	7039
TOTAL	**39769**

An overall percentage composition was then calculated and the results are presented in Figure 9.11. The biogenic waste fraction amounts to 29.65%. Recyclables form the majority of the commercial/industrial waste stream which comprises of approximately 51.07%. The most prevalent recyclable fraction is paper and cardboard (33.08%).

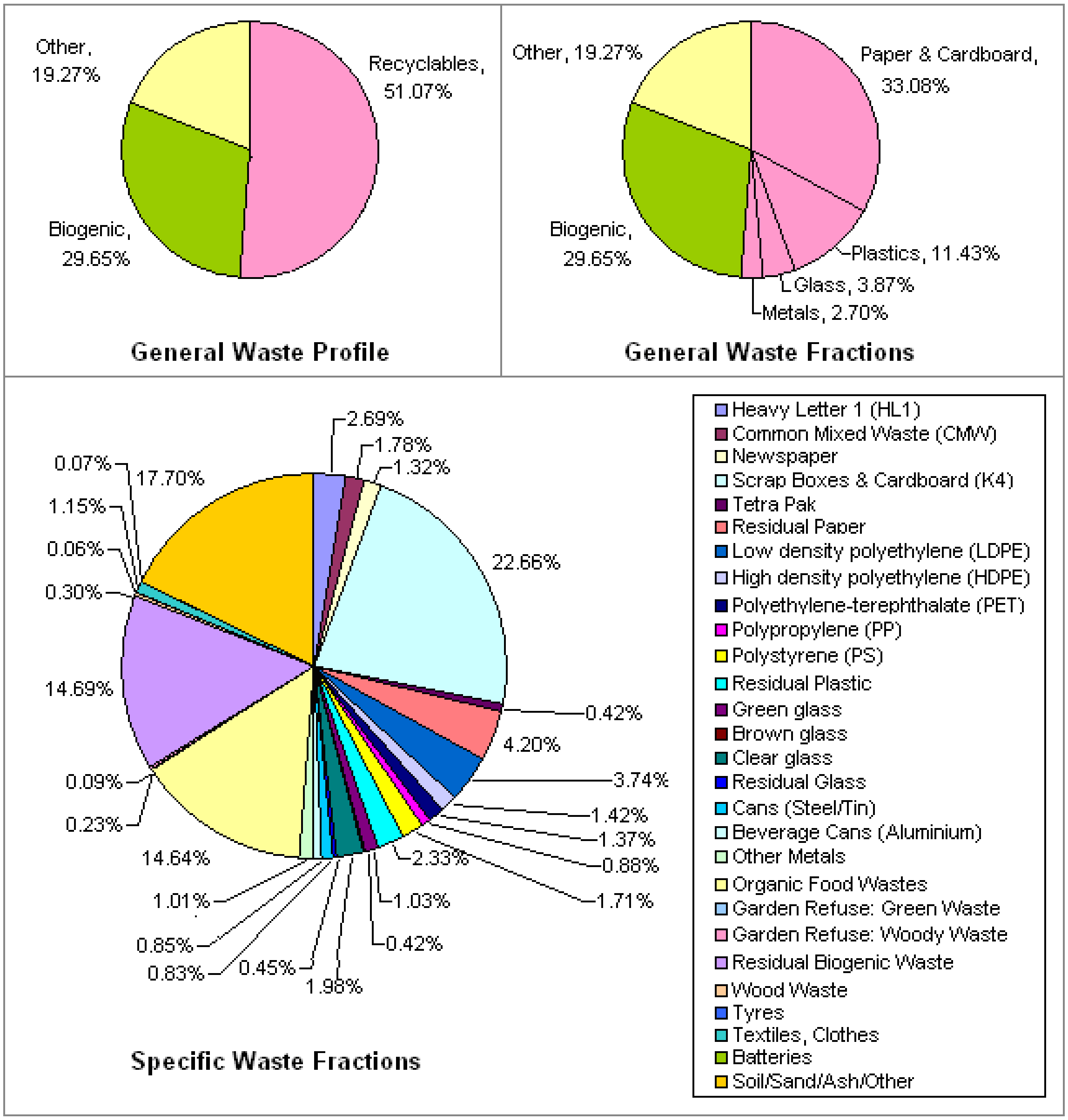


Figure 9.11 – Commercial waste profile for New England Road waste stream

9.1.13 Summary

The data from the WSA of the New England landfill site was used in conjunction with data from the UMDM IWMP review (2009) to produce both a general household and commercial waste profile of the MSW stream. The commercial waste profile comprises of over 50% (20,311 tons per annum) recyclable materials while the general residential waste profile indicates a recyclable content of approximately 35% (26,383 tons per annum), indicating that both the commercial and household waste streams produce a significant quantity of recyclables (46,694 tons per annum). The waste loads sampled comprised of largely uncontaminated or clean recyclables in comparison to eThekwini waste streams. This is due to the greater degree of compaction and mixing of wastes at transfer stations in the eThekwini Municipality (Strachan, 2010). The biogenic waste fraction consists of approximately 37,286 tons per annum (11,792 tons from the commercial sector and 25,494 from household waste). The principal finding was that the quality of general household waste produced varied by income group, rather than the type of area/dwelling (urban or rural).

The objective of the waste stream analysis was to produce data that could be used to generate a waste profile of the incoming MSW stream of the New England Road landfill. It is acknowledged and accepted that some variability or inconsistency in the results is expected due to the duration of sampling, number of samples and seasonal variation, however with the limited time and resources as often is the case with studies of this nature in developing countries, the results still provide an estimate of the quantity and quality of current waste generation/consumption in local municipalities.

9.2 eThekwini Waste Municipality: Waste Stream Analysis data

9.2.1 Household and commercial waste profile

The 1998 WSA of eThekwini conducted by SKC engineers/Haultec (1998) was used as a basis for the data required for GHG modelling as it is the most comprehensive WSA conducted for the region to date. The waste classification used in this analysis presents an anomaly as the waste material categories are not as detailed as the UMDM WSA, for instance, the different grades of plastic material (LDPE, HDPE, PET and so forth) are not included. A profile of the different plastic grades recycled in South Africa was used to estimate these specific fractions and thus the waste compositions were adjusted to include these fractions, as required for the modelling process. A detailed methodology of this modification is presented in Appendix B, and both the household and commercial waste profiles for eThekwini are presented in Figure 9.12 and Figure 9.13 respectively.

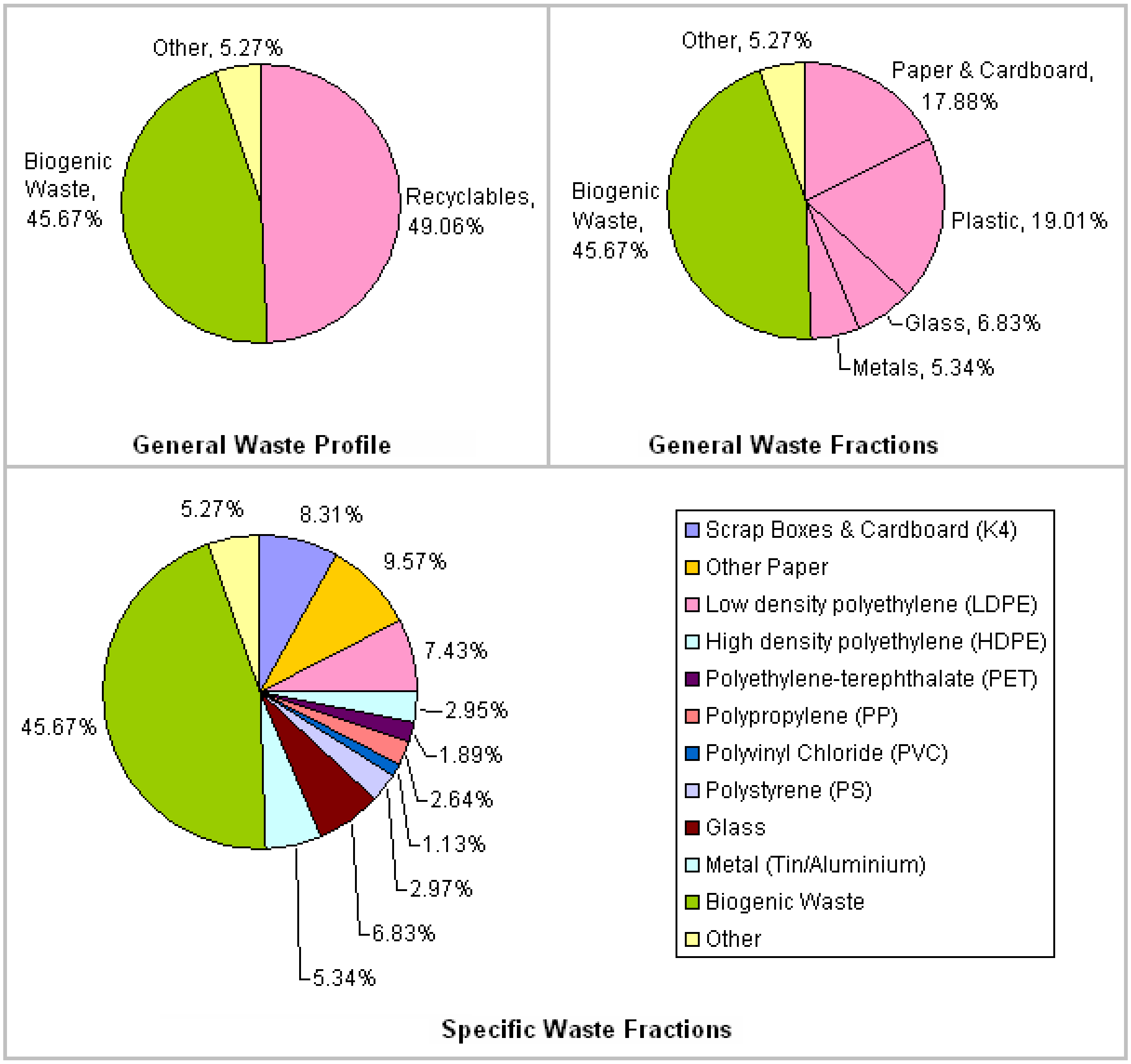


Figure 9.12 – Modified eThekwini household waste profile

(Source: SKC Engineers/Haultec, 1998)

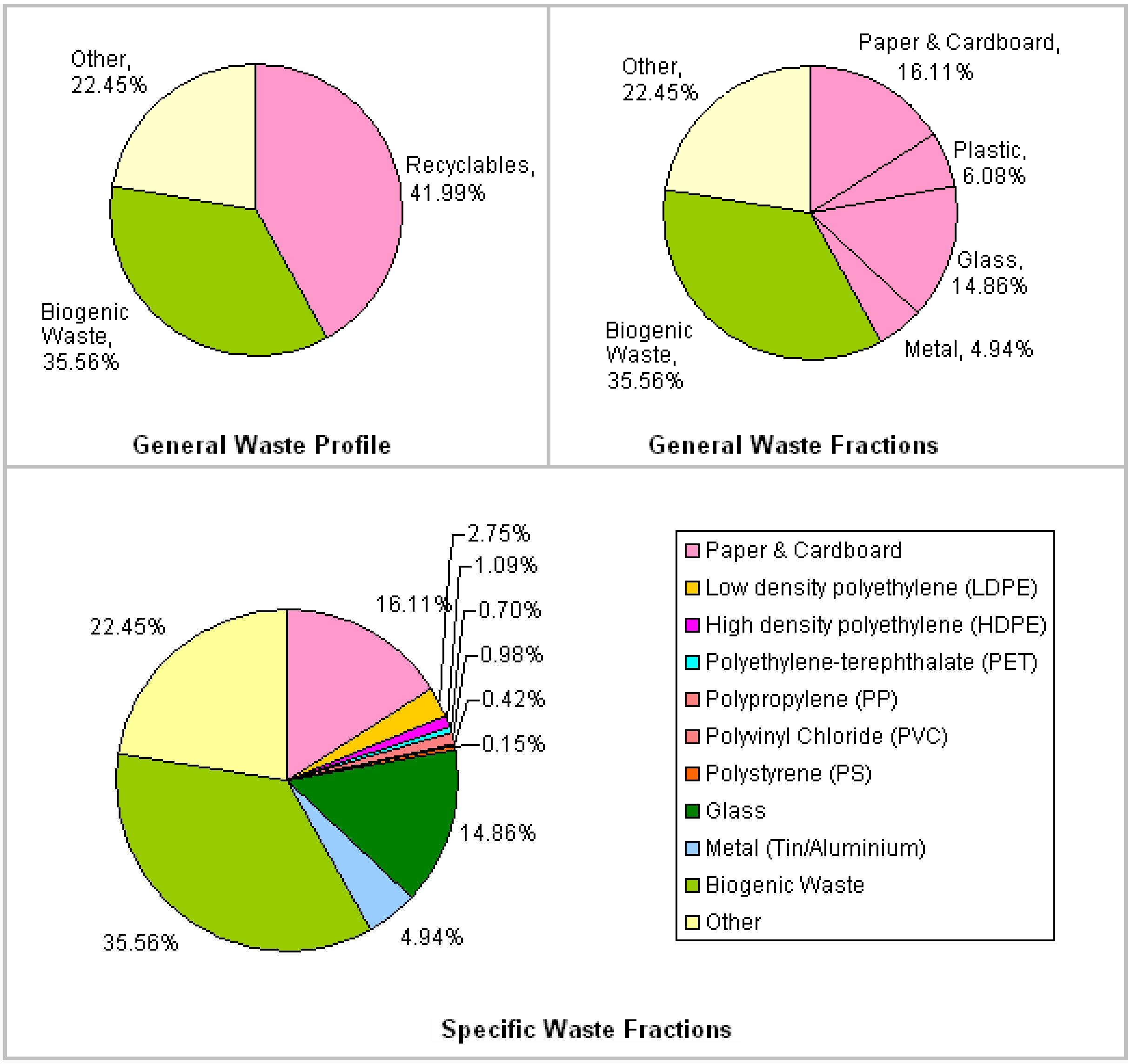


Figure 9.13 – Modified eThekwini commercial waste profile

(Source: SKC Engineers/Haultec, 1998)

9.2.2 Average annual quantities of household and commercial waste

The average annual quantities of both household and commercial wastes were calculated using the waste composition data and the weighbridge data from the Mariannhill landfill site for the year 2009-2010 supplied by Durban Solid Waste (refer to Appendix B, Table B2). The compositions of each fraction for both waste streams are multiplied by the total waste quantity as detailed in the Mariannhill weighbridge data records. The calculated quantities of each waste fraction are presented in Table 9.6.

Table 9.6 – Calculated average annual waste quantities: Mariannhill landfill

Waste Fraction	Quantity (tons)
Paper and Cardboard	19,856
Low density polyethylene (LDPE)	7,147
High density polyethylene (HDPE)	2,839
Polyethylene-terephthalate (PET)	1,815
Polypropylene (PP)	2,542
Polyvinyl Chloride (PVC)	1,089
Polystyrene (PS)	2,593
Glass	10,020
Metal (Tin/Aluminium)	5,966
Biogenic Waste	49,153
Other	10,800
Garden Refuse	8,694
TOTAL	**122,514**

9.2.3 Limitations and Comparison of eThekwini WSA with UMDM WSA

Despite the adjustment for the inclusion of all plastic grades, the specific fractions are still less detailed when compared with the UMDM WSA results. This can be attributed to less focus on waste classification and information systems prior to the institution of the Waste Act in 2008. The methodology employed in the 1998 WSA differed in terms of the component waste streams or strata evaluated. Waste streams were evaluated based on the type of area (informal or formal residential area), income classification as well as population density. The sampling methodology of the 1998 WSA also differed from the 2010 UMDM WSA in that samples were collected directly from the source – waste from waste bins and containers were collected, sorted and weighed for selected households, businesses, hotels and other sources that comprised a representative sample of the area under evaluation. The UMDM WSA instead obtained representative samples from waste collection truck loads from specific focus areas, which were considered to represent a particular income group or area classification. This difference in sampling methodology could be considered an attributing factor to the variation in the waste composition for both the household and commercial waste profiles for each methodology.

Another important factor that should be considered is the ever changing nature and composition of waste as the eThekwini WSA was conducted 12 years earlier. Increasing urbanisation and development, as well as changes in social behaviour and consumer attitudes as compared to 12 years prior could all contribute to variations in waste composition (Gaillot et al, 2005). A summary of the waste profile results from both the 1998 eThekwini WSA and the 2010 UMDM WSA is presented in Table 9.7.

Table 9.7 – Waste profile comparison for eThekwini Municipality and UMDM

Municipality	**eThekwini**	**UMDM**	**eThekwini**	**UMDM**
Waste Stream	**Household**	**Household**	**Commercial**	**Commercial**
Waste Fraction	**Waste fraction composition (%)**			
Biogenic	45.67	34.38	35.56	29.65
Other waste	5.27	30.04	22.45	19.27
Recyclables	49.06	35.58	41.99	51.07
Paper and Cardboard	17.88	14.75	16.11	33.08
Plastic	19.01	8.65	6.08	11.43
Glass	6.83	7.00	14.86	3.87
Metals	5.34	5.18	4.94	2.70

The following comparisons and variations in the waste profile compositions for both household and commercial waste profiles are noted:

- High composition of biogenic waste across all profiles of between 29-46% which warrants investigation into alternate methods of treatment and disposal of biogenic waste to yield greater benefits (methane emissions reductions, electricity from biogas projects and so forth).

- Smaller fractions of the „Other waste' fraction for the eThekwini Municipality in comparison with the UMDM. This can be attributed to the sampling methodology. Truck loads of waste were sampled in the UMDM study, and subsequent mixing of the waste to obtain representative samples may have lead to a greater fraction of indeterminable wastes. The eThekwini WSA sampled waste bins and containers at the source of generation, probably producing „cleaner' samples, where individual waste fractions were clearly identifiable.

- High composition of mixed recyclables ranging between 35-50% across all profiles for both municipalities. The high recyclable content bodes well for potential recycling and MRF projects; however the quality of the recyclables present in the waste stream should be evaluated to assess the degree of contamination and potential recovery rates.

Despite the obvious limitations of using the 1998 eThekwini WSA data, these results are the most accurate and representative data set available for the region. The data from this 1998 WSA has been adjusted where possible using valid assumptions to produce a more detailed data set. As highlighted in the methodology, the New England Road landfill is the major landfill for the UMDM and is therefore representative of the regions waste generation. eThekwini, however, comprises of three major landfill sites, and performing a full scale WSA would require significant capital, resources, and time, which at the time of the research investigation were not available. Ideally, a full scale WSA for the eThekwini region should have been undertaken, however for the objective of the study - to provide a comparative analysis of GHG impacts for various waste management scenarios – the 1998 eThekwini study is considered sufficient.

9.3 Carbon Emissions/Reductions assessment results

9.3.1 General observations and analysis of scenarios

A summary of the results obtained from the carbon emissions/reductions assessment using the WROSE model is presented in Table 9.8. All input and output data may be found in Appendix D.

Table 9.8 – Carbon Emissions/Reductions assessment results

SCENARIO	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5
DESCRIPTION	Landfilling	Landfilling and LFG Recovery	Landfilling and MRF Recycling	MBT: Landfilling, MRF Recycling and AD	MBT: Landfilling, MRF Recycling and Composting
New England Landfill Site	86,675	-8,331	-49,143	-71,522	-63,338
Mariannhill Landfill Site	111,012	-5,758	-18,122 (9.82%) -56,075 (40%)	-86,123	-71,280

The WROSE evaluation of GHG emissions confirm that the scenario one (landfill disposal of all MSW) produces the greatest GHG emissions, and is therefore the least favourable waste management strategy in terms of environmental benefit. The recovery of landfill gas at a 75% recovery rate through scenario two produces a 110% and 105% decrease in emissions for the UMDM and the eThekwini Municipality respectively. This result highlights 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 derivation of the emission factors, and subsequently the WROSE model.

Recycling, which is implemented in scenarios three, four and five, as expected produced a significantly higher GHG reduction in comparison to landfilling and landfill gas recovery scenarios. This reduction 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. In terms of the treatment of the biogenic fraction of the waste, anaerobic digestion clearly produces a high reduction in GHG's, followed by composting. MBT scenarios (scenarios four and five) produced the highest GHG reductions as they allow for integrated waste management.

9.3.2 Analysis by Strategy

9.3.2.1 Landfill Disposal and Landfill Gas Recovery

Table 9.9 shows the average percentage contribution of each waste fraction to GHG emissions from landfill disposal of waste. Scenario one produces the greatest emissions for both landfill waste streams 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. Although biogenic carbon dioxide is not considered, the methane produced from anaerobic conditions prevailing in landfill cells is considered in the analysis as this methane is produced through anthropogenic activity (landfilling of waste). The second greatest contributor to GHG emissions is the paper fraction, comprising common mixed waste and the K4 cardboard/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 (Smith et al, 2001; US EPA, 2006). 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.

Table 9.9 – Landfill emissions contribution of waste fractions

	eThekwini Municipality		**UMDM**	
Waste Fraction	**Emissions** ($MTCO_2eq$)	**% Emissions Contribution**	**Emissions** ($MTCO_2eq$)	**% Emissions Contribution**
General mixed paper (CMW)	15,814	14.25%	10,765	12.02%
Scrap Boxes and 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%**

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 transportation emissions and emissions from the operation of machinery and vehicles on site required for landfilling.

The implementation of landfill gas recovery with a gas recovery efficiency of 75% reduces the emissions from landfill disposal significantly. The recovery of methane and generation of electricity results in GHG savings of 5,758 and 8,331 $MTCO_2eq$ from the eThekwini Municipality and uMgungundlovu DM respectively. The greater GHG savings for the UMDM is attributed to the larger fraction of paper (24,089 tons/annum) generated in comparison with the Mariannhill landfill waste stream (19,856 tons/annum). It is possible that the actual amount of paper generated in the eThekwini municipality is higher than the input value which was calculated using data from the 1998 WSA. Published carbon emission reductions for the Mariannhill landfill gas to energy project amounted to approximately 16,000 $MTCO_2eq$/annum (Couth et al, 2010). The difference between this data and the value calculated differ by almost 10,000 $MTCO_2eq$/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 affecting landfill gas generation as waste composition, pH, moisture content, temperature and nutrient availability. 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 have been 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.

9.3.2.2 Recycling

The GHG reductions from recycling assuming a 40% recovery rate for both case studies are shown in Table 9.10 along with the contribution to the total GHG reductions**.**

Table 9.10 – Emission reductions contribution from recycling

	eThekwini Municipality		**UMDM**	
Waste Fraction	**Emissions (MTCO$_2$eq)**	**% Emissions Contribution**	**Emissions (MTCO$_2$eq)**	**% Emissions Contribution**
Newspaper	0.00	0.00%	-6731.59	14.29%
General mixed paper (CMW)	-16588.18	30.84%	-11292.91	23.97%
Scrap Boxes and Cardboard (K4)	-12656.87	23.53%	-15635.97	33.19%
Low density polyethylene (LDPE)	-5389.08	10.02%	-1847.25	3.92%
High density polyethylene (HDPE)	-1753.12	3.26%	-864.21	1.83%
Polyethylene-terephthalate (PET)	-1240.43	2.31%	-1392.49	2.96%
Polypropylene (PP)	-1704.00	3.17%	-1080.71	2.29%
Polyvinyl Chloride (PVC)	-730.52	1.36%	-5.03	0.01%
Polystyrene (PS)	-1737.51	3.23%	-737.23	1.57%
Glass	-1237.06	2.30%	-846.93	1.80%
Steel Cans/Tins	-3823.48	7.11%	-3369.10	7.15%
Aluminium Cans	-6931.55	12.89%	-3300.02	7.01%
Total Emissions	**-53791.80**	**100.00%**	**-47103.45**	**100.00%**

Although in theory higher recycling recovery rates can be achieved, a 40% recycling rate was chosen in line with a conservative approach toward GHG modelling. Recovery and recycling of the paper fraction produce the greatest environmental benefit, contributing to approximately 50% of the total recycling emissions reductions. The high GHG savings can be attributed to increased carbon sequestration from trees, due to the recycling of forest paper products, as well as the high quantity of paper waste present in the waste stream. The recycling of aluminium contributes to approximately 12.89% and 7.01% of the total emissions reductions for the Mariannhill and New England Road waste streams, despite the relatively low waste amount present in both waste streams (1696 tons in total). This is due to the energy intensive process of aluminium production – recycling of aluminium requires 95% less energy than production from virgin materials.

The single limitation of modelling of emissions from recovery and recycling of waste concerns the energy input required for MRF separation and sorting processes which are not included in the derivation of the US EPA emissions factors. Assuming an energy consumption of 18 kWh/ton of waste, and an energy emissions factor of 1.015 kg CO_2eq/kWh, the average emissions from MRF operations at the Mariannhill and New England Road Landfill would amount to approximately 984 and 810 $MTCO_2$eq/annum respectively – relatively small in comparison to the expected GHG savings. The benefits of recycling therefore outweigh the emissions and energy input required for recovering recyclables from the waste stream.

9.3.2.3 Anaerobic Digestion and Aerobic Composting

A comparison of the results for the biological treatment of the biogenic fraction of both the Mariannhill and New England waste streams is presented in Figure 9.14.

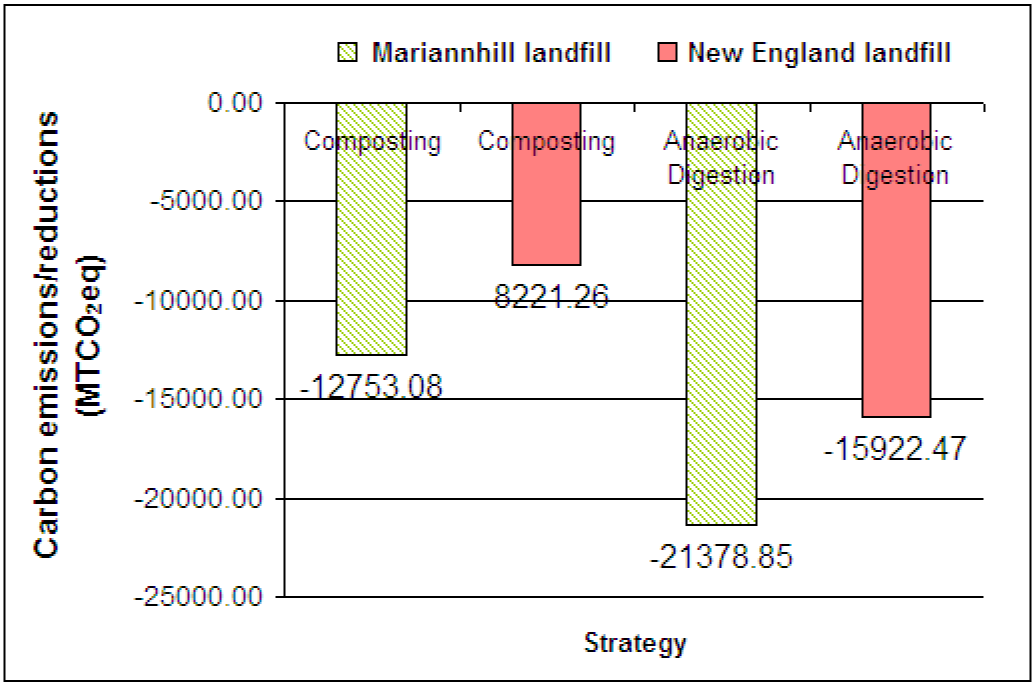


Figure 9.14 – Comparison of anaerobic digestion and composting strategies

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 outweigh the environmental benefits of both composting and landfill gas recovery, making it the preferable strategy in terms of reducing 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 cost of implementation, in comparison with a less capital intensive and carbon neutral strategy such as composting.

9.3.3 Analysis of CER Assessment: eThekwini Municipality and UMDM

The results of the Mariannhill Landfill CER Assessment are presented in Figure 9.15.

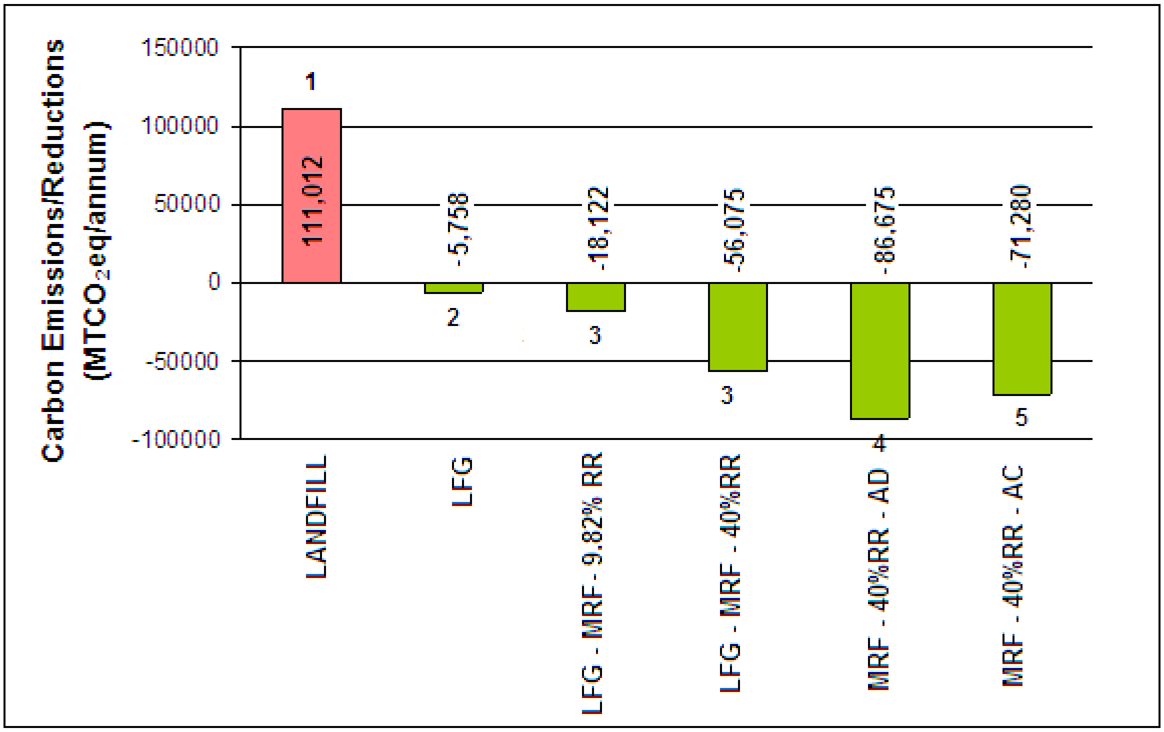


Figure 9.15 – CER Assessment of Mariannhill landfill waste stream

The landfill disposal of all MSW produces total emissions of 111,012 MTCO$_2$eq/annum. Every other scenario of waste management strategies produces a net reduction of varying degree. The status quo of waste management for the Mariannhill landfill (landfill disposal with gas recovery and 9.82% MRF recycling recovery rate) produces approximately 18,122 MTCO$_2$eq/annum. The current MRF recycling recovery rate produces approximately 13,000 MTCO$_2$eq/annum whilst an increase in the recovery rate to 40% would produce approximately 53,000 MTCO$_2$eq/annum. Recycling recovery rates should therefore be increased to improve GHG emission reductions. Scenario four which integrates several strategies: anaerobic digestion of biogenic wastes with electricity generation; recycling of recyclable fractions at a 40% recovery rate, and landfill disposal of all residual waste produces the greatest environmental benefit (GHG reductions of -86,675 MTCO$_2$eq/annum). Scenario 4, which also targets specific fractions of the waste streams (composting of biogenics, recycling of recyclable fraction and landfilling of residual waste) also produces considerable reductions (-71,280 MTCO$_2$eq/annum).

The results from the CER assessment for the New England Road landfill are presented in Figure 9.16.

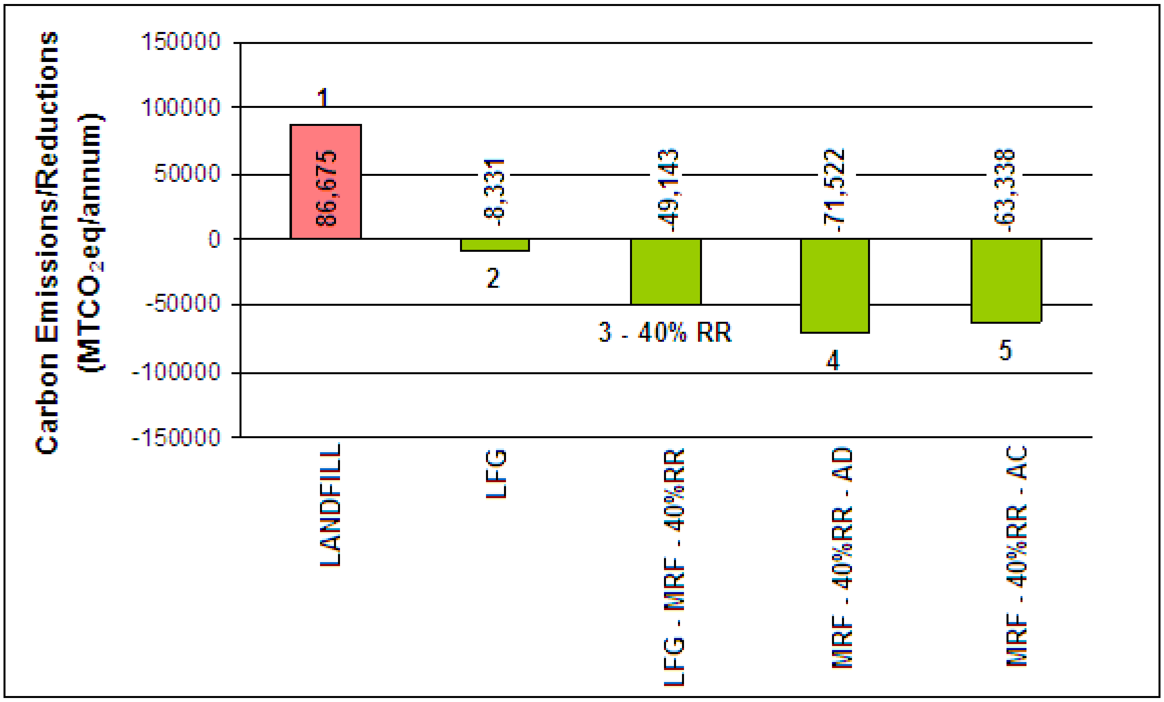


Figure 9.16 – CER Assessment of New England Road landfill waste stream

The UMDM case study generally produced similar results to the eThekwini case study in terms of the scenarios either generating net emissions or reductions. The quantity of these emissions vary, due to the variation of waste fraction quantities – a greater amount of biogenic waste is produced in the eThekwini municipality, resulting in greater methane emissions from landfilling in scenario one, and greater reductions from MBT treatment in Scenarios four and five when compared with the UMDM. The current status quo produces average GHG emissions of 86,675 MTCO$_2$eq/annum. Implementation of a landfill gas recovery system could theoretically reduce these emissions considerably, by approximately 110%. An MRF recycling facility recovering 40% of recyclables together with landfill gas recovery would reduce emissions from the current status quo by approximately 160%. The resultant savings could in reality be higher, as recyclables in the waste stream were found to be relatively clean and uncontaminated, as discussed in the WSA results in section 9.1 and therefore a greater recycling recovery rate could be achieved. Integrated waste management strategies in scenario four and five, like the Mariannhill assessment produce greater GHG reductions (71,522 and 63,338 MTCO$_2$eq/annum).

9.4 Landfill Space Savings

The results from the landfill space savings estimate for the Mariannhill and New England Road waste streams are presented in Table 9.11 and 9.12 respectively.

Table 9.11 – Landfill Space Savings: Mariannhill waste stream

METHODOLOGY	LANDFILL SPACE SAVINGS (m^3)		
	Scenario 3	**Scenario 4**	**Scenario 5**
Waste Diverted from Landfill (tons):	*5,294 **21,549	70,702	79,396
1. Mixed MSW Density Methodology (ρ_{MSW} = 1200 kg/m^3)	*4,412 **17,958	58,918	66,163
2. Environmental Benefits of Recycling Calculator	*17,919 **72,946	128,174	137,942
3. US EPA MSW Landfill Density	*13,414 **54,606	96,031	105,801
Average Landfill Space Savings (m^3)	***11,915** ****48,503**	**94,375**	**103,302**

* Current Recycling Recovery Rate - 9.82%

** Potential Recycling Rate - 40%

Table 9.12 – Landfill Space Savings: New England waste stream

METHODOLOGY	Scenario 3	Scenario 4	Scenario 5
Waste Diverted from Landfill (tons):	17,791	54,399	55,082
1. Mixed MSW Density Methodology (ρ_{MSW} = 1200 kg/m^3)	14,826	45,333	45,902
2. Environmental Benefits of Recycling Calculator	59,310	100,443	101,210
3. US EPA MSW Landfill Density	43,568	74,420	75,188
Average Landfill Space Savings	**39,235**	**73,399**	**74,100**

The results obtained, as discussed in the methodology, produce a range of landfill space savings for each scenario as conditions and operations (degree and efficiency of compaction of waste) differ from one landfill site to the next. The MSW compacted density method provided the most conservative estimate, while the EBR calculation method produced the better savings. In both case study's scenario five (MRF recycling and composting) results in the highest 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 highest 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 four or five is implemented.

The remaining airspace for the Mariannhill landfill as at June 2002 was estimated to be 3.8 million m^3 (eThekwini Municipality, n.d). 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 municipal solid waste landfilled annually. The predicted landfill airspace capacity trends as illustrated by Figure 9.17 show that if scenario three were to be achieved (40% recovery rate of recyclables) a further 4 years could be added to the landfill lifespan. The diversion of recyclables together with diversion of the biogenic fraction of the waste stream to either anaerobic digestion or composting through scenario four or five would result in an extended lifespan of between 12 -14 years.

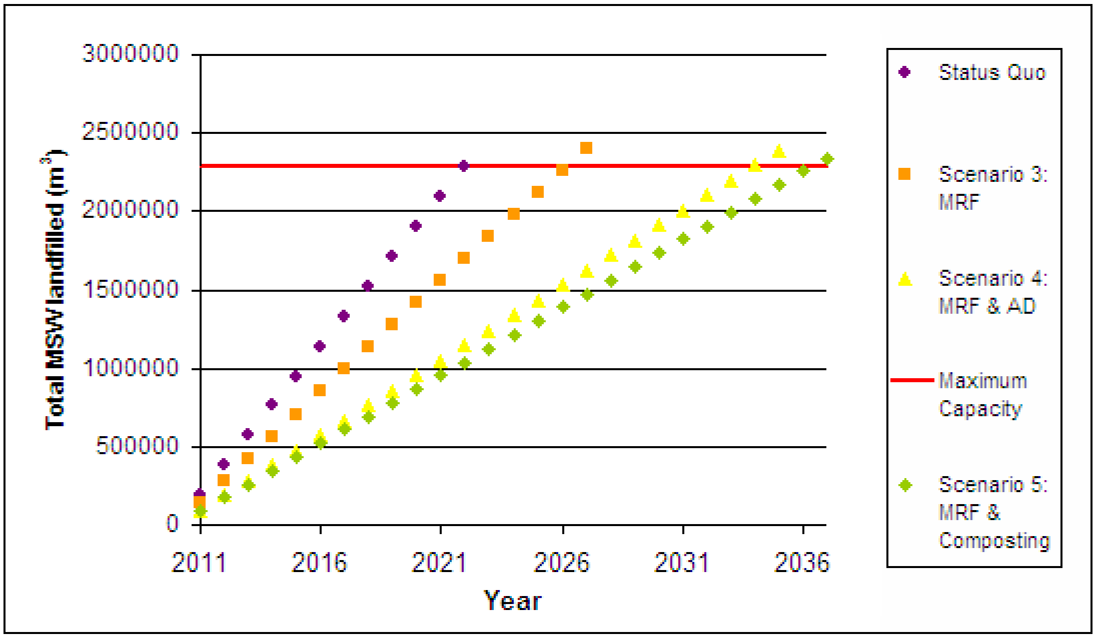


Figure 9.17 – Predicted airspace capacity trends per scenario: Mariannhill landfill

An evaluation of landfill airspace of the New England Road landfill conducted in November 2007 estimated a remaining lifespan of six to nine years, provided that 250, 000 m^3 of municipal solid waste is disposed of annually (Jogiat, 2009). Assuming a remaining average lifespan of eight years (expectant closure in 2016/2017 – a further six years landfill space currently remains), the New England Road landfill currently has capacity for 1,500,000 m^3 of MSW. The predicted landfill airspace trends are illustrated in Figure 9.18. If scenario three is implemented, the landfill lifespan would be extended by a year, while if scenario four or five were to be implemented, the lifespan would be extended by approximately two and half years.

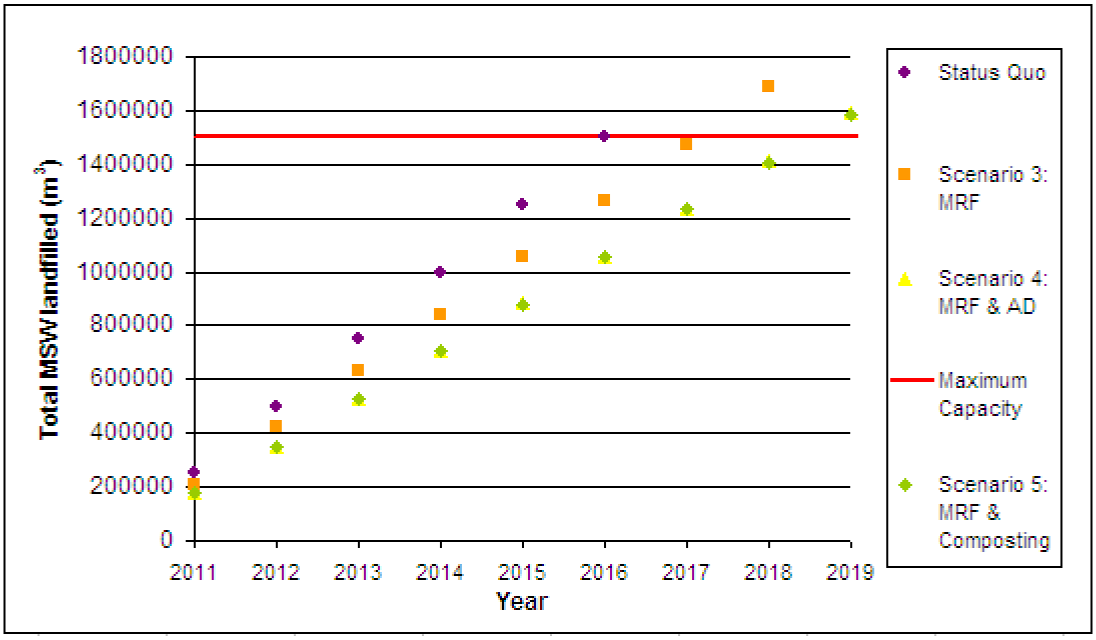


Figure 9.18 – Predicted airspace capacity trends per scenario: New England Road Landfill

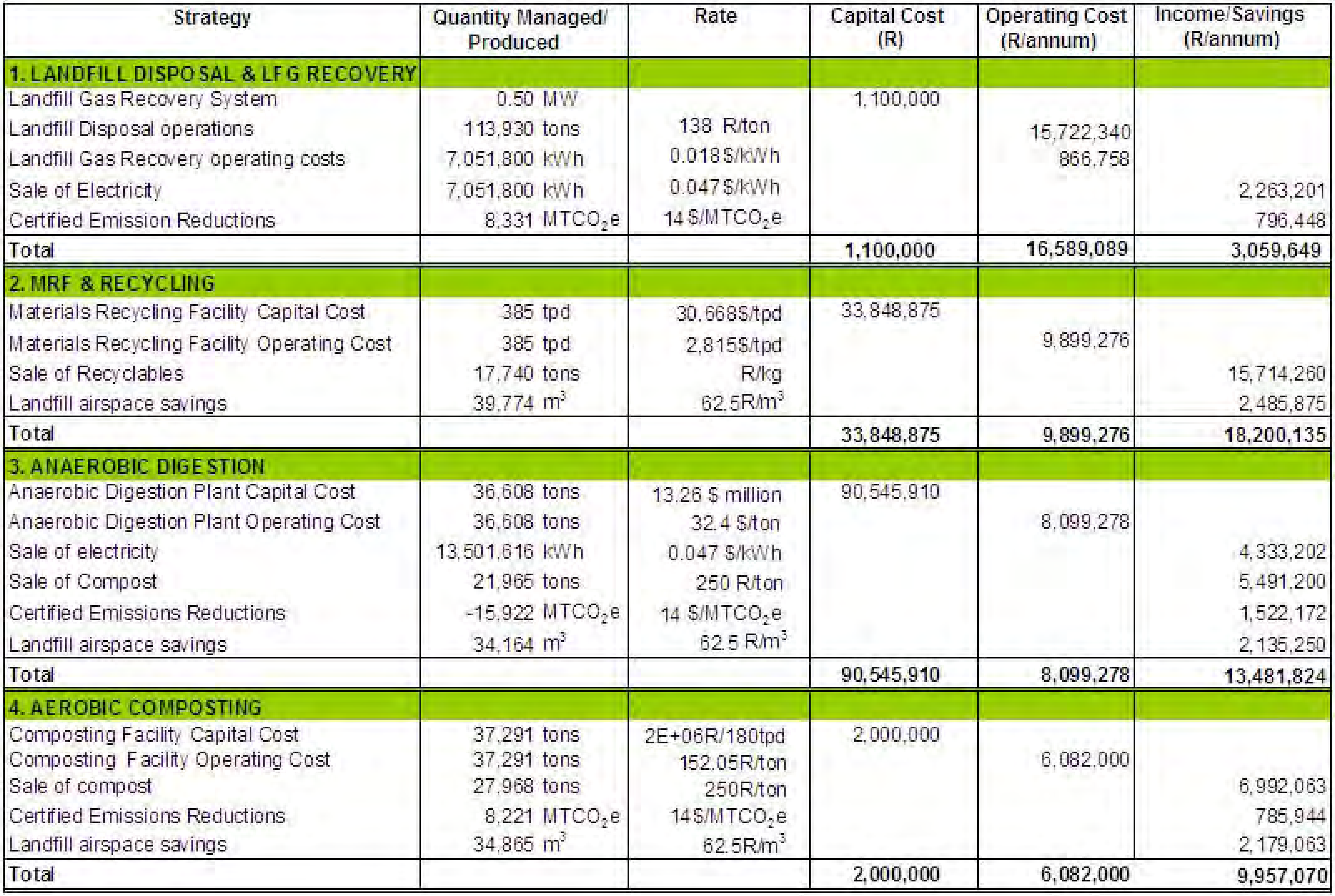
9.5 Economic Analysis: Potential cost savings and income generation

The results of the economic analysis of each strategy for both the Mariannhill and New England Road waste streams are presented in Tables 9.13 and 9.14 respectively.

Table 9.13 – Economic analysis strategy implementation: Mariannhill waste stream

Strategy	Quantity Managed/ Produced	Rate	Capital Cost (R)	Operating Cost (R/annum)	Income/Savings (R/annum)
1. LANDFILL DISPOSAL & LFG RECOVERY					
Landfill Gas Recovery System	0.50 MW		1,100,000		
Landfill Disposal operations	122,514 tons	138 R/ton		16,906,932	
Landfill Gas Recovery operating costs	7,051,800 kWh	0.018$/kWh		866,758	
Sale of Electricity	7,051,800 kWh	0.047$/kWh			2,263,201
Certified Emission Reductions	5,758 $MTCO_2e$	14$/$MTCO_2e$			550,458
Total			**1,100,000**	**17,773,690**	**2,813,659**
2. MRF & RECYCLING					
Materials Recycling Facility Capital Cost	385 tpd	30,668$/tpd	33,848,875		
Materials Recycling Facility Operating Cost	385 tpd	2,815$/tpd		9,899,276	
Sale of Recyclables	21,549 tons	R/kg			19,598,660
Landfill airspace savings	47,122 m^3	62.5R/m^3			2,945,125
Total			**33,848,875**	**9,899,276**	**22,543,785**
3. ANAEROBIC DIGESTION					
Anaerobic Digestion Plant Capital Cost	49,153 tons	15.24$ million	104,066,340		
Anaerobic Digestion Plant Operating Cost	49,153 tons	28.2$/ton		9,465,084	
Sale of electricity	18,128,413 kWh	0.047$/kWh			5,818,124
Sale of Compost	29,492 tons	250R/ton			7,372,950
Certified Emissions Reductions	21,379 $MTCO_2e$	14$/$MTCO_2e$			2,043,797
Landfill airspace savings	45,872 m^3	62.5R/m^3			2,867,000
Total			**104,066,340**	**9,465,084**	**18,101,871**
4. AEROBIC COMPOSTING					
Composting Facility Capital Cost	57,847 tons	2E+06R/180tpd	3,066,667		
Composting Facility Operating Cost	57,847 tons	152.05R/ton		9,123,000	
Sale of compost	43,385 tons	250R/ton			10,846,313
Certified Emissions Reductions	12,753 $MTCO_2e$	14$/$MTCO_2$			1,219,182
Landfill airspace savings	54,799 m^3	62.5R/m^3			3,424,938
Total			**3,066,667**	**9,123,000**	**15,490,433**

Table 9.14 – Economic analysis strategy implementation: New England Road waste stream



Strategy	Quantity Managed/ Produced	Rate	Capital Cost (R)	Operating Cost (R/annum)	Income/Savings (R/annum)
1. LANDFILL DISPOSAL & LFG RECOVERY					
Landfill Gas Recovery System	0.50 MW		1,100,000		
Landfill Disposal operations	113,930 tons	138 R/ton		15,722,340	
Landfill Gas Recovery operating costs	7,051,800 kWh	0.018 $/kWh		866,758	
Sale of Electricity	7,051,800 kWh	0.047 $/kWh			2,263,201
Certified Emission Reductions	8,331 $MTCO_2e$	14 $/$MTCO_2e$			796,448
Total			**1,100,000**	**16,589,089**	**3,059,649**
2. MRF & RECYCLING					
Materials Recycling Facility Capital Cost	385 tpd	30,668$/tpd	33,848,875		
Materials Recycling Facility Operating Cost	385 tpd	2,815$/tpd		9,899,276	
Sale of Recyclables	17,740 tons	R/kg			15,714,260
Landfill airspace savings	39,774 m^3	62.5R/m^3			2,485,875
Total			**33,848,875**	**9,899,276**	**18,200,135**
3. ANAEROBIC DIGESTION					
Anaerobic Digestion Plant Capital Cost	36,608 tons	13.26 $ million	90,545,910		
Anaerobic Digestion Plant Operating Cost	36,608 tons	32.4 $/ton		8,099,278	
Sale of electricity	13,501,616 kWh	0.047 $/kWh			4,333,202
Sale of Compost	21,965 tons	250 R/ton			5,491,200
Certified Emissions Reductions	-15,922 $MTCO_2e$	14 $/$MTCO_2e$			1,522,172
Landfill airspace savings	34,164 m^3	62.5 R/m^3			2,135,250
Total			**90,545,910**	**8,099,278**	**13,481,824**
4. AEROBIC COMPOSTING					
Composting Facility Capital Cost	37,291 tons	2E+06R/180tpd	2,000,000		
Composting Facility Operating Cost	37,291 tons	152.05R/ton		6,082,000	
Sale of compost	27,968 tons	250R/ton			6,992,063
Certified Emissions Reductions	8,221 $MTCO_2e$	14$/$MTCO_2e$			785,944
Landfill airspace savings	34,865 m^3	62.5R/m^3			2,179,063
Total			**2,000,000**	**6,082,000**	**9,957,070**

The following conclusions can be drawn from the cost and income analysis:

- Landfill disposal with landfill gas recovery is the least capital intensive for the scale of application on both landfill sites. This result highlights the previous recommendations that landfill gas recovery (at the very least) should be implemented for future landfills planned in the UMDM. Landfill gas electricity projects have been implemented successfully in eThekwini, and lessons learnt from the CDM process and the operation of such projects will aid in implementation. The potential income could increase with the implementation of the Renewable Energy Feed in Tariff (REFIT). REFIT is currently being developed by the government to provide incentives for investment in renewable energy sources. REFIT allows suppliers of renewable energy (from landfill gas, hydroelectricity, wind and solar power) to sell electricity at a set price that covers the cost of generation and ensures a significant profit (Couth et al, 2010). Couth et al (2010) 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.

- Operating costs of all waste diversion strategies are lower than landfill disposal of waste. The capital costs of landfill disposal were not included as landfill disposal is the current method of waste management. The cost of developing, siting and constructing a new landfill may vary between R 80-100 million, depending on the design life and capacity required (City of Cape Town IWMP, 2004). As both The New England Road and Mariannhill landfill sites are scheduled to close within the next ten years, these costs should be taken into consideration for future planning in comparison with the capital investment and benefits associated with anaerobic digestion, materials recovery and composting.

- The implementation of an MRF processing 100,000 tons per annum requires significant capital investment of approximately R34 million however the highest income and savings is achieved: approximately R22 million and R18 million for Mariannhill and New England Road waste streams per annum. Although price volatility in the recycling market is of concern as discussed in Chapter 5, an MRF is still a requirement for mechanical pre-treatment phase of MBT strategies, as source separation is not currently implemented (Stromberg, 2004; Matete and Trois, 2008; Lavee et al, 2009).

- A full scale anaerobic digestion plant for the New England Road (40,000 tons/annum) and Mariannhill (60,000 tons/annum) waste streams requires the highest capital investment (R 90-100 million), with an estimated net profit of approximately R 5.3 million for the New England waste stream and R 8.6 million for the Mariannhill 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 R 3.91 million and R 6.37 million for a required capital expenditure of R 2 million and R 3 million for the New England and Mariannhill 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 potential costs are not accounted for (MGP, 2010). In this respect anaerobic digestion plants have a definite advantage over composting, as the major potential income sources are through the sale of electricity, and certified emission reductions, which account for approximately 50% of the total net profit for both waste streams.

- Economic analyses usually do not take into account the social and environmental context of implementing waste management strategies. The 2006 Stern Review (by former chief economist of the World Bank, Sir Nicholas Stern) estimated the societal cost of climate change to be US$ 110 (approximately R750) per ton of CO_2 equivalent (Warnken ISE, 2007). Although the validity of this Figure has been questioned, the estimate raises the issue of actually considering the benefits (both societal and environmental) to accurately gauge the full potential of strategies such as anaerobic digestion in both waste management and global warming mitigation.

It should be noted that the cost and income estimates are based on available data and similar cost studies, and are not a full economic feasibility study of the waste diversion strategies. There is a general lack of local data especially with regard to MRF and AD plant costs as these strategies are not employed extensively throughout South Africa as is the case with European countries. The reliance on European/North American data and estimates may affect cost estimates as simply converting from one currency to another does not constitute an accurate estimate as costs such as labour, electricity and other utilities vary with the economy (Rapport et al, 2008). The estimates included in this study are intended to provide a general understanding of the nature and type of costs and income.

9.6 Summary of results

A summary of the results obtained from the WSA, CER assessment and LSS analysis is presented for the Mariannhill and New England Road waste streams in Figures 9.19 and 9.20 respectively. These figures show the amount of waste diverted (quantity), the proportion of the total MSW stream diverted (quality), landfill space savings, and GHG emissions from each strategy for all scenarios.

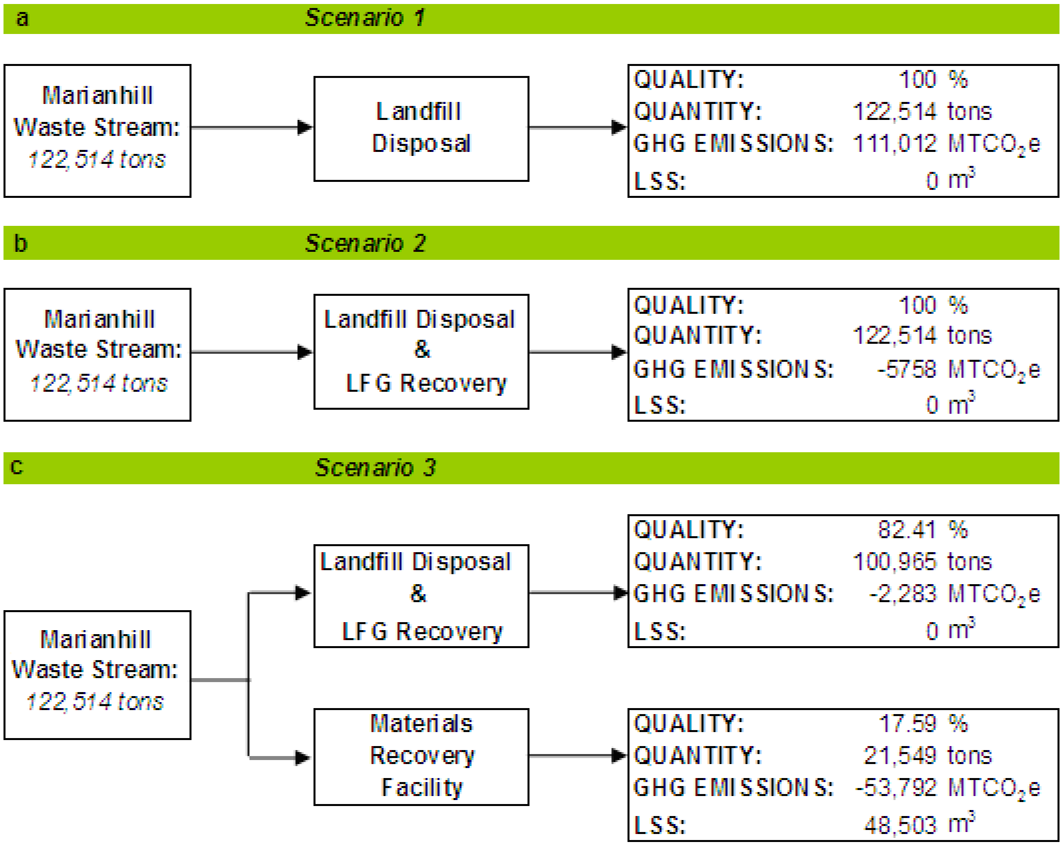


Figure 9.19 a, b, c – Summary of results: Mariannhill waste stream (Scenario 1-3)

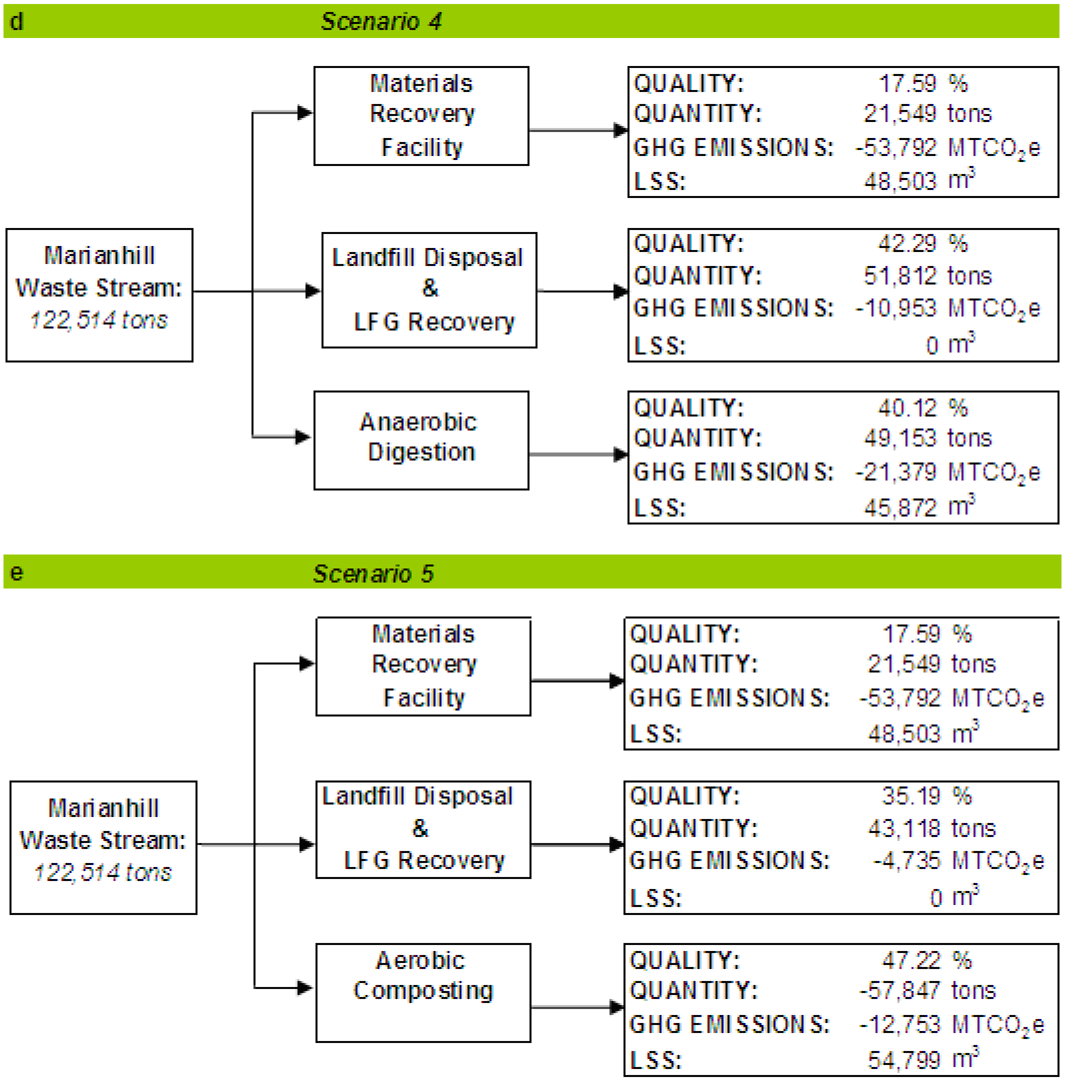


Figure 9.19 d, e – Summary of results: Mariannhill waste stream (Scenario 4 and 5)

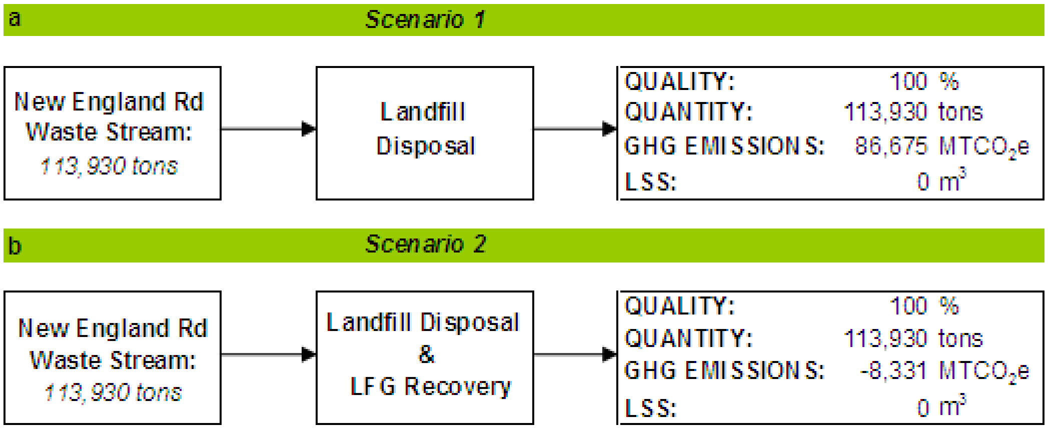


Figure 9.20 a, b – Summary of results: New England waste stream (Scenario 1 and 2)

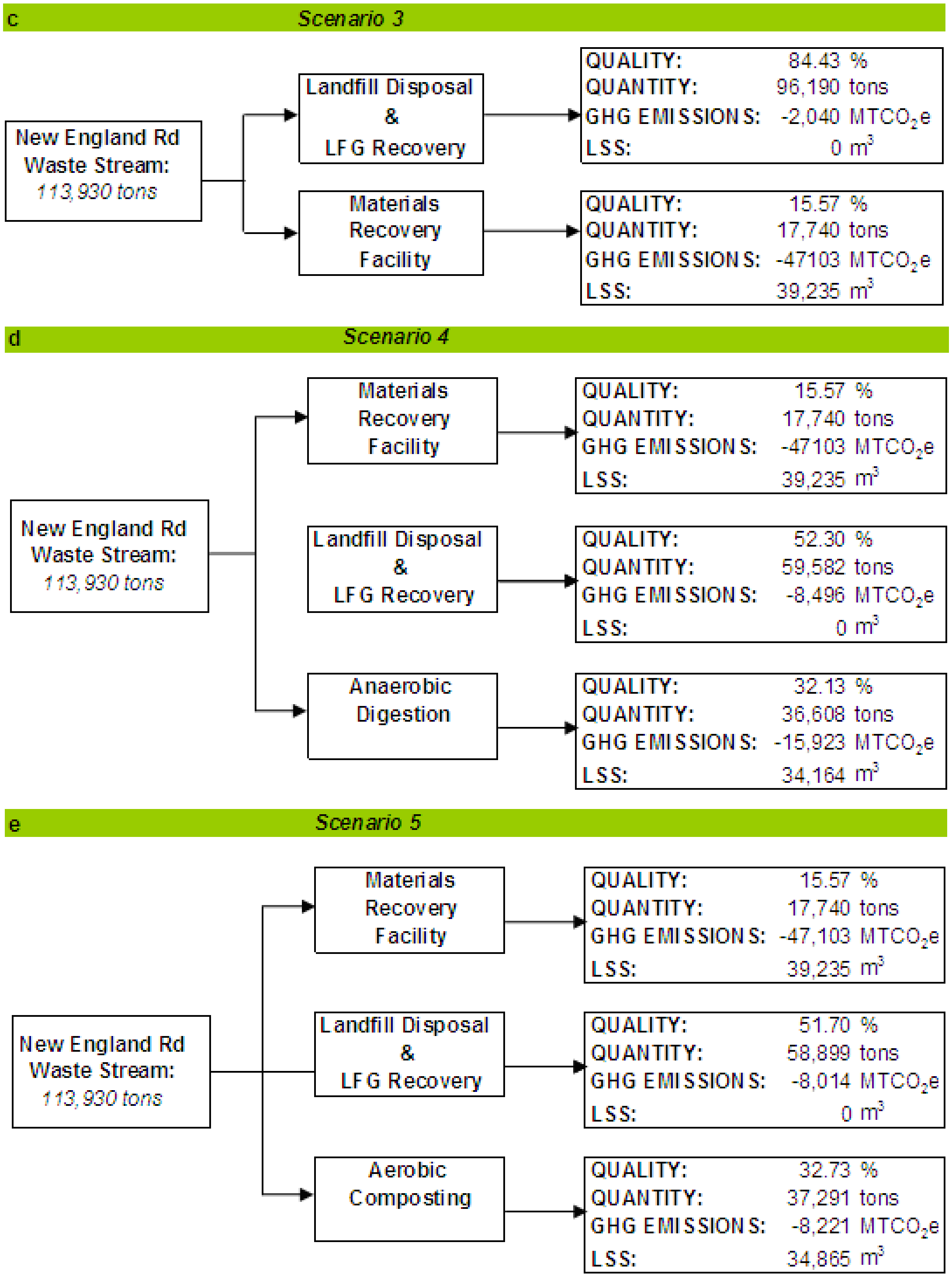


Figure 9.20 c, d, e – Summary of Results: New England Waste Stream (Scenario 3-5)

CHAPTER 10 – CONCLUSION AND RECOMMENDATIONS

10.1 Summary of results

This study comprised of the following components in assessing potential zero waste strategies:

i. Definition of the different zero waste scenarios and development of the zero waste model.
ii. A waste stream analysis to determine the composition of the incoming MSW stream of the Mariannhill and New England landfill sites.
iii. A carbon emission/reduction assessment of each strategy.
iv. A landfill airspace assessment.
v. An evaluation of the costs and potential income and savings associated with each strategy.

The results of the WSA showed that the biogenic fraction of the waste stream is significant. An average composition of approximately 32% and 40% biogenic waste for the total waste stream (including both residential and commercial waste) was obtained for the UMDM and the eThekwini Municipality respectively. The total recyclable fraction amounted to approximately 38.9% for the UMDM and 44% for eThekwini. The results indicate that the biogenic and recyclable fractions are significant, and illustrate the potential for alternative waste management strategies that divert these wastes from landfill disposal.

The results of the carbon emission/reduction assessment using the WROSE model of several waste management strategies and technologies have shown that every alternative strategy to landfilling produces some level of GHG reduction. The results confirmed that recycling, anaerobic digestion and composting all produce GHG reductions, in comparison with the baseline scenario of landfill disposal, and a combination thereof through Mechanical Biological Treatment (MBT) produced the highest net GHG reductions (between -63,338 to -71,522 $MTCO_2e$/annum for the New England Road MSW stream, and -71,280 to -86,123/annum $MTCO_2e$ for the Mariannhill MSW stream).These reductions are of particular interest as they may produce income from the trading of certified emission reductions in CDM projects such as landfill gas recovery, anaerobic digestion and composting (Couth and Trois, 2010; Couth et al, 2010). The assessment showed that an integrated approach to waste management for both landfills which incorporates several strategies targeting specific waste fractions produce the greatest environmental benefit. This integrated approach is represented through Mechanical Biological Treatment (MBT) by scenario four and five (MRF recycling with either anaerobic digestion or aerobic composting of the biogenic fraction). The landfill airspace assessment indicated that scenario four and five produce the highest landfill space savings. The implementation of MBT scenarios would produce landfill space savings of 94,375 to 103,302 m^3 for the Mariannhill landfill, extending the landfill lifespan by 12-14 years, while savings of 73,399 – 74,100 m^3 could be realised for the New England Road landfill, extending the landfill lifespan by 2-3 years.

10.2 Implementation challenges

Like any new technology, there are significant challenges that come with implementation along with the benefits. 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.

- **Economic challenges**

The capital costs for implementing waste diversion/zero waste strategies, in particular anaerobic digestion (R 90-100 million) and MRF recycling (R 34 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. A possible rationale for implementing an expensive technology such as AD is the investment in infrastructure that promotes growth and development 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 biggest producer of GHG emissions on the African continent, producing an annual average of 9.25 $MTCO_2$ per capita (US Energy Information Agency, 2008). South Africa therefore has a responsibility to reduce carbon emissions. The eThekwini landfill gas projects are examples of how new technologies benefit developing countries, however the financial implication of implementation of new waste management strategies should be reviewed in their entirety for a complete assessment of the costs and benefits.

- **Public perception and associated risks**

There is a general hesitancy from the public where waste management strategies or facilities are concerned, which essentially stems from the NIMBY (Not in my Backyard) principle (Ostrem, 2004; Matete, 2009). Anaerobic digestion and aerobic composting however can be implemented successfully with minimum impact in terms of odour and pollution as plants may be constructed as enclosed facilities. Biofilters may also be employed to reduce odours. Ostrem (2004) argues that anaerobic digestion of wastes will result in improved air quality, as biogenic waste is diverted from being landfilled thus preventing the release of putrid landfill odours as waste degrades on site. Public perceptions of waste management technology can be changed by enlisting public support and participation, and providing information with regard to zero waste strategies and their benefits. Every effort should be made to make sustainable waste management attractive to the public.

- **Legislation, regulations and incentives**

Anaerobic digestion is widely implemented in Europe and most technology has been developed by European companies. This arose from the environmental legislation in place by the European Union, the 1994 Landfill and 2004 Biowaste directives in particular (Monnet, 2003). Major incentives for implementing anaerobic digestion have also been provided to encourage investment into renewable energy. Creating a market for the products of anaerobic digestion, chiefly energy, is vital in ensuring long term economic viability for biogas energy producers. The UK government, having recognized the environmental benefits of anaerobic digestion has created the Renewable Obligations Scotland (ROS) Policy (Monnet, 2003). The ROS requires conventional electricity suppliers to distribute a proportion of the total electricity demand from renewable energy sources, and therefore effectively guarantee a market for biogas electricity. Renewable

Obligation Certificates (ROC's) are issued to producers of renewable energy. 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. Green energy is sold at approximately three times as much as electricity generated from fossil fuels in Europe, making renewable energy more financially rewarding to energy producers. Incentives are also in place to deter waste disposal by landfilling though annually increasing landfilling taxes. The UK government has also amended and formulated environmental policy such as the Climate Change Levy, which is applied to all energy used in the public, industrial and commercial sectors, with the exception of renewable energy – thus providing another incentive (Monnet, 2003). Commitment from the government and initiatives such as these are required to make anaerobic digestion an attractive and financially sustainable waste management option. Legislation governing the implementation and operations of large scale anaerobic digestion plants will also have to be developed for South Africa.

10.3 Recommendations

The following recommendations and research gaps have been realised through this study:

- The modelling of GHG emissions from waste management can be improved greatly by the development of emissions factors using South African data (electricity grid, calorific values of fuel), instead of models based on North American and European data. A software tool similar to the WARM model would assist greatly in improving the accuracy and relevance of such estimates for the South African context and eliminate inconsistency in results.

- A detailed feasibility study of anaerobic digestion of biogenic MSW on a macro-scale for municipalities should be determined in order to accurately assess costs. The cost estimates included in this study were based on general assumptions and parameters (biogas yield, compost yield, energy consumption, total solids content and so forth) for the quantity of input waste.

- The introduction of source separation of waste by waste generators into simply a wet and dry fraction (that is a separate bin or refuse bag for biogenic waste, one for recyclables and another for all other general household waste) would reduce the capital costs for the MRF pre-treatment phase by approximately R 8.85 million as the required MRF capacity would be reduced to a 200tpd facility (capital cost of R 25 million) processing and sorting only the recyclable fraction of the waste stream. Source separation was not evaluated in the model, as previous studies have indicated that it would not be feasible economically (Douglas, 2007). Although high levels of compliance and public participation are required, source separation has been implemented in many countries (United Kingdom, Italy, Japan). The exact implications of source separation in conjunction with MRF recycling and anaerobic digestion should therefore be evaluated.

- The co-digestion of sewage sludge and MSW should be explored. Currently, there is existing anaerobic digestion infrastructure present on many wastewater treatment facilities in South Africa that are under utilised, with many not being operational at all (Greben et al, 2010). One example of such a facility is the Amanzimtoti wastewater treatment plant in eThekwini. This presents a unique opportunity for co-digestion of sewage sludge with biogenic wastes – which was found to produce a greater biogas yield (Greben et al, 2010). The upgrading of such facilities for this purpose should require a lower capital investment, and could be launched as a pilot study to evaluate anaerobic digestion of wastes in the South African situation. Many production and manufacturing processes in the commercial, industrial and agricultural sectors also produce biogenic wastes that may be treated through anaerobic digestion. Biogenic MSW supplemented with biogenic wastes from these sectors could also serve to improve yields of biogas through co-digestion. The challenge however lies in the placement and proximity of biogas plants to the sources of biogenic waste from other sectors, as transportation of large volumes of waste may result in excessive transportation costs. Feasibility studies and pilot projects would provide necessary understanding and experience of the process whilst exploring its limitations.

- Aerobic composting and anaerobic digestion plants could also be launched on existing landfill sites, termed co-location, which may reduce operating costs (RIS International, 2005). Local landfills that are scheduled to close within a few years can be rehabilitated and turned into waste treatment centres such as the Ieper facility in Belgium which incorporates anaerobic digestion, composting and recycling. The nature and extent of such projects is ambitious and requires significant investment, however there are benefits (as discussed in section 3.4.6) which would herald the way forward in effective and sustainable waste management and treatment technologies. A study by Balance and King (1999) noted that continuing with the current status quo of waste management in South Africa would lead to ecological and social collapse as continued environmental degradation, pollution and GHG emissions associated with landfill disposal occur. In short, sustained development and growth is not possible without investment in projects that encompass „best practice'.

10.4 Conclusion

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 limitations 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 these 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 the 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.

REFERENCES

Alternate Resources International (ARI). 2006. *Focused verification and validation of advanced solid waste management conversion studies*. ARI. United States of America.

Arrow Bio. 2010. *The Arrow Bio process for unsorted municipal waste.* [online]. Available at: http://www.arrowbio.com/technology/. Accessed: 12 April 2010.

Austin, G., Gets, A. 2009. *Biogas energy from waste: A feasibility study and guidelines for implementing biogas from waste projects in municipalities.* South African Cities Network. [online]. Available at: http://www.sacities.net/members/pdfs/guidelines_report.pdf. Accessed: 5 March 2010.

Balance, A., King, N. 1999. *State of the environment South Africa 1999 - an overview*. Department of Environmental Affairs and Tourism (DEAT). Pretoria.

de Baere, L. Mattheeuws, B. 2010. Anaerobic digestion of MSW in Europe. *BioCycle*, volume 51 no.2, pp 24.

Baker, P. 2010. *Opportunities abound in anaerobic digestion*. [online]. Available at: http://www.waste-management-world.com. Accessed: 12 April 2010.

Barton, J.R., I., Issaias, Stentiford, E.I. 2007. Carbon – making the right choice for waste management in developing countries. *Waste Management,* volume 28, pp 690-698.

Berry, L. 2009. *Seventy-two per cent recovery rate of cans through recycling***.** [online]. Available at: http://www.engineeringnews.co.za. Accessed: 23 October 2009.

Biogen Greenfinch. 2009. *South Shropshire Biowaste Digester*. [online]. Biogen Greenfinch. Available at: www.rrsp.org.uk/pdfs/AD%20biowaste_digester.pdf. Accessed: 2 April 2010.

Blanchard, O. 2000. *Macroeconomics* (2nd ed.). Prentice Hall. New Jersey.

Blend, J., Elsaesser, M. 2004. *The economic and ecological impacts of recycling in Montana.* Montana Department of Environmental Quality. United States.
Blishke, J. 2004. *Combining anaerobic digestion with open tunnel composting*. [online]. Available at*:* http://www.biotecsistemi.it/biotec_sistemi_img/01.pdf. Accessed: 9 April 2010.

Bogner, J., Pipatti, R., Hashimoto, S., Diaz, C., Mareckova, K., Diaz, L., Kjeldson, P., Monni, S., Faaij, A., Gao, Q., Zhang, T., Mohamed, A.A., Sutamijardja, R.T.M., Gregory, R. 2008. Mitigation of global greenhouse gas emissions from waste: Conclusions from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. *Waste Management and Research,* volume 26, pp 11-32.

Boldrin, A., Anderson, J.K., Christensen. 2009. Composting and composting utilisation: accounting of greenhouse gases and global warming contributions. *Waste Management and Research,* volume 27, pp 800-812.

Cascadia. 2003. *Wisconsin statewide waste characterisation study*. [online]. Available at: http//:www.dnr.wi.gov/org/aw/wm/publications. Accessed: 26 June 2010.

Cascadia and DSM. 2007. *DSWA statewide waste characterisation study* [online]. Available at: http//*:www.*dswa.com/Statewide%20Waste%20Characterization. Accessed: 26 June 2010.

Cascadia Consulting. 2009. *California statewide waste characterisation study*. [online]. Available at: http//:www.calrecycle.ca.gov/Publications/General/2009023.pdf*.* Accessed: 26 June 2010.

Chang, N.B., Davila, E., Dyson B., Brown, R. 2005. Optimal design for sustainable development of a material recovery facility in a fast growing urban setting. *Waste Management,* volume 25, pp 833-846.

Cheng, H., Hu, Y. 2010. Municipal Solid Waste (MSW) as a renewable source of energy: current and future practices in China*. Bioresource Technology*, volume 101, pp 3816 – 3824.

City of Toronto Policy Planning Group. 2004. *Waste composition study of multi-family households receiving collection of source separated organics*. [online]. Available at: http//:www.toronto.ca/wes/.../net/.../. Accessed: 26 June 2010.

Collect-a-Can. 2009. *Beverage can recycling process.* [online]. Available at: http://www.collectacan.co.za. Accessed: 17 August 2009.

Coulon, F. 2010. Personal communication.

Couth, R., Trois, C. 2010. Carbon emissions reduction strategies in Africa from improved waste management: A review. *Waste Management.* volume 30, pp 2336-2346.

Couth, R., Trois, C. 2011. Waste management activities and carbon emissions in Africa, *Waste Management*, volume 31, pp 131-137.

Couth, R., Trois, C., Parkin, J., Strachan, L.J., Gilder, A. and Wright, M. 2010. Delivery and viability of landfill gas CDM projects in Africa - A South African experience. *Renewable and Sustainable Energy Reviews*, volume 15, pp 392-403.

Craighill, A.L., Powell, J.C. 1996. Lifecycle assessment and economic evaluation of recycling: A Case Study. *Resources, Conservation and Recycling*, volume 17, pp 75-96.

Dahlbo, H., Korhonnen, M. 2007. *Reducing greenhouse gas emissions by recycling plastics and textiles into products.* Finnish Environment Institute. Helsinki.

Dahlen, L., Vukicevic, S., Meijer J.E., Lagerkvist, A. 2007. Comparison of different collection systems for sorted household waste in Sweden. *Waste Management*, volume 27, pp 1298-1305.

Department of Energy. 2009. *Digest of South African energy statistics*. Department of Energy. Pretoria.

Department of Environment and Conservation of Western Australia. 2008. The environmental benefits of recycling calculator. [online]. Available at:

http://www.zerowastewa.com.au/documents/WA_BR43%20Calculator.xls. Accessed: 10 October 2010.

Department for Environment Food and Rural Affairs (DEFRA). 2005. *New technologies for landfill diversion.* Enviros Consulting Ltd. Crown.

Department for Environment Food and Rural Affairs (DEFRA). 2010. *South Shropshire Biowaste Digester.* [online]. Available at: http:www.defra.gov.uk/environment/waste/residual/.../ Accessed: 2 April 2010.

Department of Environmental Affairs and Tourism (DEAT). 2000. *White paper of integrated pollution and waste management for South Africa*. [online]. Available at http://www.environment.gov.za/PolLeg/Whitepapers/. Accessed: 20 March 2010.

Department of Environmental Affairs and Tourism (DEAT). 2001. Polokwane Declaration, drafted by government, civil society and the business community. National Waste Summit. 26th-28th September 2001. Polokwane.

Department of Environmental Affairs and Tourism (DEAT). 2007. *Assessment of the status of waste service delivery at local government level*. DEAT. Pretoria.

Department of Environmental Affairs and Tourism (DEAT). 2007. State of the environment report. [online]. Available at: http://soer.deat.gov.za/369.html Accessed 05 December 2010.

Department of Environmental Affairs and Tourism (DEAT). 2009a. Initial National Communication under the United Nations Framework: Climate Change. DEAT. Pretoria.

Department of Environmental Affairs and Tourism (DEAT). 2009b. *National inventory report: 1990 – 2000*. Government Gazette (No 32490).

Department of Environmental Affairs and Tourism (DEAT). n.d. *Working with waste: Guideline on recycling of solid waste*. (DEAT). Pretoria.

Department of Minerals and Energy (DME). 2003. *White paper on renewable energy*. DME. Pretoria.

Department of Water Affairs and Forestry (DWAF). 1998a. *Waste management series: Minimum requirements for solid waste disposal*. CTP Printers. Cape Town.

Department of Water Affairs and Forestry (DWAF). 1998b. *Waste management series: Minimum requirements for waste disposal by landfill*. CTP Printers. Cape Town.

DiStefano, D.T., P.E. M.ASCE, Belenky, L.G. Life cycle analysis of energy and greenhouse gas emissions from anaerobic biodegradation of municipal solid waste. *Journal of Environmental Engineering*, volume 135, pp 1097-1105.

Durban Industry Climate Change Project. (n.d). [online]. Available at: http://durbanportal.net.climatechange. Accessed: 03 November 2010.

Douglas, J. 2007. *Sustainable options for diversion of waste from landfill in Durban, South Africa.* Masters dissertation. University of Cambridge.

Engineering News. 2009. *Biogas recovery project to reduce fossil fuel dependence.* [online] Available at: http://www.engineeringnews.co.za/article/brewerys-organic-waste-used-to-replace-fossil-fuels-2009-10-02. Accessed: 17 April 2010.

Environmental Agency Wales. 2009. *Environmental life cycle assessment of waste management options for priority waste materials.* [online]. Available at: http://wales.gov.uk/docs/desh/consultation/090429wasteenvirolifecycleen.pdf. Accessed: 20 May 2010.

eThekwini Municipality. n.d. *Durban Solid Waste profile*. [online]. Available at: http://www.durban.gov.za/durban/services/cleansing/.../dsw_profile.pdf. Accessed: 10 June 2010.

Fitzgerald, G.C. 2009. *Technical and economic analysis of pre-shredding municipal solid wastes prior to disposal*. MSc Thesis. University of Columbia. New York.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: *Changes in atmospheric constituents and in radiative forcing In: Climate change 2007: The physical science basis. contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. 2007. Cambridge University Press. United Kingdom.

Fricke, K., Santen, H., Bidlingmaier, W. 2007. Biotechnological processes for solving waste management problems in economically less developed countries. In Diaz, L.F., Egerth, L.L., Savage, G.M. (Eds). Managing solid waste in developing countries. CISA. Italy.

Friedrich, E., Trois, C. 2010. Greenhouse gases accounting and reporting for waste management: A South African perspective. *Waste Management. volume 30, pp 2347-2353.*

Fruergaard, T., Astrup T., Moller, J., Ekvall, T. Christensen, T.H. Energy use and recovery in waste management and implications for accounting of greenhouse gas accounting and management. *Waste Management and Research*, volume 27, 696-706.

Gaillot, O., Gibson, C., Hogan, J. 2005. *Final report: programme for municipal waste characterisation surveys*. [online] Available at: https://www.epa.ie/.../waste/.../epa_municipal_waste_characterisation_final_report.pdf. Accessed: 7 May 2010.

Glavic, P., Lukman, R. 2007. Review of sustainability terms and their definitions. *Journal of Cleaner Production, v*olume 15, pp 1875 – 1885.

Gonzalez-Torre, P.L., Adenso-Diaz, B. 2005. Influence of distance on the motivation and frequency of household recycling. *Waste Management,* volume 25, pp 15-23.

Government of South Africa. 2008. *National Environmental Management: Waste Act 2008*. Government Gazette (No 32000).

Greben, H.A., Oelofse, S.H.H. 2009. *Unlocking the resource potential of organic waste: a South African perspective.* [online]. Available at: http://www.researchspace.csir.co.za/dspace/bitstream/10204/3910/.../Greben2_2009. Accessed: 19 April 2010.

Greben, H., Burke, L.M., Szewczuk, S. 2010. *Biogas as a renewable energy source produced during anaerobic digestion of organic waste*. [online] Available at: http://researchspace.csir.co.za/dspace/handle/10204/3716. Accessed: 19 April 2010.

GreenEng. 2010. *UMDM waste characterisation study – inception report.*

Griffith, M., Trois, C. 2006. Long-term emissions from mechanically biologically treated waste: influence on leachate quality. *Water SA*, volume 32, no 3, pp 307-314.

van Haaren, R. 2009. *Large scale aerobic composting of source separated organic wastes: a comparative study of environmental impacts, costs and contextual effects*. MSc Thesis. University of Columbia. New York.

Haight M. 2004. *Technical report: Integrated Waste Management model*. [online]. Available at: http://www.iwm-model.uwaterloo.ca/ Accessed: 20 May 2010.

Hart, J. 2011. Personal Communication.

He, P. 2010. Anaerobic digestion: an intriguing long history in china. *Waste Management*, volume 30, pp 549-550.

Houghton, J. 2002. *Global warming: The complete brief*. Cambridge University Press. United Kingdom.

Hydroplan, Aurecon. 2010. UMDM Inception report presentation.

ICF Consulting. 2005. *Determination of the impact of waste management activities on greenhouse gas emissions*. ICF Consulting. Canada.

Igoni, A.H., Ayotamuno, M.J, Eze, C.L., Ogaji, S.O.T., Probert, S.D. 2008. Designs of anaerobic digesters for producing biogas from municipal solid waste. *Applied Energy*, volume 85, pp 430 – 438.

Intergovernmental Panel on Climate Change (IPCC). 2006. *2006 IPCC guidelines for national greenhouse gas inventories.*

International Solid Waste Association. 1992. *1000 terms in solid waste management..* ISWA. Denmark.

Jogiat, R. 2009. *Assessing the implementation prospects of the waste act within the uMsunduzi municipality through the theory U*. Masters dissertation. University of KwaZulu-Natal.

Jogiat, R. Sheard, H., Lombard, J., Bulman, R., Nadar, V., Manqele, M. 2010. *Overcoming the challenges of developing an integrated waste management plan at local government level – a Case Study of the uMgungundlovu District Municipality.* Proceedings of the 20th Waste Conference. 4th - 8th October, Institute for Waste Management Southern Africa, Gauteng, pp. 8-16.

Jogiat, R. 2010. Personal communication.

Krieg and Fischer Ingenieure. 2010. *Planning and construction of biogas plants for solid waste digestion in agriculture*. Available at: http://www.kriegfischer.de/texte/BioCycle_12_2002.pdf. Accessed: 6 April 2010.

Lavee, D., Regev, U., Zemel, A. 2009. The effect of recycling price uncertainty on municipal waste management choices. *Journal of Environmental Management*, volume 90, pp 3599-3606.

Letete, T., Guma, M., Marquard, A. 2009. *Information on climate change in South Africa: greenhouse gas emissions and mitigation options.* Energy Research Centre. University of Cape Town. Cape Town.

Levis, J.W., Barlaz, M.A., Themelis, N.J., Ulloa, P. 2010. Assessment of the state of food waste treatment in the United States and Canada. *Waste Management*, in press: doi:10.1016/j.wasman.2010.01.031.

Lou, X.F., Nair, J. 2009. The impact of landfilling and composting on greenhouse gas emissions – a review. *Bioresource Technology*, volume 100, pp 3792-3798.

Manfredi, S., Davide, T., Christensen, T.H., Scharff, H. 2009. Landfilling of waste: accounting of greenhouse gases and global warming contributions. *Waste Management and Research*, volume 27, pp 825-836.

Matete, N., Trois, C. 2008. Towards zero waste in emerging countries - a South African experience. *Waste Management,* volume 28, pp 1480-1492.

Matete, N.O. 2009. *Towards a zero waste South Africa: A case study on post-consumer solid waste management in rural and urban areas*. PhD thesis. University of KwaZulu-Natal. Durban.

Master Garden Products. 2010. Organic fertilser. [online]. Available at: http://www.mastergardenproducts.com/gardenerscorner/organic_fertilizer.htm. Accessed: 03 December, 2010.

Metcalf and Eddy Inc. 2004. *Wastewater engineering: treatment and reuse, 4th edition.* McGraw-Hill. New York.

Metal Recyclers Association MRA. 2010. [online]. Available at: http://www.mra.co.za/about-us.html. Accessed 17 June 2010.

Mihelcic, J.R., Troschinetz, A.M. 2009. Sustainable recycling of municipal solid waste in developing countries. *Waste Management,* volume 29, pp 915-923.

.

Mohareb, A.K., Warith, M.A. and Diaz, R. 2008. Modelling greenhouse gas emissions for municipal solid waste management strategies in Ottawa, Ontario, Canada. *Resources, Conservation and Recycling,* volume 52, pp 1241-1251.

Møller, J., Boldren, A., Christensen, T.H. 2009. Anaerobic digestion and digestate use: accounting of GHG and global warming contribution. *Waste Management and Research,* volume 27, pp 813-824.

Mondi. 2009. *Paper recycling process*. [online]. Available at: http://www.paperpickup.co.za/process.asp. Accessed: 21 August 2009.

Monnet, F. 2003. *An introduction to aerobic digestion of organic wastes*. [online]. Available at: www.biogasmax.co.uk/.../introanaerobicdigestion. Accessed: 6 April 2010.

Monson, K.D., Esteves, S.R., Guwy, A.J., Dinsdale, R.M. 2007. *Ludlow (Greenfinch) trial scale kitchen waste treatment plant.* Sustainable Environment Research Centre. University of Glamorgan.

Moodley, L. 2010. Personal communication.

Nahman, A. 2009. *Extended Producer Responsibility for packaging waste in South Africa: current approaches and lessons learned*. Council for Scientific and Industrial Research. Stellenbosch.

Naidoo, C. 2010. Personal communication.

National Recycling Coalition. 2009. *Recycling facts*. [online]. Available at: http://www.nrc-recycle.org/top10reasonstorecycle.aspx. Accessed: 17 September 2009.

Nationmaster. 2010. *latest waste generation rates.* [online]. Available at: http://www.nationmaster.com/graph/env_mun_was_gen-environment-municipal-waste-generation. Accessed: 28 April 2010.

van Nes, W.J. 2006. *Asia hits the gas*. Renewable Energy World. [online]. Available at: http//:www.unapcaem.org/Activities%20Files/A01/AsiaHitsTheGas.pdf. Accessed: 17 April 2010.

Oelofse, S. 2009. *Addressing challenges with waste service provision in South Africa: waste sector challenges and visions report*. Council for Scientific and Industrial Research. Stellenbosch.

Oelofse, S., Nhamo, G., Mvuma G. 2009. *Addressing challenges with waste service provision in South Africa: discussion document towards a national policy on free basic refuse removal and national waste collection standards*. Council for Scientific and Industrial Research. Stellenbosch.

Olver, C., Gaylard, G., Newton, L., Kewaskiewitz, S., Willicott, S. 2009. *Regulation, compliance and enforcement in implementing the Waste Act, 2008.* [online]. Available at: http://www.wastepolicy.co.za/nwms/sites/default/files/Regulation.pdf. Accessed: 17 October 2010.

Ostrem, K. 2004. *Greening waste: anaerobic digestion for treating the organic fraction of municipal waste*. MSc Thesis. University of Columbia. New York.

Paper Recycling Association of South Africa (PRASA). 2009. *PRASA mission statement*. [online]. Available at: http//www.prasa.co.za. Accessed: 21 August 2009.

Payne, G.J. 2005. *Buffelsdraai landfill: A new regional landfill for the eThekwini council.* Thekwini Geocivils. Durban.

Polprasert, C. 1996. *Organic waste recycling*. John Wiley and Sons. United Kingdom.

Purdy and Sabugal. 1999. *Waste composition study for the city of Davao*. Proceedings of the 7th International Waste Management and Landfill Symposium. 4th- 8th October. Sardinia.

Purnell, G. 2009. National waste quantification and waste information system. [online]. http://www.wastepolicy.co.za/nwms/sites/default/files/Waste_quantification_WIS.pdf. Accessed: 21 April 2010.

Purchase S.J. 2008. *Materials Recycling Facilities: case study.* Conference proceedings of the 19th Waste Management Conference. Institute for Waste Management in South Africa. Durban.

Rapport, J., Jenkins, B.M., Williams, R.B., Zhang, R. 2008. *Current anaerobic technologies used for treatment of municipal organic solid waste*. California Environmental Protection Agency. California.

Recycling Revolution. 2009. *Recycling benefits: the main reasons why*. [online]. Available at: http://www.recycling-revolution.com/recycling-benefits.html. Accessed: 07 September 2009.

Renewable Energy Focus. 2009. *Efw: Could biogas be used to power fuel cells*. [online]. Available at: www.renewableenergyfocus.com/.../efw-could-biogas-be-used-to-power-fuel-cells/. Accessed: 20 March 2010.

Reinhart, D., and McCauley-Bell, P. 1996. *Methodology for conducting composition study for discarded solid waste.* Florida Centre for Solid and Hazardous Waste Management. Florida.

RIS International. 2005. *Feasibility of generating green power through anaerobic digestion of garden refuse from the Sacramento area*. RIS International. Sacramento.

Ritchie, N., Smith, C. 2009. *Comparison of greenhouse gas emissions from waste to energy facilities in Vancouver.* CH2M Hill Canada Limited. Vancouver.

Robinson, H.D. 1996. *Sustainable management: Is there a future for landfills.* Proceedings of the Biennial Congress of the Institute of Waste Management in Southern Africa (IWMSA). WasteCon: 1996. Durban, South Africa.

R.W.Beck Inc. and Cascadia. 2006*. Characterisation and quantification of residuals from Materials Recovery Facilities*. [online]. Available at: http://www.ciwmb.ca.gov/Publications. Accessed 20 May 2010.

Sarvannan, S., Meenambal, T., Uma, R.N. 2003. *Study on biodegradation of fruit waste: aerobic composting*. [online]. Available at: www.pdfgeni.com/.../Biodegradation-of-Waste-pdf.html. Accessed: 14 May 2010.

Schϋbeler, P., Wehrle, K., Christen, J. 1996. *Urban infrastructure management: conceptual framework for municipal solid waste management in low income countries*. Swiss Centre for Development Cooperation in Technology and Management. Switzerland.

Sharholy, M., Ahmed, K., Mahmood, G., Trivedi, R.C. 2008. Municipal waste management in Indian cities – A review. *Waste Management*, volume 28, pp 459 – 467.

Sharma, V.K., Canditelli, M., Fortuna, F., Cornacchia, G. 1997. Processing of urban and agro-industrial residues by aerobic composting – a review. *Energy Conversion Management*, volume 38, pp 453-478.

Shindell, D.T., Faluvegi, G., Koch, D.M., Schmidt G.A., Unger, N., Bauer S. 2009. *Improved attribution of climate forcing to emissions.* Science 326. (5953), pp 716-719.

SKC Engineers, Haultec. 1998. *Waste stream analysis report Durban Metro*. Document 1815/A0001.

SKC Engineers, Haultec. 2002. *Master plan 2002 for solid waste management in eThekwini municipal area*. Document 2085/DO132.

SKC Engineers, Blue Square, Haultec, Mallinicks. 2004. Integrated waste management plan for eThekwini Municipality. Document 2214/DO147.

Sky Valley Associates and Cascadia. 2004. Waste Stream Analysis: Clark county [online]. Available at: http://www.co.clark.wa.us/recycle/documents/. Accessed: 11 June 2010.

Smith, A., Brown, K., Ogilvie, S., Rushton, K., Bates, J. 2001. *Waste management options and climate change: Final report to the European Commission*. [online]. Available at: http://ec.europa.eu/environment/waste/studies/pdf/climate_change.pdf. Accessed: 19 August 2009.

South African Plastic Recyclers Organisation (SAPRO). 2009. [online]. Available at: http://www.plasticsinfo.co.za/sapro.asp. Accessed: 28 August 2009.

Statistics South Africa. 2005. [online]. Available at: https:// www.statssa.gov.za/keyindicators/cpi.asp . Accessed: 11 June 2009.

Strachan, L.J., Rampersad, R., Wienand, R., Moroka K.S., Couth, B., Beg, N., Chronowski, R. 2003. Proceedings of the Ninth International Waste Management and Landfilling Symposium. 6-10 Oct. Italy.

Strachan, L.J, Couth, B., Chronowski, R. 2004. *Harnessing landfill methane to address global warming and renewable energy: An overview of the Durban CDM landfill gas to electricity project.* [online]. Available at: http://www.dme.gov.za/pdfs/energy/. Accessed: 17 October 2009.

Strachan, L.J., Bowers, A. (n.d). *Mariannhill landfill conservancy – A 'closed loop' design'*. [online]. Available at: https://www.durban.gov.za/durban/services/cleansing/gastoelec. Accessed: 11 June 2009.

Stotko, O. 2006. An economic comparison of the waste management schemes employed in Cape Town and Johannesburg. MSc dissertation. University of KwaZulu-Natal.

Stromberg, P. 2004. Market imperfections in recycling markets: conceptual and study of price volatility in plastics. *Resources Conservation and Recycling*. Volume 4, pp 339-364.

The Glass Recycling Company. 2008. *Annual review 2007/08*. [online]. Available at: http://www.theglassrecyclingcompany.co.za. Accessed: 28 August 2009.

Themelis, N.J. and Verma, S. 2004. The better option: Anaerobic digestion of organic waste in MSW. Waste management world.

Tchobanoglous, G., Theisen, H., Vigil, S. 1993. *Integrated solid waste management: engineering principles and management issues* (2nd edition). McGraw Hill Inc. New York.

Thornloe, S.A, Weitz, K.A., Nishtala, S.R. 2001. *US case studies using municipal solid waste decision support tool*. USEPA. North Carolina.

Toerisme-Ieper. 2010. [online]. Available at: http://www.toerisme-ieper.be/en/home.html. Accessed: 05 December 2010.

Trois, C. Griffith, M., Brummack, J., Mollekopf, N. 2007. Introducing mechanical biological treatment in South Africa: A comparative study. *Waste Management*, volume 27, pp 1704 - 1714.

Trois, C., Simelane, O.T. 2010. Implementing separate waste collection and mechanical biological waste treatment in South Africa: A comparison with Austria and England. *Waste Management,* volume 30, no. 8-9, pp 1457-1463.

Troschinetz, A.M., Mihelcic, J.R. 2009. Sustainable recycling of municipal solid waste in developing countries. *Waste Management*, volume 29, pp 915-923.

Tsilemou, K. and Panagiotakopolous. 2006. Approximate cost functions for solid waste treatment facilities. *Waste Management and Research, v*olume 24, pp 310-322.

UK Environment Agency. 2002. Guidance on landfill gas flaring. UK Environment Agency. Bristol.

UK National Statistics. 2010. [online]. Available at: http://www.statistics.gov.uk/. Accessed: 23 April 2010.

uMgungundlovu District Municipality (UMDM). 2009. *Advanced integrated solid waste management system: Terms of reference*. uMgungundlovu District Municipality.

uMgungundlovu District Municipality (UMDM). (n.d). *uMgungundlovu District Municipality Corporate Profile*. [online]. Available at: http://umdm.gov.za/. Accessed: 26 June 2010.

United Nations. 1997. *Glossary of environment statistics: studies in methods - series F*, No. 67. United Nations. New York.

United Nations. 2007. *Recycling Definition*. [online]. Available at: http://unstats.un.org/unsd/environment/wastetreatment.htm. Accessed 04 August 2009

United States Energy Information Agency. 2008. [online]. Available at: http://www.ucsusa.org/global_warming/science_and_impacts/science/. Accessed: 17 November 2010.

United States Environmental Protection Agency (US EPA). 1994. *Characterisation of municipal solid waste in the United States: 1994 update*. [online]. Available at: http://www.epa.gov/osw/nonhaz/municipal/pubs/msw94.pdf. Accessed: 25 October 2010.

United States Environmental Protection Agency (US EPA). 2006. Solid waste management and greenhouse gases: *A life-cycle assessment of emissions and sinks*, 3rd edition. US EPA. Washington, D.C.

United States Environmental Protection Agency (US EPA). 2009. *Waste Reduction Model users guide*. [online]. Available at: http://www.epa.gov/climatechange/wycd/waste/calculators/Warm_UsersGuide.html. Accessed: 25 September 2009.

United States Environmental Protection Agency (US EPA). (n.d). *Municipal solid waste characterisation methodology.* [online]. Available at: http://www.epa.gov/osw/nonhaz/municipal/pubs/06numbers.pdf . Accessed: 20 May 2010.

Warnken ISE. 2007. *Potential for greenhouse gas abatement from waste management and resource recovery activities in Australia*. [online]. Available at: http://*www.wmaa.asn.au/uploads/documents/Final_PGGAWMRRAA.pdf*. Accessed: 5 March 2010.

Waste and Resources Action Programme (WRAP). 2006. *Environmental benefits of recycling.* [online]. Available at: http://www.plasfed.co.za/downloads/WRAP%20LCA%20Report_ExecSUM.pdf Accessed: 20 August 2009.

Waste and Resources Action Programme (WRAP). 2007*. Market situation report: realising the value of recovered paper*. Available at: http://www.wrap.org.uk/.../WRAP_Paper_market_situation_report_Feb2010.a1c504bb.8440.pdf. Accessed: 20 August 2009.

Waste Online. 2004. [online]. Available at: http://www.wasteonline.org.uk. Accessed: 22 April 2010.

White, F. 2000. *Fluid Mechanics, Fourth edition*. McGraw-Hill. New York.

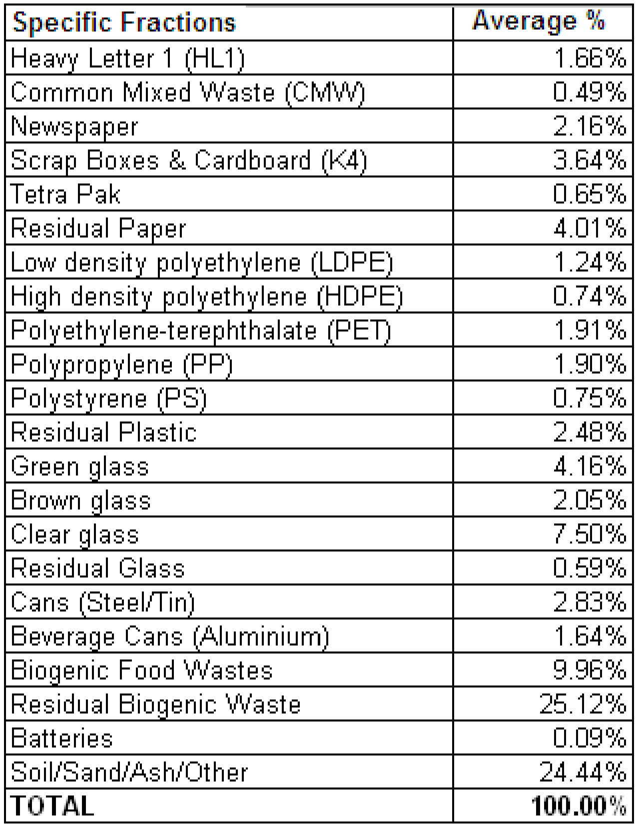
Zero Waste International Alliance (ZWIA). 2010. Zero waste definition. [online]. Available at: http://www.zwia.org. Accessed: 26 April 2010.

APPENDIX A – UMDM Waste Stream Analysis

Table A1 – Waste Stream Analysis Record Sheet

Day & Date:	**Waste Collection Area/s:**		
Waste Collection Truck Registration:	**Area Classification:**		
Notes:			
Waste Material Classification	**Weight (kg)**		
	Sample 1	**Sample 2**	**Sample 3**
Paper & Cardboard			
Heavy Letter 1 (HL1) (Clean White Paper)			
Common Mixed Waste (CMW) (general mixed paper)			
Newspaper			
Scrap Boxes & Cardboard (K4)			
Tetrapak			
Residual Paper			
Plastic			
Low density polyethylene (LDPE)			
High density polyethylene (HDPE)			
Polyethylene-terephthalate (PET)			
Polypropylene (PP)			
Polyvinyl Chloride (PVC)			
Polystyrene (PS)			
Residual Plastic			
Glass			
Green glass bottles & containers			
Brown glass bottles & containers			
Clear glass bottles & containers			
Residual Glass			
Metals			
Cans (Steel/Tin)			
Beverage Cans (Aluminium)			
Other Metals			
Biogenic Wastes			
Organic Food Wastes (Putrescibles)			
Garden Refuse: Green Waste			
Garden Refuse: Woody Waste			
Residual Biogenic Waste			
Other Wastes			
Wood Waste			
Tyres			
Textiles, Cloths			
e-Waste			
Batteries			
Soil/Sand/Ash/Other			
Residual Waste [75 litre mass: 13.75kg and 13.95kg]			
i. Foodstuffs			
ii. Paper & Cardboard			
iii. Plastics			
iv. Glass			
v. Green/Garden			
vi. Soil/Sand/Ash/Other			
Total Weight			

Table A2 – Waste Fractions: Rural High Income

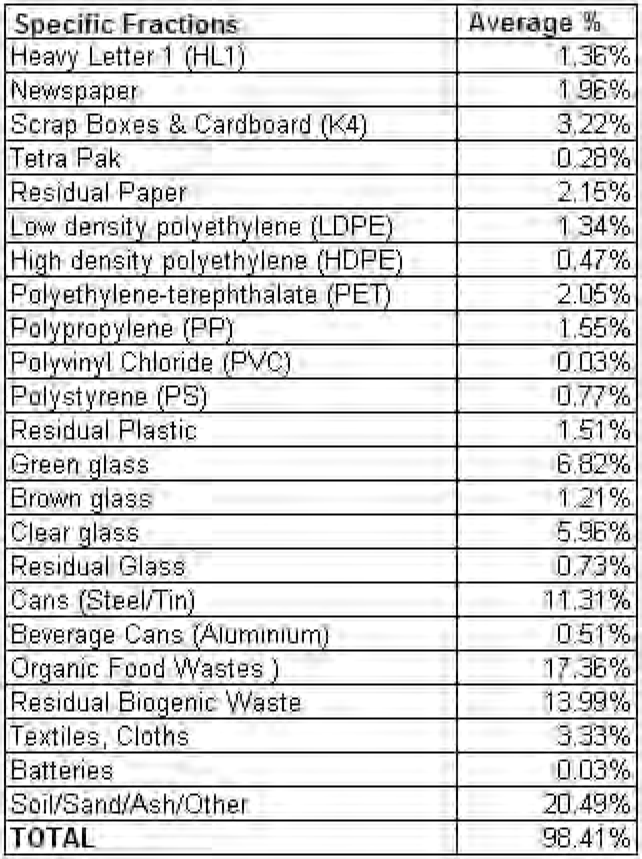


Specific Fractions	Average %
Heavy Letter 1 (HL1)	1.66%
Common Mixed Waste (CMW)	0.49%
Newspaper	2.16%
Scrap Boxes & Cardboard (K4)	3.64%
Tetra Pak	0.65%
Residual Paper	4.01%
Low density polyethylene (LDPE)	1.24%
High density polyethylene (HDPE)	0.74%
Polyethylene-terephthalate (PET)	1.91%
Polypropylene (PP)	1.90%
Polystyrene (PS)	0.75%
Residual Plastic	2.48%
Green glass	4.16%
Brown glass	2.05%
Clear glass	7.50%
Residual Glass	0.59%
Cans (Steel/Tin)	2.83%
Beverage Cans (Aluminium)	1.64%
Biogenic Food Wastes	9.96%
Residual Biogenic Waste	25.12%
Batteries	0.09%
Soil/Sand/Ash/Other	24.44%
TOTAL	**100.00%**

Table A3 – Waste Fractions: Rural Medium Income

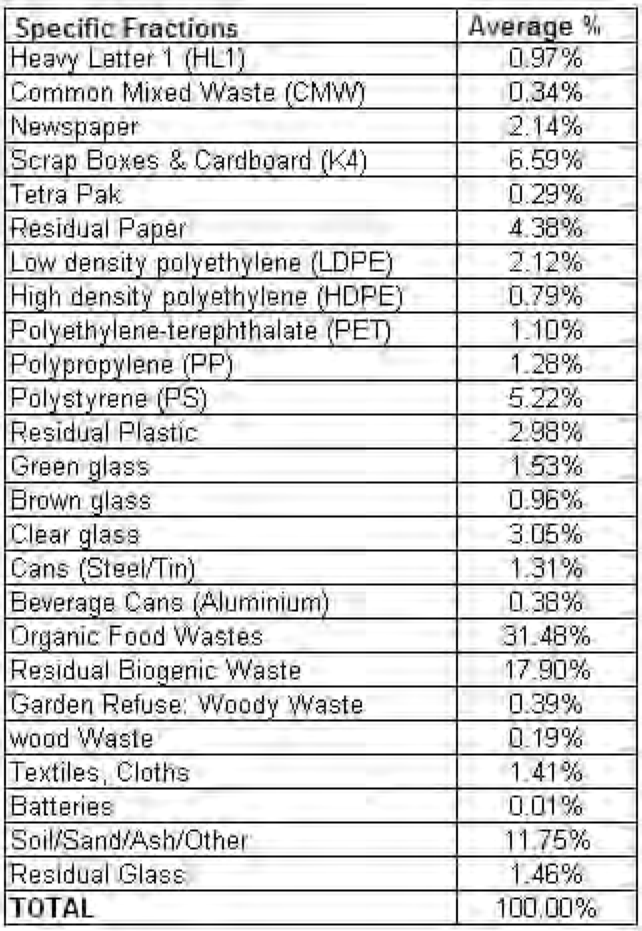
Specific Fractions	Average %
Heavy Letter 1 (HL1)	1.09%
Common Mixed Waste (CMW)	0.48%
Newspaper	2.88%
Scrap Boxes & Cardboard (K4)	4.50%
Tetra Pak	1.03%
Residual Paper	2.82%
Low density polyethylene (LDPE)	2.15%
High density polyethylene (HDPE)	0.88%
Polyethylene-terephthalate (PET)	2.16%
Polypropylene (PP)	0.94%
Polystyrene (PS)	0.64%
Residual Plastic	2.04%
Green glass	1.35%
Brown glass	0.21%
Clear glass	4.21%
Cans (Steel/Tin)	1.56%
Beverage Cans (Aluminium)	0.54%
Other Metals	0.10%
Organic Food Wastes	15.55%
Garden Refuse: Green Waste	0.35%
Residual Biogenic Waste	27.74%
Textiles, Cloths	0.34%
Soil/Sand/Ash/Other	26.46%
TOTAL	**100.00%**

Table A4 – Waste Fractions: Rural Low Income



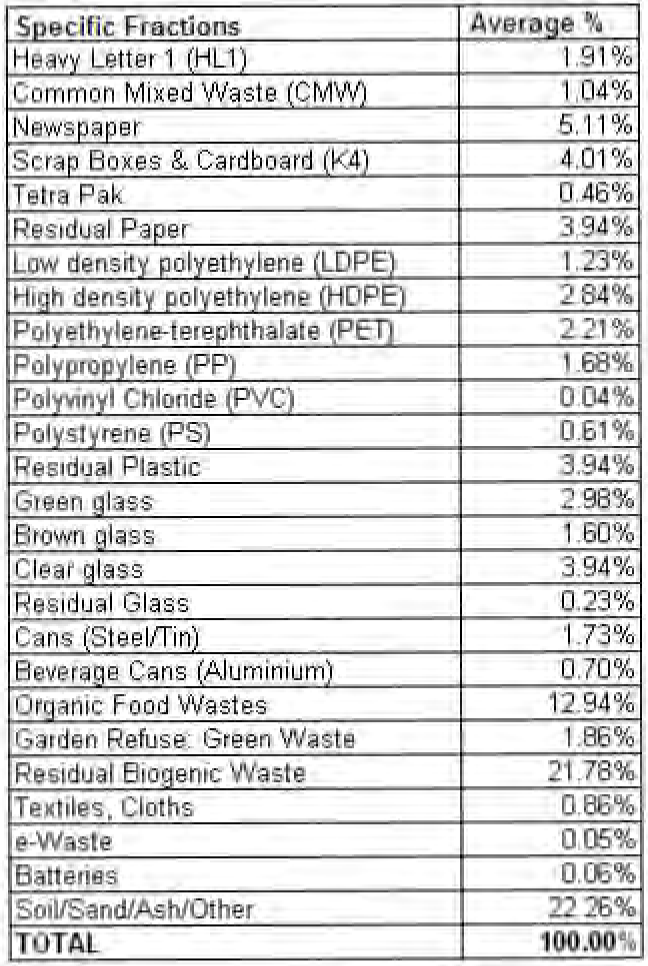
Specific Fractions	Average %
Heavy Letter 1 (HL1)	1.36%
Newspaper	1.96%
Scrap Boxes & Cardboard (K4)	3.22%
Tetra Pak	0.28%
Residual Paper	2.15%
Low density polyethylene (LDPE)	1.34%
High density polyethylene (HDPE)	0.47%
Polyethylene-terephthalate (PET)	2.05%
Polypropylene (PP)	1.55%
Polyvinyl Chloride (PVC)	0.03%
Polystyrene (PS)	0.77%
Residual Plastic	1.51%
Green glass	6.82%
Brown glass	1.21%
Clear glass	5.96%
Residual Glass	0.73%
Cans (Steel/Tin)	11.31%
Beverage Cans (Aluminium)	0.51%
Organic Food Wastes)	17.36%
Residual Biogenic Waste	13.99%
Textiles, Cloths	3.33%
Batteries	0.03%
Soil/Sand/Ash/Other	20.49%
TOTAL	98.41%

Table A5 – Waste Fractions: Rural Commercial



Specific Fractions	Average %
Heavy Letter 1 (HL1)	0.97%
Common Mixed Waste (CMW)	0.34%
Newspaper	2.14%
Scrap Boxes & Cardboard (K4)	6.59%
Tetra Pak	0.29%
Residual Paper	4.38%
Low density polyethylene (LDPE)	2.12%
High density polyethylene (HDPE)	0.79%
Polyethylene-terephthalate (PET)	1.10%
Polypropylene (PP)	1.28%
Polystyrene (PS)	5.22%
Residual Plastic	2.98%
Green glass	1.53%
Brown glass	0.96%
Clear glass	3.05%
Cans (Steel/Tin)	1.31%
Beverage Cans (Aluminium)	0.38%
Organic Food Wastes	31.48%
Residual Biogenic Waste	17.90%
Garden Refuse: Woody Waste	0.39%
wood Waste	0.19%
Textiles, Cloths	1.41%
Batteries	0.01%
Soil/Sand/Ash/Other	11.75%
Residual Glass	1.46%
TOTAL	100.00%

Table A6 - Waste Fractions: Urban High Income

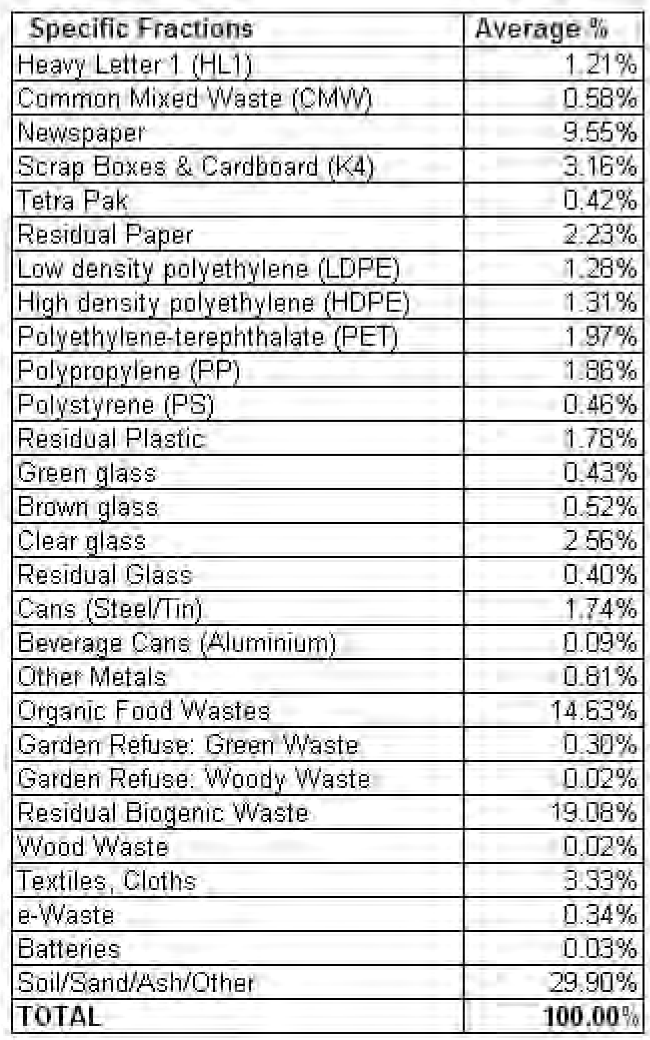


Specific Fractions	Average %
Heavy Letter 1 (HL1)	1.91%
Common Mixed Waste (CMW)	1.04%
Newspaper	5.11%
Scrap Boxes & Cardboard (K4)	4.01%
Tetra Pak	0.46%
Residual Paper	3.94%
Low density polyethylene (LDPE)	1.23%
High density polyethylene (HDPE)	2.84%
Polyethylene-terephthalate (PET)	2.21%
Polypropylene (PP)	1.68%
Polyvinyl Chloride (PVC)	0.04%
Polystyrene (PS)	0.61%
Residual Plastic	3.94%
Green glass	2.98%
Brown glass	1.60%
Clear glass	3.94%
Residual Glass	0.23%
Cans (Steel/Tin)	1.73%
Beverage Cans (Aluminium)	0.70%
Organic Food Wastes	12.94%
Garden Refuse: Green Waste	1.86%
Residual Biogenic Waste	21.78%
Textiles, Cloths	0.86%
e-Waste	0.05%
Batteries	0.06%
Soil/Sand/Ash/Other	22.26%
TOTAL	**100.00%**

Table A7 - Waste Fractions: Urban Medium Income

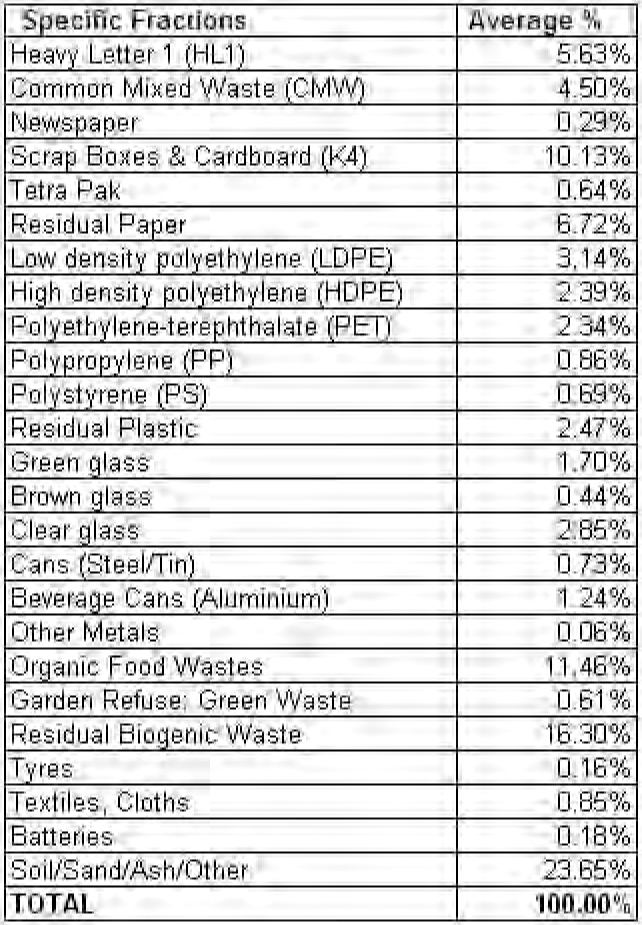
Specific Fractions	Average %
Heavy Letter 1 (HL1)	1.56%
Common Mixed Waste (CMW)	5.01%
Newspaper	3.32%
Scrap Boxes & Cardboard (K4)	2.81%
Tetra Pak	0.69%
Residual Paper	2.85%
Low density polyethylene (LDPE)	0.96%
High density polyethylene (HDPE)	1.49%
Polyethylene-terephthalate (PET)	2.09%
Polypropylene (PP)	1.42%
Polyvinyl Chloride (PVC)	0.02%
Polystyrene (PS)	0.65%
Residual Plastic	3.26%
Green glass	1.15%
Brown glass	0.58%
Clear glass	3.44%
Residual Glass	0.61%
Cans (Steel/Tin)	1.30%
Beverage Cans (Aluminium)	0.41%
Other Metals	0.13%
Organic Food Wastes	12.84%
Garden Refuse: Green Waste	2.08%
Residual Biogenic Waste	22.77%
Textiles, Cloths	1.84%
e-Waste	0.13%
Batteries	0.04%
Soil/Sand/Ash/Other	26.57%
TOTAL	**100.00%**

Table A8 - Waste Fractions: Urban Low Income



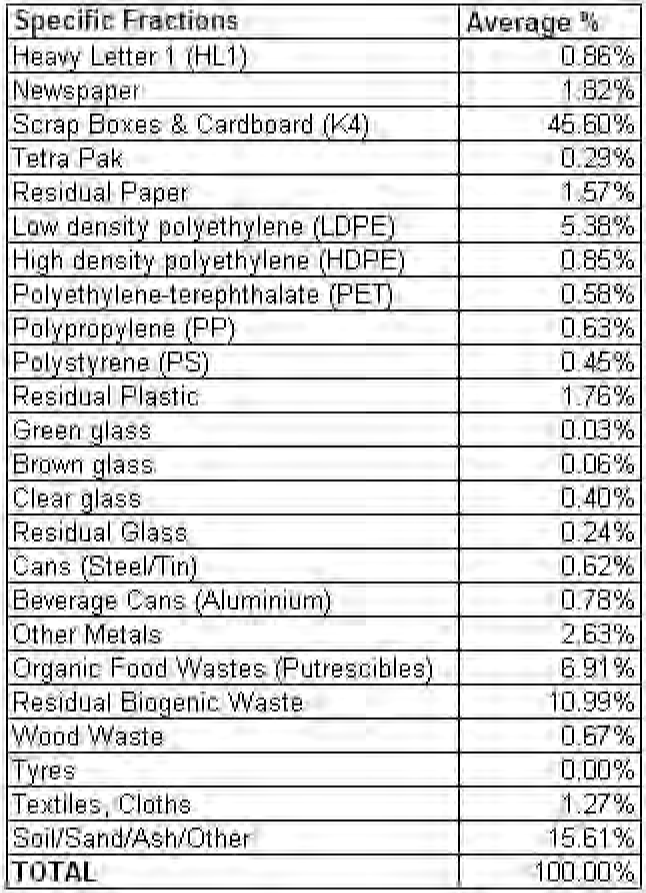
Specific Fractions	Average %
Heavy Letter 1 (HL1)	1.21%
Common Mixed Waste (CMW)	0.58%
Newspaper	9.55%
Scrap Boxes & Cardboard (K4)	3.16%
Tetra Pak	0.42%
Residual Paper	2.23%
Low density polyethylene (LDPE)	1.28%
High density polyethylene (HDPE)	1.31%
Polyethylene-terephthalate (PET)	1.97%
Polypropylene (PP)	1.86%
Polystyrene (PS)	0.46%
Residual Plastic	1.78%
Green glass	0.43%
Brown glass	0.52%
Clear glass	2.56%
Residual Glass	0.40%
Cans (Steel/Tin)	1.74%
Beverage Cans (Aluminium)	0.09%
Other Metals	0.81%
Organic Food Wastes	14.63%
Garden Refuse: Green Waste	0.30%
Garden Refuse: Woody Waste	0.02%
Residual Biogenic Waste	19.08%
Wood Waste	0.02%
Textiles, Cloths	3.33%
e-Waste	0.34%
Batteries	0.03%
Soil/Sand/Ash/Other	29.90%
TOTAL	**100.00%**

Table A9 - Waste Fractions: Urban Commercial



Specific Fractions	Average %
Heavy Letter 1 (HL1)	5.63%
Common Mixed Waste (CMW)	4.50%
Newspaper	0.29%
Scrap Boxes & Cardboard (K4)	10.13%
Tetra Pak	0.64%
Residual Paper	6.72%
Low density polyethylene (LDPE)	3.14%
High density polyethylene (HDPE)	2.39%
Polyethylene-terephthalate (PET)	2.34%
Polypropylene (PP)	0.86%
Polystyrene (PS)	0.69%
Residual Plastic	2.47%
Green glass	1.70%
Brown glass	0.44%
Clear glass	2.85%
Cans (Steel/Tin)	0.73%
Beverage Cans (Aluminium)	1.24%
Other Metals	0.06%
Organic Food Wastes	11.46%
Garden Refuse: Green Waste	0.61%
Residual Biogenic Waste	16.30%
Tyres	0.16%
Textiles, Cloths	0.85%
Batteries	0.18%
Soil/Sand/Ash/Other	23.65%
TOTAL	**100.00%**

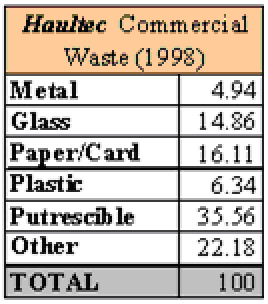
Table A10 - Waste Fractions: Urban Industrial



Specific Fractions	Average %
Heavy Letter 1 (HL1)	0.86%
Newspaper	1.82%
Scrap Boxes & Cardboard (K4)	45.60%
Tetra Pak	0.29%
Residual Paper	1.57%
Low density polyethylene (LDPE)	5.38%
High density polyethylene (HDPE)	0.85%
Polyethylene-terephthalate (PET)	0.58%
Polypropylene (PP)	0.63%
Polystyrene (PS)	0.45%
Residual Plastic	1.76%
Green glass	0.03%
Brown glass	0.06%
Clear glass	0.40%
Residual Glass	0.24%
Cans (Steel/Tin)	0.62%
Beverage Cans (Aluminium)	0.78%
Other Metals	2.63%
Organic Food Wastes (Putrescibles)	6.91%
Residual Biogenic Waste	10.99%
Wood Waste	0.67%
Tyres	0.00%
Textiles, Cloths	1.27%
Soil/Sand/Ash/Other	15.61%
TOTAL	100.00%

APPENDIX B – eThekwini Waste Stream Analysis and weighbridge data

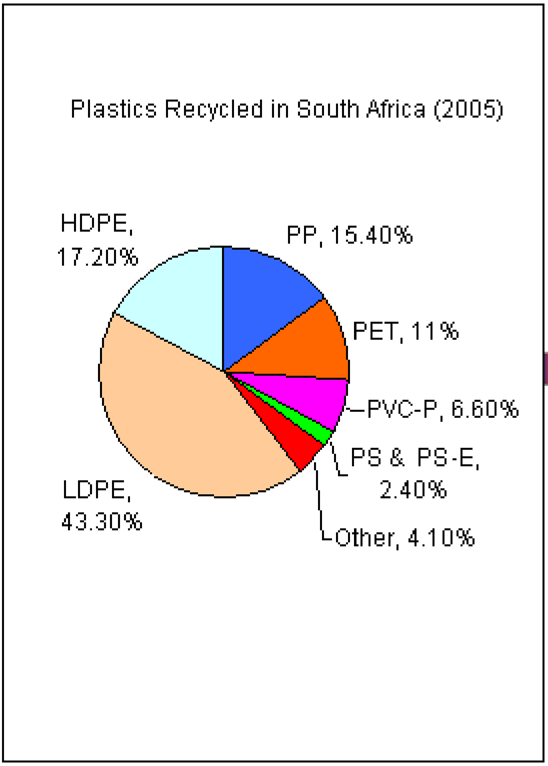
Haultec Household Waste (1998)	
Putrescibles	45.67
Cardboard	8.31
Hard plastics	6.28
Soft plastics	10.88
Textiles	4.15
Other paper	9.57
Polystyrene	2.97
Glass	6.83
Tin/Aluminium	5.34
TOTAL	100



Haultec Commercial Waste (1998)	
Metal	4.94
Glass	14.86
Paper/Card	16.11
Plastic	6.34
Putrescible	35.56
Other	22.18
TOTAL	100

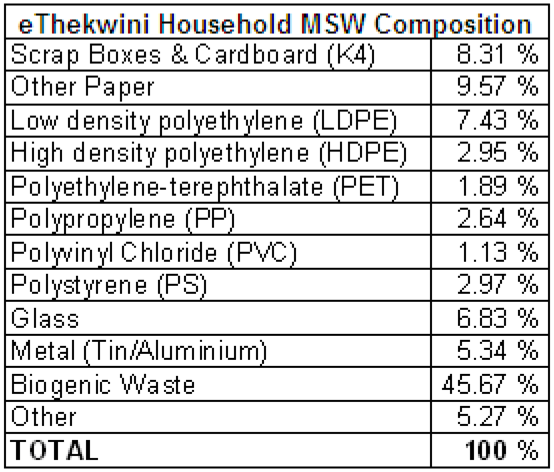
Source:

SKC Engineers/Haultec, 1998

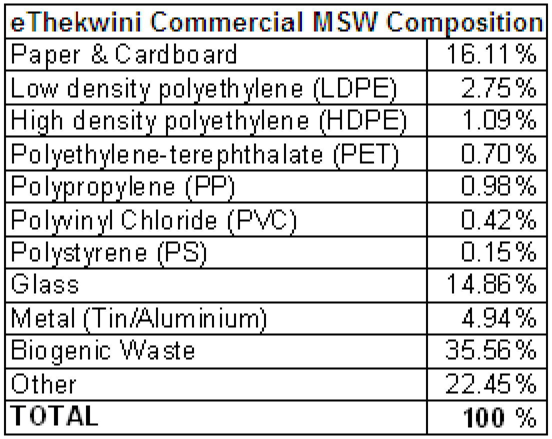


Source:

South African Plastic Recycling Organisation/Buyisa-e-Bag, 2005



eThekwini Household MSW Composition	
Scrap Boxes & Cardboard (K4)	8.31 %
Other Paper	9.57 %
Low density polyethylene (LDPE)	7.43 %
High density polyethylene (HDPE)	2.95 %
Polyethylene-terephthalate (PET)	1.89 %
Polypropylene (PP)	2.64 %
Polyvinyl Chloride (PVC)	1.13 %
Polystyrene (PS)	2.97 %
Glass	6.83 %
Metal (Tin/Aluminium)	5.34 %
Biogenic Waste	45.67 %
Other	5.27 %
TOTAL	**100 %**

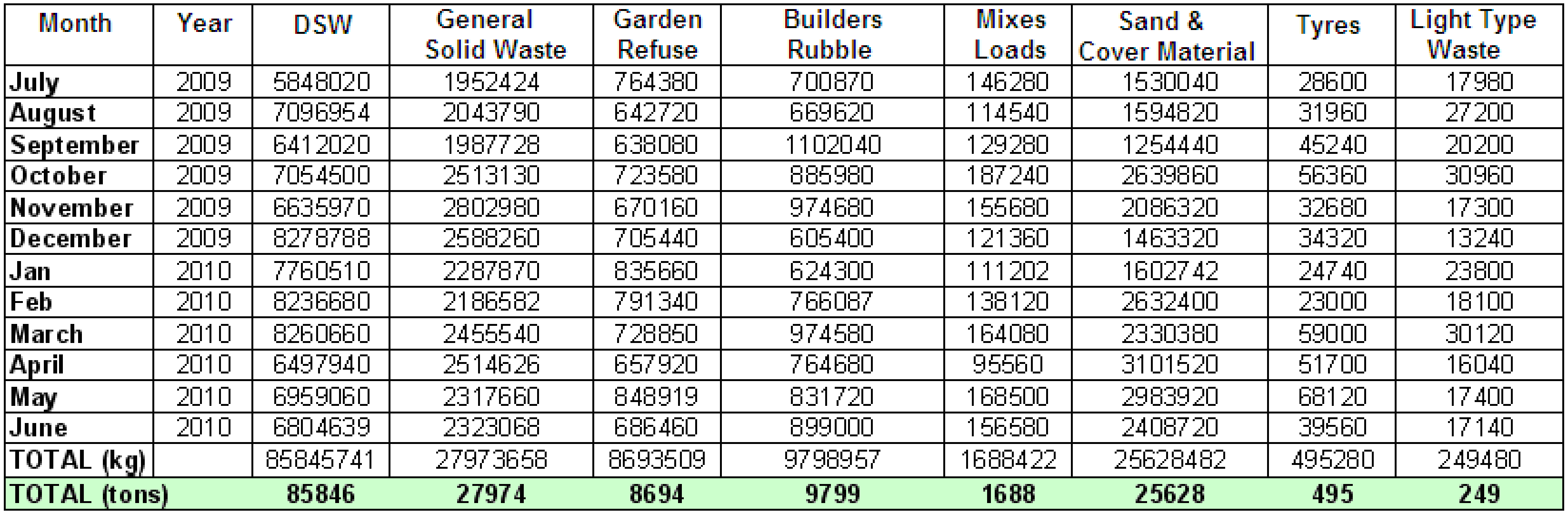


eThekwini Commercial MSW Composition	
Paper & Cardboard	16.11 %
Low density polyethylene (LDPE)	2.75 %
High density polyethylene (HDPE)	1.09 %
Polyethylene-terephthalate (PET)	0.70 %
Polypropylene (PP)	0.98 %
Polyvinyl Chloride (PVC)	0.42 %
Polystyrene (PS)	0.15 %
Glass	14.86 %
Metal (Tin/Aluminium)	4.94 %
Biogenic Waste	35.56 %
Other	22.45 %
TOTAL	**100 %**

Figure B2 – Modification of 1998 WSA categories

Table B1 – Weighbridge data: Mariannhill Landfill Site

(Source: Durban Solid Waste, 2010)



Month	Year	DSW	General Solid Waste	Garden Refuse	Builders Rubble	Mixes Loads	Sand & Cover Material	Tyres	Light Type Waste
July	2009	5848020	1952424	764380	700870	146280	1530040	28600	17980
August	2009	7096954	2043790	642720	669620	114540	1594820	31960	27200
September	2009	6412020	1987728	638080	1102040	129280	1254440	45240	20200
October	2009	7054500	2513130	723580	885980	187240	2639860	56360	30960
November	2009	6635970	2802980	670160	974680	155680	2086320	32680	17300
December	2009	8278788	2588260	705440	605400	121360	1463320	34320	13240
Jan	2010	7760510	2287870	835660	624300	111202	1602742	24740	23800
Feb	2010	8236680	2186582	791340	766087	138120	2632400	23000	18100
March	2010	8260660	2455540	728850	974580	164080	2330380	59000	30120
April	2010	6497940	2514626	657920	764680	95560	3101520	51700	16040
May	2010	6959060	2317660	848919	831720	168500	2983920	68120	17400
June	2010	6804639	2323068	686460	899000	156580	2408720	39560	17140
TOTAL (kg)		85845741	27973658	8693509	9798957	1688422	25628482	495280	249480
TOTAL (tons)		**85846**	**27974**	**8694**	**9799**	**1688**	**25628**	**495**	**249**

The three categories of waste included in the eThekwini case study included „DSW', „General Solid Waste' and „Garden Refuse'. The Category „DSW' comprises all household waste collected by municipal service providers Durban Solid Waste, whilst the category „General Solid Waste' refers to commercial waste from businesses, shopping centres, and other commercial sources.

The quantity of each waste fraction is obtained by multiplying the fraction composition from the relevant waste profile (either commercial or household waste profiles) by the total quantity of waste generated by the waste stream.

Table B2 – Mariannhill MRF statistics (DSW, 2010)

DATE:	Recyclable Fractions (tons)											
	CARDBOARD	**GLASS**	**STEEL CANS**	**PET BOTTLES**	**CMW**	**HL1**	**PLASTIC**	**TETRA-PAK**	**HD BOTTLES**	**TOTAL OUTPUT**	**TOTAL INPUT**	**Recovery Rate (%)**
Oct 07	63	41	52	32	75	0	47	0	26	337	2960	11.38
Nov 07	54	48	41	30	87	0	48	0	21	328	3409	9.63
Dec 07	47	44	47	29	75	0	49	0	17	308	2312	13.31
Jan 08	46	77	61	49	10	0	78	0	25	346	3762	9.19
Feb 08	43	78	69	47	10	0	54	0	25	326	3762	8.68
Mar 08	43	72	65	46	100	0	53	0	25	403	3800	10.62
April 08	32	58	45	30	79	0	41	0	19	304	2394	12.70
May 08	44	46	55	36	11	0	52	0	24	267	2914	9.18
June 08	49	37	60	44	12	0	65	0	28	295	3709	7.95
July 08	61	37	62	46	13	0	78	0	28	326	3740	8.70
Aug 08	55	38	75	38	11	0	62	0	23	302	3487	8.65
Sept 08	67	38	86	42	11	0	69	0	27	340	3636	9.34
Oct 08	66	42	94	46	13	0	74	0	37	372	3768	9.88
Nov 08	59	35	86	43	11	0	60	0	33	327	3679	8.90
Dec 08	56	43	86	48	11	0	50	0	30	325	3757	8.64
Jan 09	50	41	73	41	76	0	20	0	23	324	3016	10.75
Feb 09	58	38	80	46	74	12	18	0	28	355	3419	10.39
March 09	62	48	97	55	78	14	38	0	34	425	3970	10.71
April 09	59	52	85	51	81	15	35	0	30	408	3109	13.13
May 09	59	50	74	44	74	13	40	0	28	381	2820	13.50
June 09	34	54	75	39	73	12	49	0	31	367	3130	11.74
July 09	45	73	85	45	83	15	44	7	34	431	3538	12.19
Aug 09	52	93	84	47	93	13	42	9	33	463	4150	11.15
Sept 09	69	88	83	51	98	19	53	1	39	501	4454	11.25
Oct 09	56	16	52	38	81	17	41	0	29	329	3491	9.43
Nov 09	48	77	44	34	67	16	15	0	25	326	3243	10.06
Dec 09	26	158	76	72	0	30	32	0	47	440	5592	7.87
Jan 10	7	112	59	71	0	32	21	0	46	347	5585	6.22
Feb 10	10	73	45	51	0	17	17	1	30	243	3708	6.56
TOTAL	**1420**	**1705**	**1996**	**1289**	**1407**	**225**	**1343**	**18**	**844**	**10247**	**104313**	**9.82**

APPENDIX C – ANNUAL WASTE QUANTITIES

Table C1 – Mariannhill Waste Stream Quantity (Household and Commercial waste)

Waste Fraction	Total Quantity (tons)
General mixed paper (CMW)	10627
Scrap Boxes & Cardboard (K4)	9229
Low density polyethylene (LDPE)	7147
High density polyethylene (HDPE)	2839
Polyethylene-terephthalate (PET)	1815
Polypropylene (PP)	2542
Polyvinyl Chloride (PVC)	1089
Polystyrene (PS)	2593
Glass	10020
Steel Cans/Tins	4817
Aluminium Cans	1149
Biogenic Food Waste	49153
Garden Refuse: Green	7887
Garden Refuse: Wood	807
Other	10800
TOTAL	**122,514**

Table C2 – New England Road Stream Quantity (Household and Commercial waste)

Waste Fraction	Total Quantity (tons)
Newspaper	5,453
General mixed paper (CMW)	7,234
Scrap Boxes & Cardboard (K4)	11,402
Low density polyethylene (LDPE)	2,450
High density polyethylene (HDPE)	1,401
Polyethylene-terephthalate (PET)	2,037
Polypropylene (PP)	1,613
Polyvinyl Chloride (PVC)	8
Polystyrene (PS)	1,101
Glass	6,861
Steel Cans/Tins	4,245
Aluminium Cans	547
Biogenic Food Waste	36,608
Garden Refuse: Green	637
Garden Refuse: Wood	46
Other	32,287
TOTAL	**113,930**

*NOTES: Input amount for anaerobic digestion is equal to the total wet weight. It is assumed that 0.6m^3 of water is required per ton of waste. Therefore for Mariannhill waste stream:

Total volume of water added = 0.66 m^3/ton x 49153 tons = 29491.8 m^3

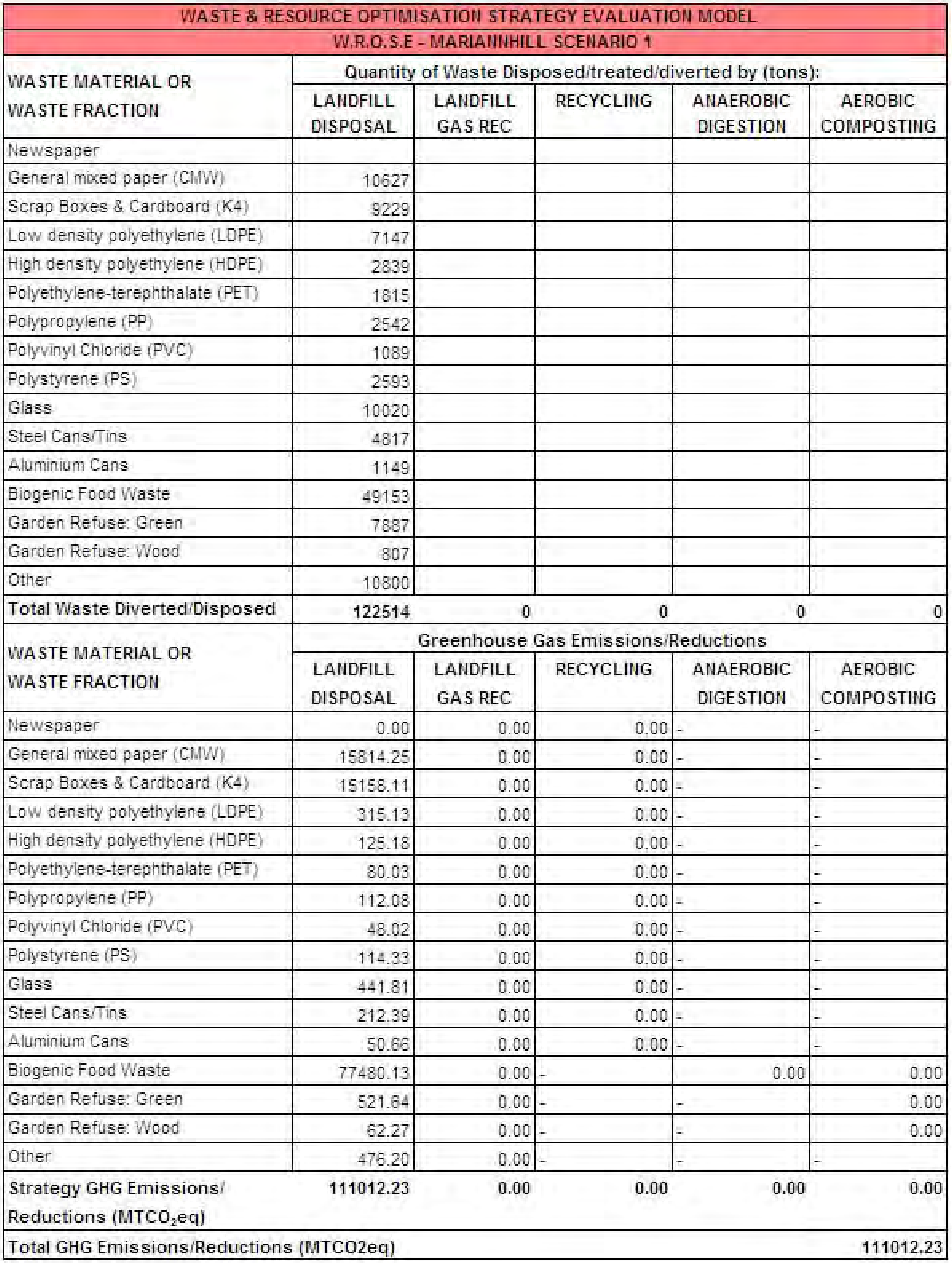
Density of water = 1000 kg/m^3 = 1 ton/ m^3

Total Wet Weight = 49153 + 29491.8 m^3 (1 ton/ m^3) = 78644.8 tons

Similarly the input value for the AD process for the UMDM = 58572.8 tons

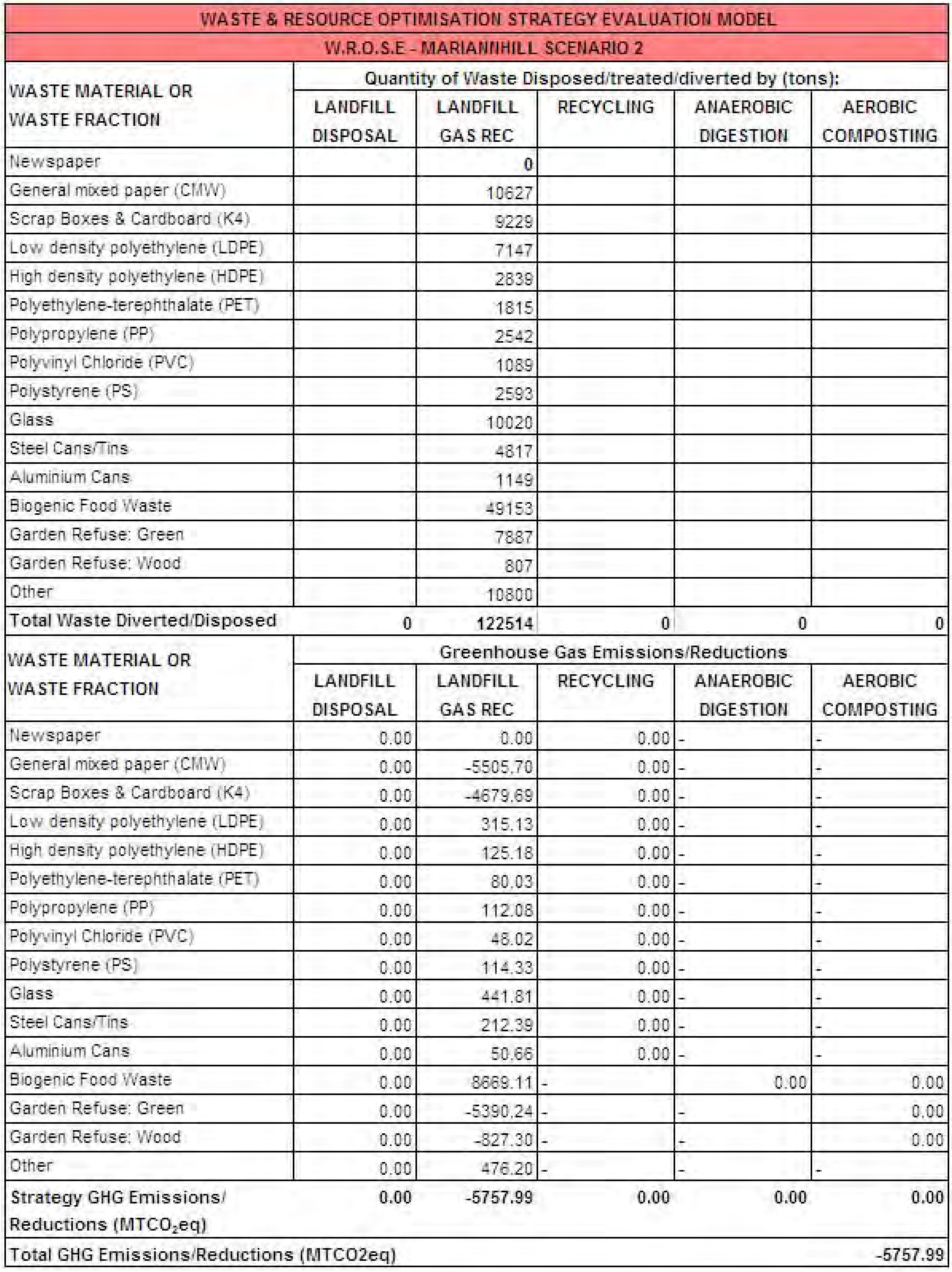
APPENDIX D – WROSE DATA SHEETS

Table D1 – WROSE input and output screen: Mariannhill Scenario 1



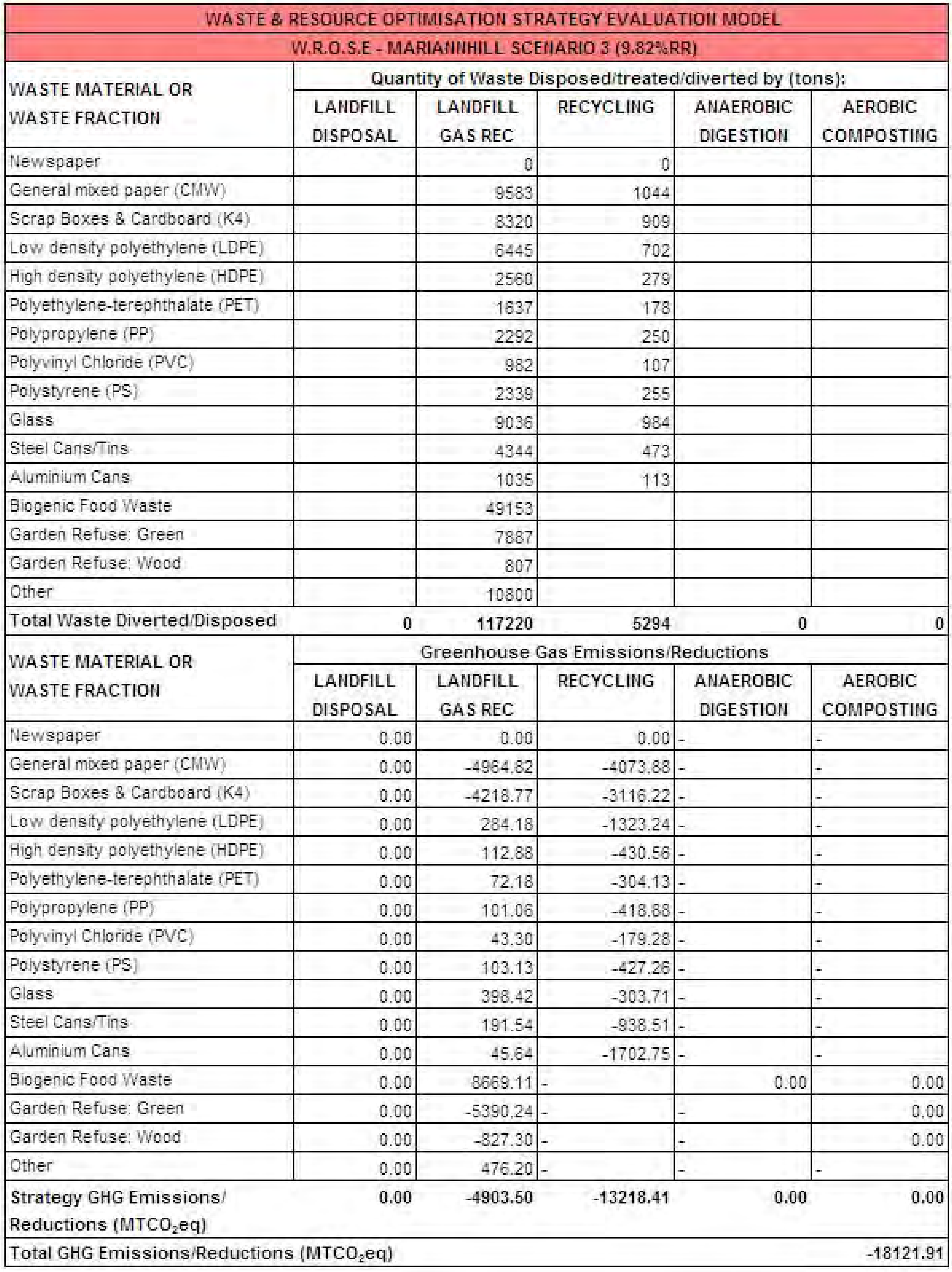
WASTE & RESOURCE OPTIMISATION STRATEGY EVALUATION MODEL					
W.R.O.S.E - MARIANNHILL SCENARIO 1					
WASTE MATERIAL OR WASTE FRACTION	Quantity of Waste Disposed/treated/diverted by (tons):				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
Newspaper					
General mixed paper (CMW)	10627				
Scrap Boxes & Cardboard (K4)	9229				
Low density polyethylene (LDPE)	7147				
High density polyethylene (HDPE)	2839				
Polyethylene-terephthalate (PET)	1815				
Polypropylene (PP)	2542				
Polyvinyl Chloride (PVC)	1089				
Polystyrene (PS)	2593				
Glass	10020				
Steel Cans/Tins	4817				
Aluminium Cans	1149				
Biogenic Food Waste	49153				
Garden Refuse: Green	7887				
Garden Refuse: Wood	807				
Other	10800				
Total Waste Diverted/Disposed	**122514**	**0**	**0**	**0**	**0**
WASTE MATERIAL OR WASTE FRACTION	Greenhouse Gas Emissions/Reductions				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
Newspaper	0.00	0.00	0.00	-	-
General mixed paper (CMW)	15814.25	0.00	0.00	-	-
Scrap Boxes & Cardboard (K4)	15158.11	0.00	0.00	-	-
Low density polyethylene (LDPE)	315.13	0.00	0.00	-	-
High density polyethylene (HDPE)	125.18	0.00	0.00	-	-
Polyethylene-terephthalate (PET)	80.03	0.00	0.00	-	-
Polypropylene (PP)	112.08	0.00	0.00	-	-
Polyvinyl Chloride (PVC)	48.02	0.00	0.00	-	-
Polystyrene (PS)	114.33	0.00	0.00	-	-
Glass	441.81	0.00	0.00	-	-
Steel Cans/Tins	212.39	0.00	0.00	-	-
Aluminium Cans	50.66	0.00	0.00	-	-
Biogenic Food Waste	77480.13	0.00	-	0.00	0.00
Garden Refuse: Green	521.64	0.00	-	-	0.00
Garden Refuse: Wood	62.27	0.00	-	-	0.00
Other	476.20	0.00	-	-	-
Strategy GHG Emissions/ Reductions (MTCO$_2$eq)	**111012.23**	**0.00**	**0.00**	**0.00**	**0.00**
Total GHG Emissions/Reductions (MTCO2eq)					**111012.23**

Table D2 – WROSE input and output screen: Mariannhill Scenario 2



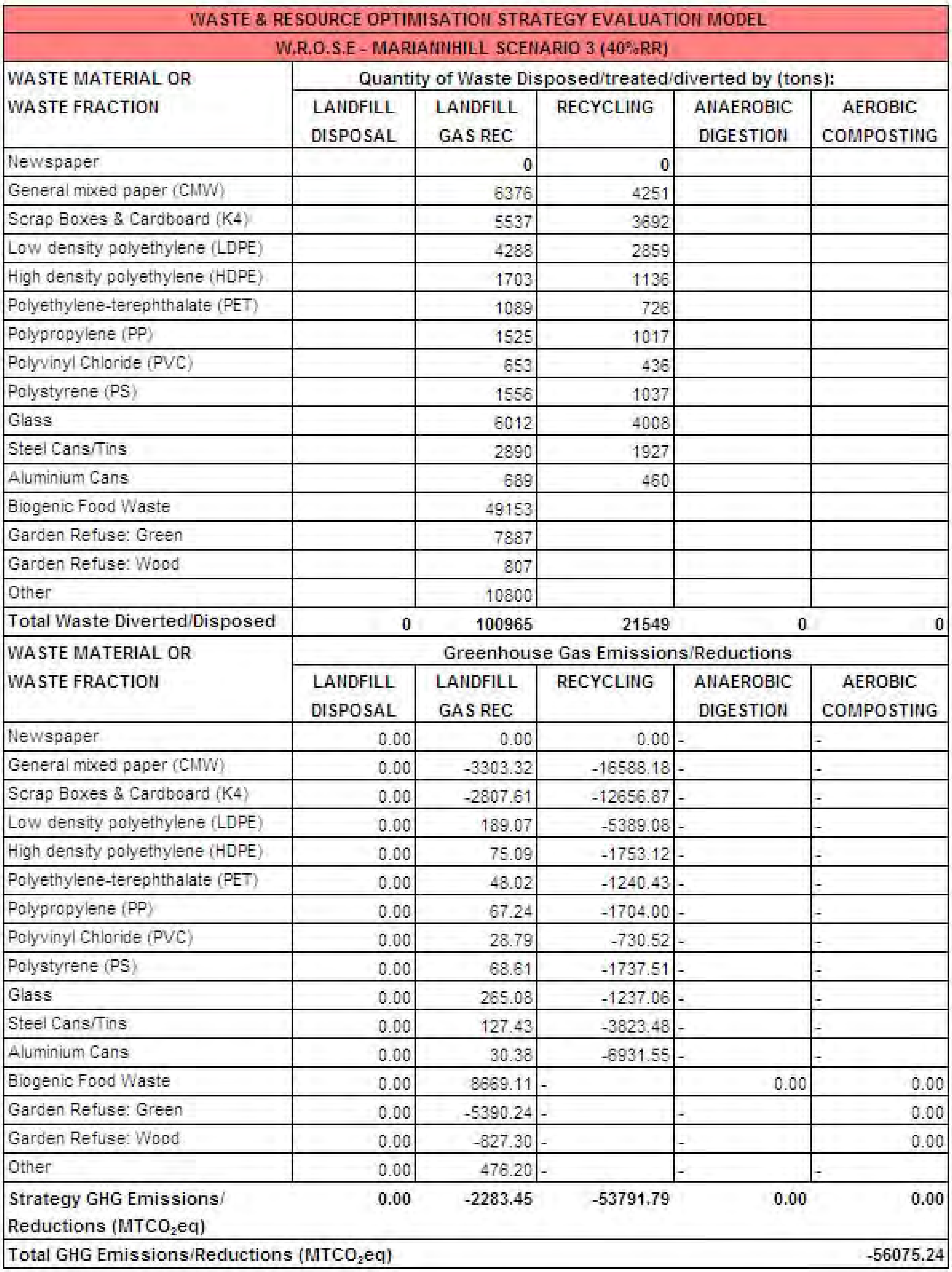
WASTE & RESOURCE OPTIMISATION STRATEGY EVALUATION MODEL W.R.O.S.E - MARIANNHILL SCENARIO 2					
WASTE MATERIAL OR WASTE FRACTION	Quantity of Waste Disposed/treated/diverted by (tons):				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
Newspaper		0			
General mixed paper (CMW)		10627			
Scrap Boxes & Cardboard (K4)		9229			
Low density polyethylene (LDPE)		7147			
High density polyethylene (HDPE)		2839			
Polyethylene-terephthalate (PET)		1815			
Polypropylene (PP)		2542			
Polyvinyl Chloride (PVC)		1089			
Polystyrene (PS)		2593			
Glass		10020			
Steel Cans/Tins		4817			
Aluminium Cans		1149			
Biogenic Food Waste		49153			
Garden Refuse: Green		7887			
Garden Refuse: Wood		807			
Other		10800			
Total Waste Diverted/Disposed	**0**	**122514**	**0**	**0**	**0**
WASTE MATERIAL OR WASTE FRACTION	Greenhouse Gas Emissions/Reductions				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
Newspaper	0.00	0.00	0.00	-	-
General mixed paper (CMW)	0.00	-5505.70	0.00	-	-
Scrap Boxes & Cardboard (K4)	0.00	-4679.69	0.00	-	-
Low density polyethylene (LDPE)	0.00	315.13	0.00	-	-
High density polyethylene (HDPE)	0.00	125.18	0.00	-	-
Polyethylene-terephthalate (PET)	0.00	80.03	0.00	-	-
Polypropylene (PP)	0.00	112.08	0.00	-	-
Polyvinyl Chloride (PVC)	0.00	48.02	0.00	-	-
Polystyrene (PS)	0.00	114.33	0.00	-	-
Glass	0.00	441.81	0.00	-	-
Steel Cans/Tins	0.00	212.39	0.00	-	-
Aluminium Cans	0.00	50.66	0.00	-	-
Biogenic Food Waste	0.00	8669.11	-	0.00	0.00
Garden Refuse: Green	0.00	-5390.24	-	-	0.00
Garden Refuse: Wood	0.00	-827.30	-	-	0.00
Other	0.00	476.20	-	-	-
Strategy GHG Emissions/ Reductions (MTCO$_2$eq)	**0.00**	**-5757.99**	**0.00**	**0.00**	**0.00**
Total GHG Emissions/Reductions (MTCO2eq)					**-5757.99**

Table D3 – WROSE Input and output screen: Mariannhill Scenario 3



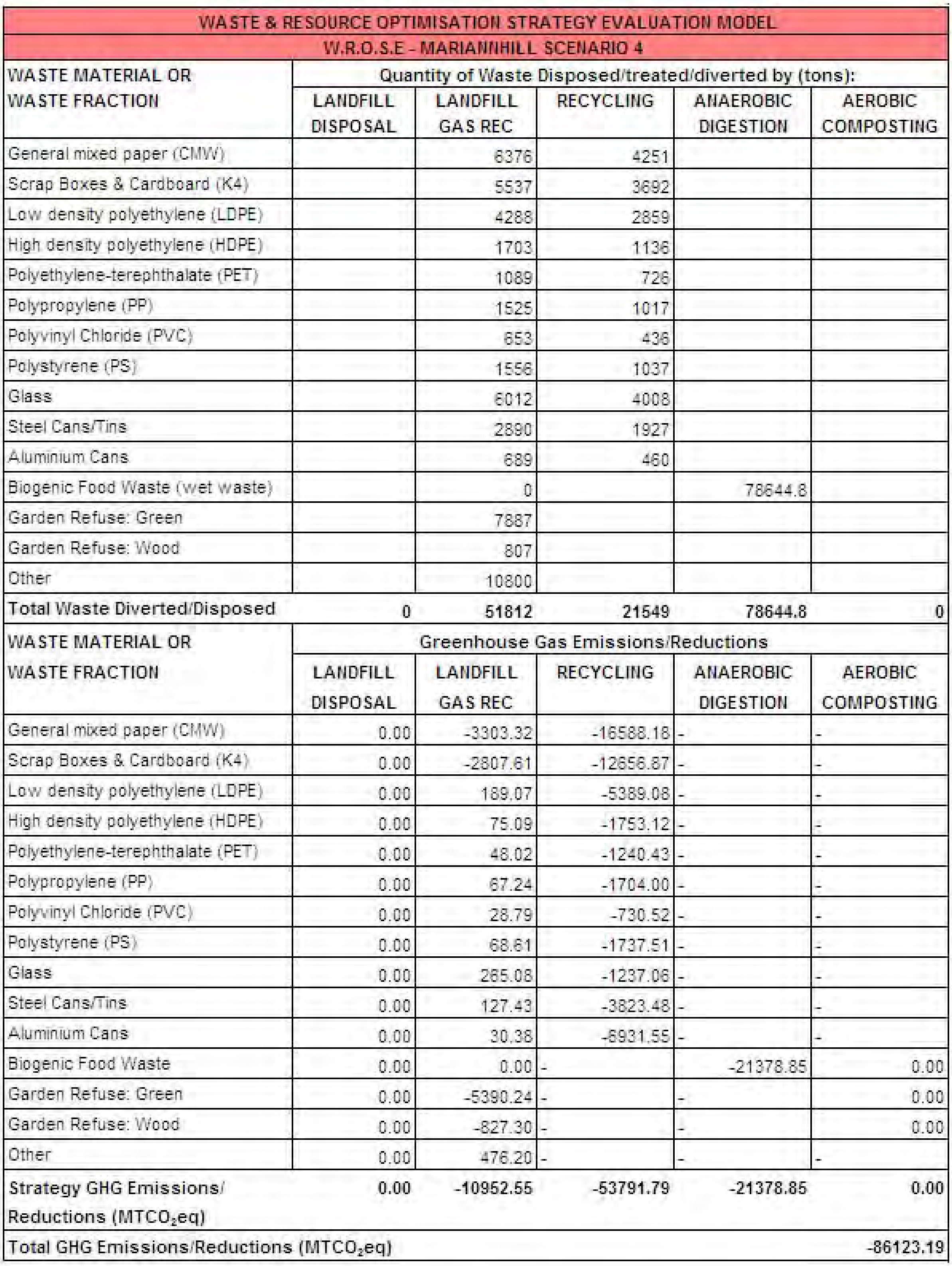
WASTE & RESOURCE OPTIMISATION STRATEGY EVALUATION MODEL					
W.R.O.S.E - MARIANNHILL SCENARIO 3 (9.82%RR)					
WASTE MATERIAL OR WASTE FRACTION	Quantity of Waste Disposed/treated/diverted by (tons):				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
Newspaper		0	0		
General mixed paper (CMW)		9583	1044		
Scrap Boxes & Cardboard (K4)		8320	909		
Low density polyethylene (LDPE)		6445	702		
High density polyethylene (HDPE)		2560	279		
Polyethylene-terephthalate (PET)		1637	178		
Polypropylene (PP)		2292	250		
Polyvinyl Chloride (PVC)		982	107		
Polystyrene (PS)		2339	255		
Glass		9036	984		
Steel Cans/Tins		4344	473		
Aluminium Cans		1035	113		
Biogenic Food Waste		49153			
Garden Refuse: Green		7887			
Garden Refuse: Wood		807			
Other		10800			
Total Waste Diverted/Disposed	**0**	**117220**	**5294**	**0**	**0**
WASTE MATERIAL OR WASTE FRACTION	Greenhouse Gas Emissions/Reductions				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
Newspaper	0.00	0.00	0.00	-	-
General mixed paper (CMW)	0.00	-4964.82	-4073.88	-	-
Scrap Boxes & Cardboard (K4)	0.00	-4218.77	-3116.22	-	-
Low density polyethylene (LDPE)	0.00	284.18	-1323.24	-	-
High density polyethylene (HDPE)	0.00	112.88	-430.56	-	-
Polyethylene-terephthalate (PET)	0.00	72.18	-304.13	-	-
Polypropylene (PP)	0.00	101.06	-418.88	-	-
Polyvinyl Chloride (PVC)	0.00	43.30	-179.28	-	-
Polystyrene (PS)	0.00	103.13	-427.26	-	-
Glass	0.00	398.42	-303.71	-	-
Steel Cans/Tins	0.00	191.54	-938.51	-	-
Aluminium Cans	0.00	45.64	-1702.75	-	-
Biogenic Food Waste	0.00	8669.11	-	0.00	0.00
Garden Refuse: Green	0.00	-5390.24	-	-	0.00
Garden Refuse: Wood	0.00	-827.30	-	-	0.00
Other	0.00	476.20	-	-	-
Strategy GHG Emissions/ Reductions (MTCO$_2$eq)	**0.00**	**-4903.50**	**-13218.41**	**0.00**	**0.00**
Total GHG Emissions/Reductions (MTCO$_2$eq)					**-18121.91**

Table D4 – WROSE Input and output screen: Mariannhill Scenario 3



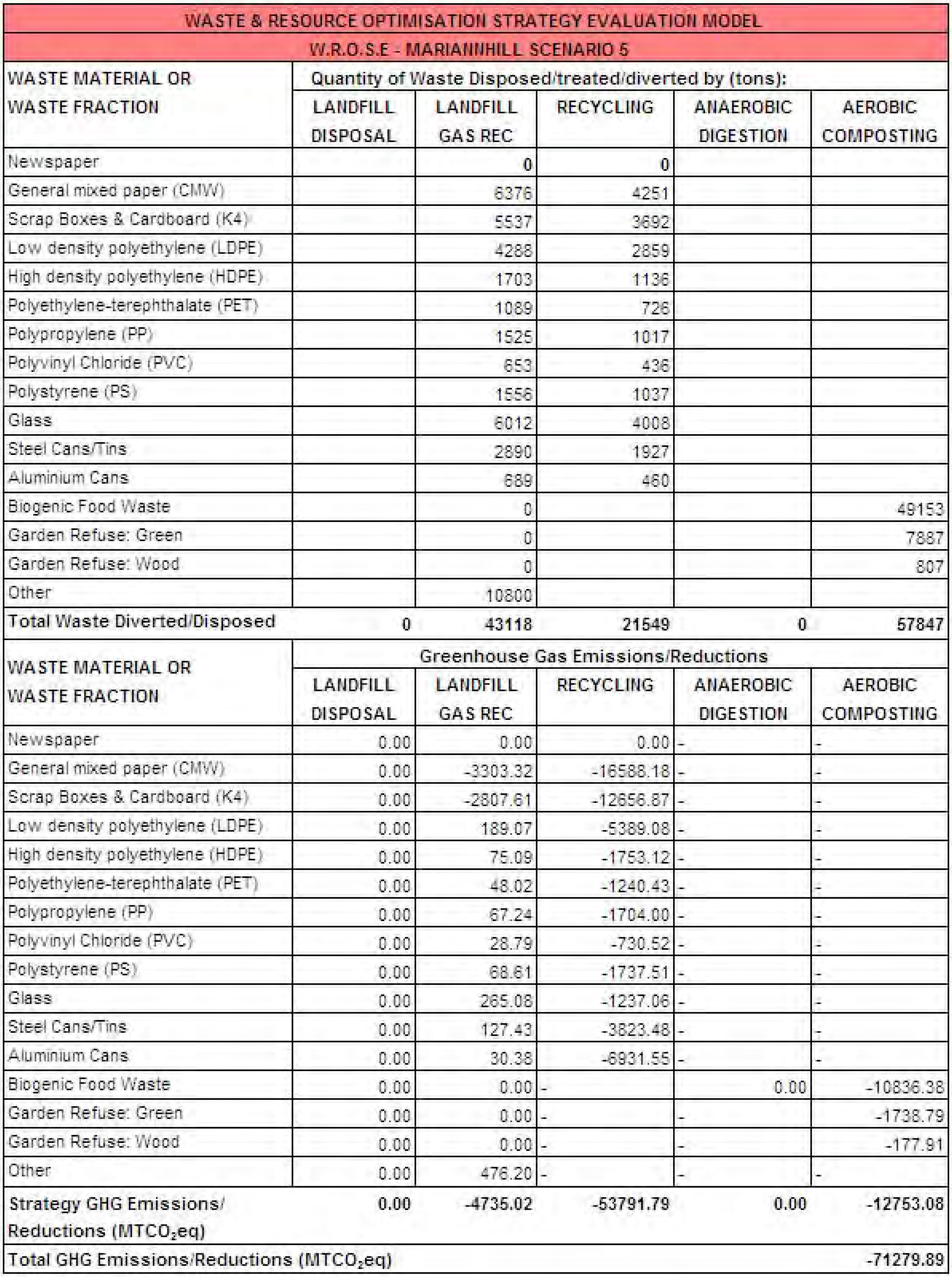
WASTE & RESOURCE OPTIMISATION STRATEGY EVALUATION MODEL					
W.R.O.S.E - MARIANNHILL SCENARIO 3 (40%RR)					
WASTE MATERIAL OR WASTE FRACTION	**Quantity of Waste Disposed/treated/diverted by (tons):**				
	LANDFILL DISPOSAL	**LANDFILL GAS REC**	**RECYCLING**	**ANAEROBIC DIGESTION**	**AEROBIC COMPOSTING**
Newspaper		0	0		
General mixed paper (CMW)		6376	4251		
Scrap Boxes & Cardboard (K4)		5537	3692		
Low density polyethylene (LDPE)		4288	2859		
High density polyethylene (HDPE)		1703	1136		
Polyethylene-terephthalate (PET)		1089	726		
Polypropylene (PP)		1525	1017		
Polyvinyl Chloride (PVC)		653	436		
Polystyrene (PS)		1556	1037		
Glass		6012	4008		
Steel Cans/Tins		2890	1927		
Aluminium Cans		689	460		
Biogenic Food Waste		49153			
Garden Refuse: Green		7887			
Garden Refuse: Wood		807			
Other		10800			
Total Waste Diverted/Disposed	**0**	**100965**	**21549**	**0**	**0**
WASTE MATERIAL OR WASTE FRACTION	**Greenhouse Gas Emissions/Reductions**				
	LANDFILL DISPOSAL	**LANDFILL GAS REC**	**RECYCLING**	**ANAEROBIC DIGESTION**	**AEROBIC COMPOSTING**
Newspaper	0.00	0.00	0.00	-	-
General mixed paper (CMW)	0.00	-3303.32	-16588.18	-	-
Scrap Boxes & Cardboard (K4)	0.00	-2807.61	-12656.87	-	-
Low density polyethylene (LDPE)	0.00	189.07	-5389.08	-	-
High density polyethylene (HDPE)	0.00	75.09	-1753.12	-	-
Polyethylene-terephthalate (PET)	0.00	48.02	-1240.43	-	-
Polypropylene (PP)	0.00	67.24	-1704.00	-	-
Polyvinyl Chloride (PVC)	0.00	28.79	-730.52	-	-
Polystyrene (PS)	0.00	68.61	-1737.51	-	-
Glass	0.00	265.08	-1237.06	-	-
Steel Cans/Tins	0.00	127.43	-3823.48	-	-
Aluminium Cans	0.00	30.38	-6931.55	-	-
Biogenic Food Waste	0.00	8669.11	-	0.00	0.00
Garden Refuse: Green	0.00	-5390.24	-	-	0.00
Garden Refuse: Wood	0.00	-827.30	-	-	0.00
Other	0.00	476.20	-	-	-
Strategy GHG Emissions/ Reductions (MTCO$_2$eq)	**0.00**	**-2283.45**	**-53791.79**	**0.00**	**0.00**
Total GHG Emissions/Reductions (MTCO$_2$eq)					**-56075.24**

Table D5 – WROSE Input and output screen: Mariannhill Scenario 4



WASTE & RESOURCE OPTIMISATION STRATEGY EVALUATION MODEL W.R.O.S.E - MARIANNHILL SCENARIO 4					
WASTE MATERIAL OR WASTE FRACTION	Quantity of Waste Disposed/treated/diverted by (tons):				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
General mixed paper (CMW)		6376	4251		
Scrap Boxes & Cardboard (K4)		5537	3692		
Low density polyethylene (LDPE)		4288	2859		
High density polyethylene (HDPE)		1703	1136		
Polyethylene-terephthalate (PET)		1089	726		
Polypropylene (PP)		1525	1017		
Polyvinyl Chloride (PVC)		653	436		
Polystyrene (PS)		1556	1037		
Glass		6012	4008		
Steel Cans/Tins		2890	1927		
Aluminium Cans		689	460		
Biogenic Food Waste (wet waste)		0		78644.8	
Garden Refuse: Green		7887			
Garden Refuse: Wood		807			
Other		10800			
Total Waste Diverted/Disposed	**0**	**51812**	**21549**	**78644.8**	**0**
WASTE MATERIAL OR WASTE FRACTION	Greenhouse Gas Emissions/Reductions				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
General mixed paper (CMW)	0.00	-3303.32	-16588.18	-	-
Scrap Boxes & Cardboard (K4)	0.00	-2807.61	-12856.87	-	-
Low density polyethylene (LDPE)	0.00	189.07	-5389.08	-	-
High density polyethylene (HDPE)	0.00	75.09	-1753.12	-	-
Polyethylene-terephthalate (PET)	0.00	48.02	-1240.43	-	-
Polypropylene (PP)	0.00	67.24	-1704.00	-	-
Polyvinyl Chloride (PVC)	0.00	28.79	-730.52	-	-
Polystyrene (PS)	0.00	68.61	-1737.51	-	-
Glass	0.00	265.08	-1237.06	-	-
Steel Cans/Tins	0.00	127.43	-3823.48	-	-
Aluminium Cans	0.00	30.38	-6931.55	-	-
Biogenic Food Waste	0.00	0.00	-	-21378.85	0.00
Garden Refuse: Green	0.00	-5390.24	-	-	0.00
Garden Refuse: Wood	0.00	-827.30	-	-	0.00
Other	0.00	476.20	-	-	-
Strategy GHG Emissions/ Reductions (MTCO$_2$eq)	**0.00**	**-10952.55**	**-53791.79**	**-21378.85**	**0.00**
Total GHG Emissions/Reductions (MTCO$_2$eq)					**-86123.19**

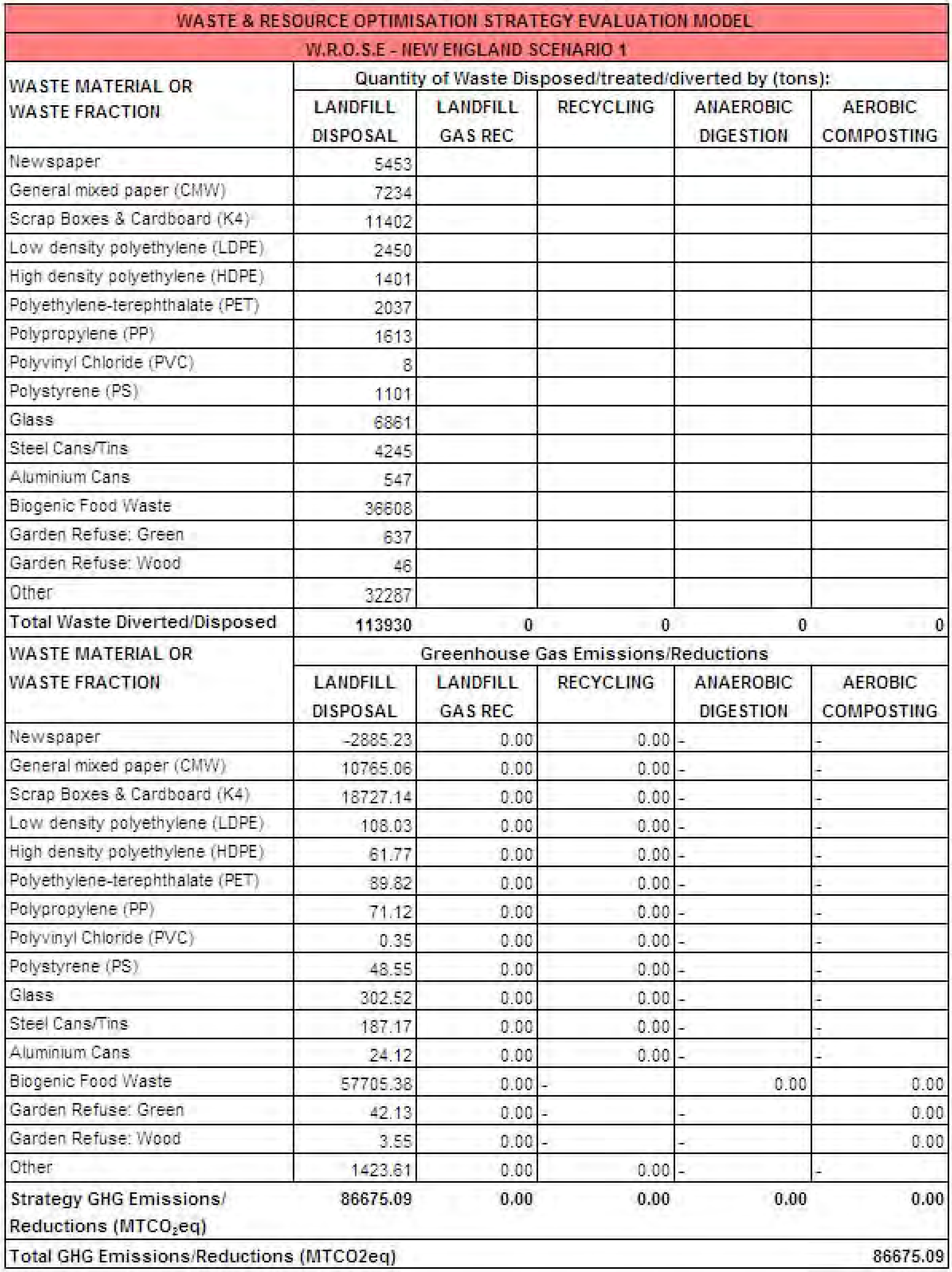
Table D6 – WROSE Input and output screen: Mariannhill Scenario 5



WASTE & RESOURCE OPTIMISATION STRATEGY EVALUATION MODEL					
W.R.O.S.E - MARIANNHILL SCENARIO 5					
WASTE MATERIAL OR WASTE FRACTION	Quantity of Waste Disposed/treated/diverted by (tons):				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
Newspaper		0	0		
General mixed paper (CMW)		6376	4251		
Scrap Boxes & Cardboard (K4)		5537	3692		
Low density polyethylene (LDPE)		4288	2859		
High density polyethylene (HDPE)		1703	1136		
Polyethylene-terephthalate (PET)		1089	726		
Polypropylene (PP)		1525	1017		
Polyvinyl Chloride (PVC)		653	436		
Polystyrene (PS)		1556	1037		
Glass		6012	4008		
Steel Cans/Tins		2890	1927		
Aluminium Cans		689	460		
Biogenic Food Waste		0			49153
Garden Refuse: Green		0			7887
Garden Refuse: Wood		0			807
Other		10800			
Total Waste Diverted/Disposed	**0**	**43118**	**21549**	**0**	**57847**

WASTE MATERIAL OR WASTE FRACTION	Greenhouse Gas Emissions/Reductions				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
Newspaper	0.00	0.00	0.00	-	-
General mixed paper (CMW)	0.00	-3303.32	-16588.18	-	-
Scrap Boxes & Cardboard (K4)	0.00	-2807.61	-12656.87	-	-
Low density polyethylene (LDPE)	0.00	189.07	-5389.08	-	-
High density polyethylene (HDPE)	0.00	75.09	-1753.12	-	-
Polyethylene-terephthalate (PET)	0.00	48.02	-1240.43	-	-
Polypropylene (PP)	0.00	67.24	-1704.00	-	-
Polyvinyl Chloride (PVC)	0.00	28.79	-730.52	-	-
Polystyrene (PS)	0.00	68.61	-1737.51	-	-
Glass	0.00	265.08	-1237.06	-	-
Steel Cans/Tins	0.00	127.43	-3823.48	-	-
Aluminium Cans	0.00	30.38	-6931.55	-	-
Biogenic Food Waste	0.00	0.00	-	0.00	-10836.38
Garden Refuse: Green	0.00	0.00	-	-	-1738.79
Garden Refuse: Wood	0.00	0.00	-	-	-177.91
Other	0.00	476.20	-	-	-
Strategy GHG Emissions/ Reductions (MTCO$_2$eq)	**0.00**	**-4735.02**	**-53791.79**	**0.00**	**-12753.08**
Total GHG Emissions/Reductions (MTCO$_2$eq)					**-71279.89**

Table D7 – WROSE Input and output screen: New England Road Scenario 1

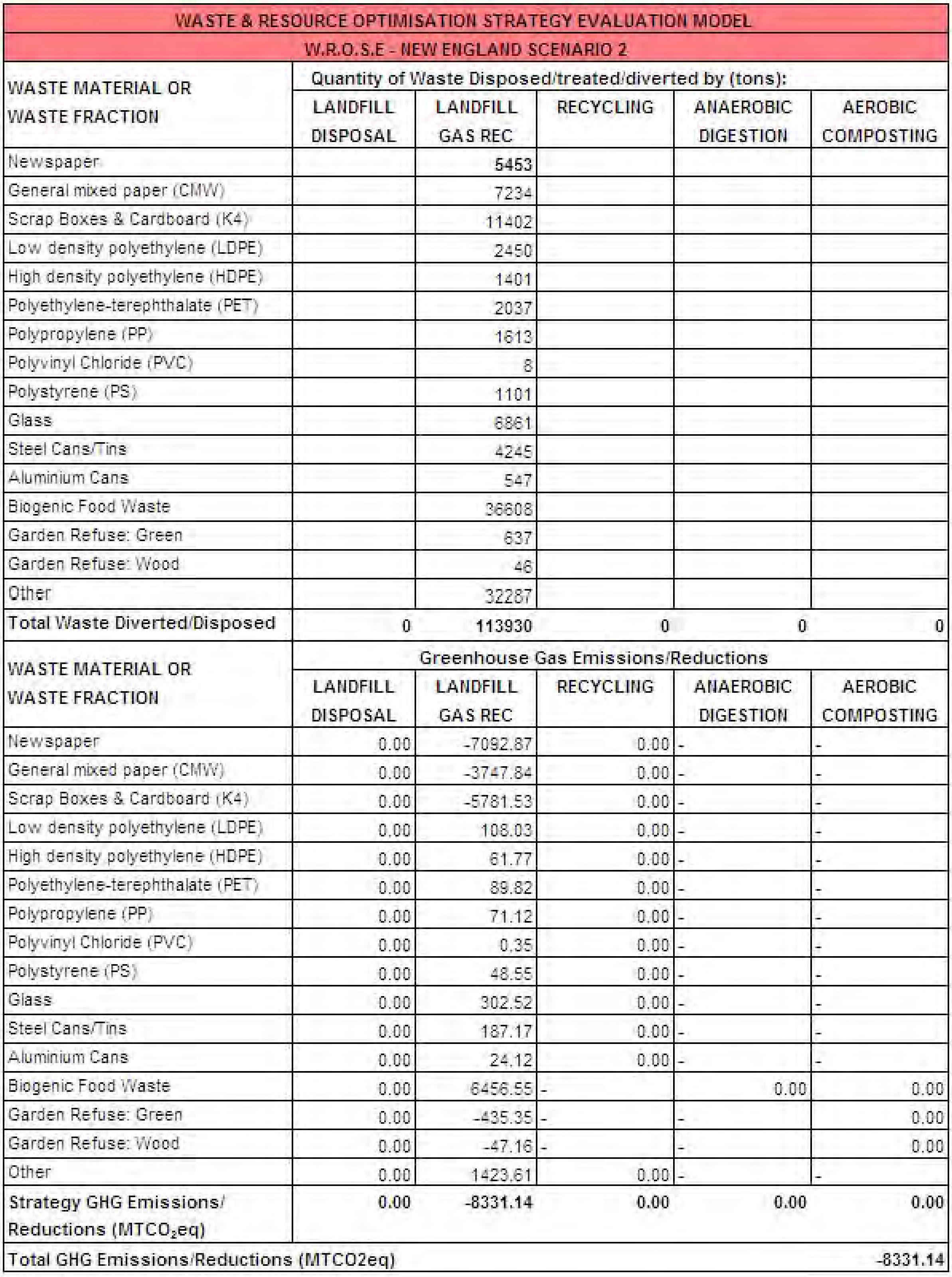


WASTE & RESOURCE OPTIMISATION STRATEGY EVALUATION MODEL

W.R.O.S.E - NEW ENGLAND SCENARIO 1

WASTE MATERIAL OR WASTE FRACTION	Quantity of Waste Disposed/treated/diverted by (tons):				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
Newspaper	5453				
General mixed paper (CMW)	7234				
Scrap Boxes & Cardboard (K4)	11402				
Low density polyethylene (LDPE)	2450				
High density polyethylene (HDPE)	1401				
Polyethylene-terephthalate (PET)	2037				
Polypropylene (PP)	1613				
Polyvinyl Chloride (PVC)	8				
Polystyrene (PS)	1101				
Glass	6861				
Steel Cans/Tins	4245				
Aluminium Cans	547				
Biogenic Food Waste	36608				
Garden Refuse: Green	637				
Garden Refuse: Wood	46				
Other	32287				
Total Waste Diverted/Disposed	**113930**	**0**	**0**	**0**	**0**
WASTE MATERIAL OR WASTE FRACTION	**Greenhouse Gas Emissions/Reductions**				
	LANDFILL DISPOSAL	**LANDFILL GAS REC**	**RECYCLING**	**ANAEROBIC DIGESTION**	**AEROBIC COMPOSTING**
Newspaper	-2885.23	0.00	0.00	-	-
General mixed paper (CMW)	10765.06	0.00	0.00	-	-
Scrap Boxes & Cardboard (K4)	18727.14	0.00	0.00	-	-
Low density polyethylene (LDPE)	108.03	0.00	0.00	-	-
High density polyethylene (HDPE)	61.77	0.00	0.00	-	-
Polyethylene-terephthalate (PET)	89.82	0.00	0.00	-	-
Polypropylene (PP)	71.12	0.00	0.00	-	-
Polyvinyl Chloride (PVC)	0.35	0.00	0.00	-	-
Polystyrene (PS)	48.55	0.00	0.00	-	-
Glass	302.52	0.00	0.00	-	-
Steel Cans/Tins	187.17	0.00	0.00	-	-
Aluminium Cans	24.12	0.00	0.00	-	-
Biogenic Food Waste	57705.38	0.00	-	0.00	0.00
Garden Refuse: Green	42.13	0.00	-	-	0.00
Garden Refuse: Wood	3.55	0.00	-	-	0.00
Other	1423.61	0.00	0.00	-	-
Strategy GHG Emissions/ Reductions (MTCO$_2$eq)	**86675.09**	**0.00**	**0.00**	**0.00**	**0.00**
Total GHG Emissions/Reductions (MTCO2eq)					**86675.09**

Table D8 – WROSE Input and output screen: New England Road Scenario 2



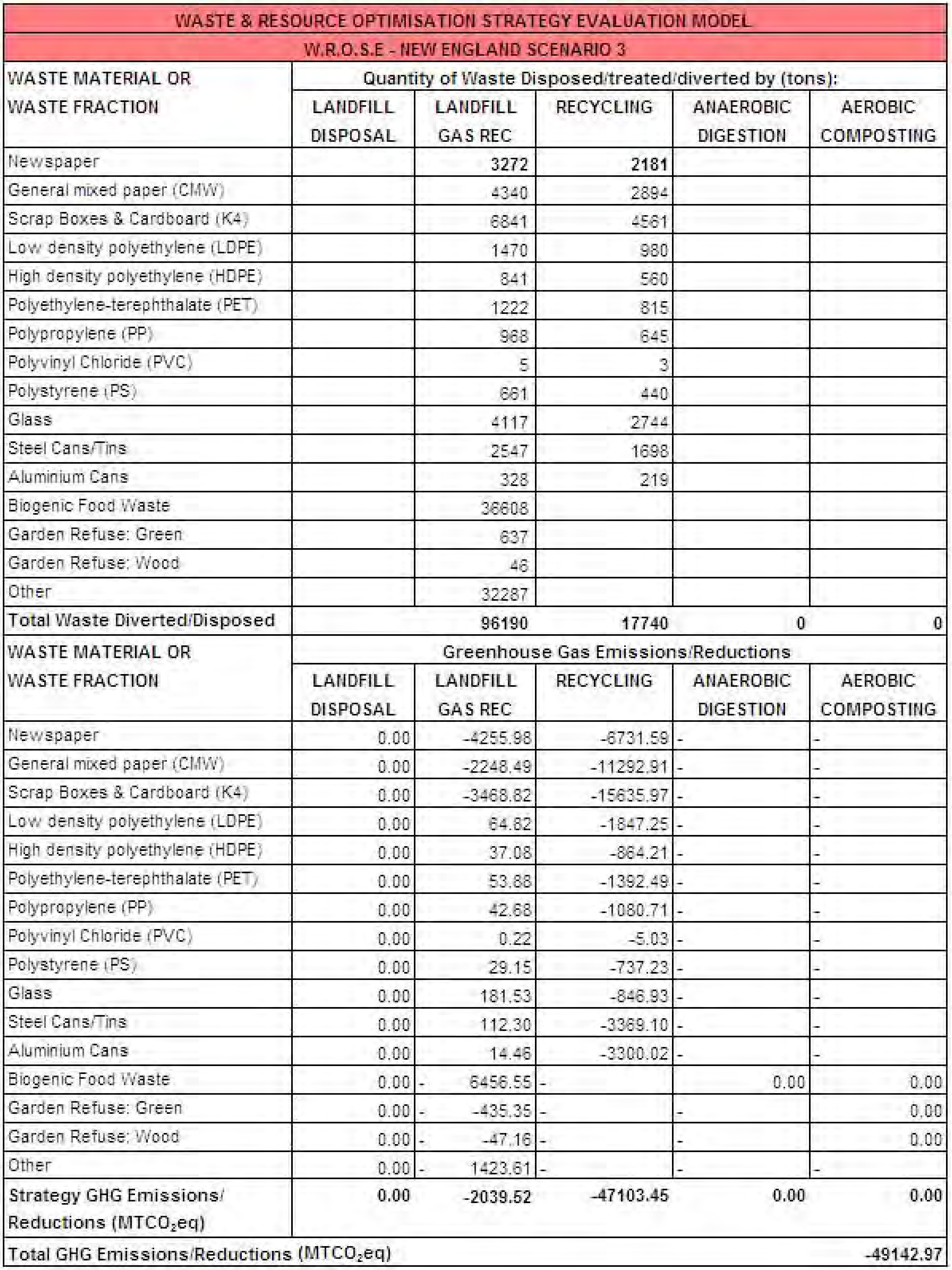
WASTE & RESOURCE OPTIMISATION STRATEGY EVALUATION MODEL

W.R.O.S.E - NEW ENGLAND SCENARIO 2

WASTE MATERIAL OR WASTE FRACTION	Quantity of Waste Disposed/treated/diverted by (tons):				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
Newspaper		5453			
General mixed paper (CMW)		7234			
Scrap Boxes & Cardboard (K4)		11402			
Low density polyethylene (LDPE)		2450			
High density polyethylene (HDPE)		1401			
Polyethylene-terephthalate (PET)		2037			
Polypropylene (PP)		1613			
Polyvinyl Chloride (PVC)		8			
Polystyrene (PS)		1101			
Glass		6861			
Steel Cans/Tins		4245			
Aluminium Cans		547			
Biogenic Food Waste		36608			
Garden Refuse: Green		637			
Garden Refuse: Wood		46			
Other		32287			
Total Waste Diverted/Disposed	**0**	**113930**	**0**	**0**	**0**

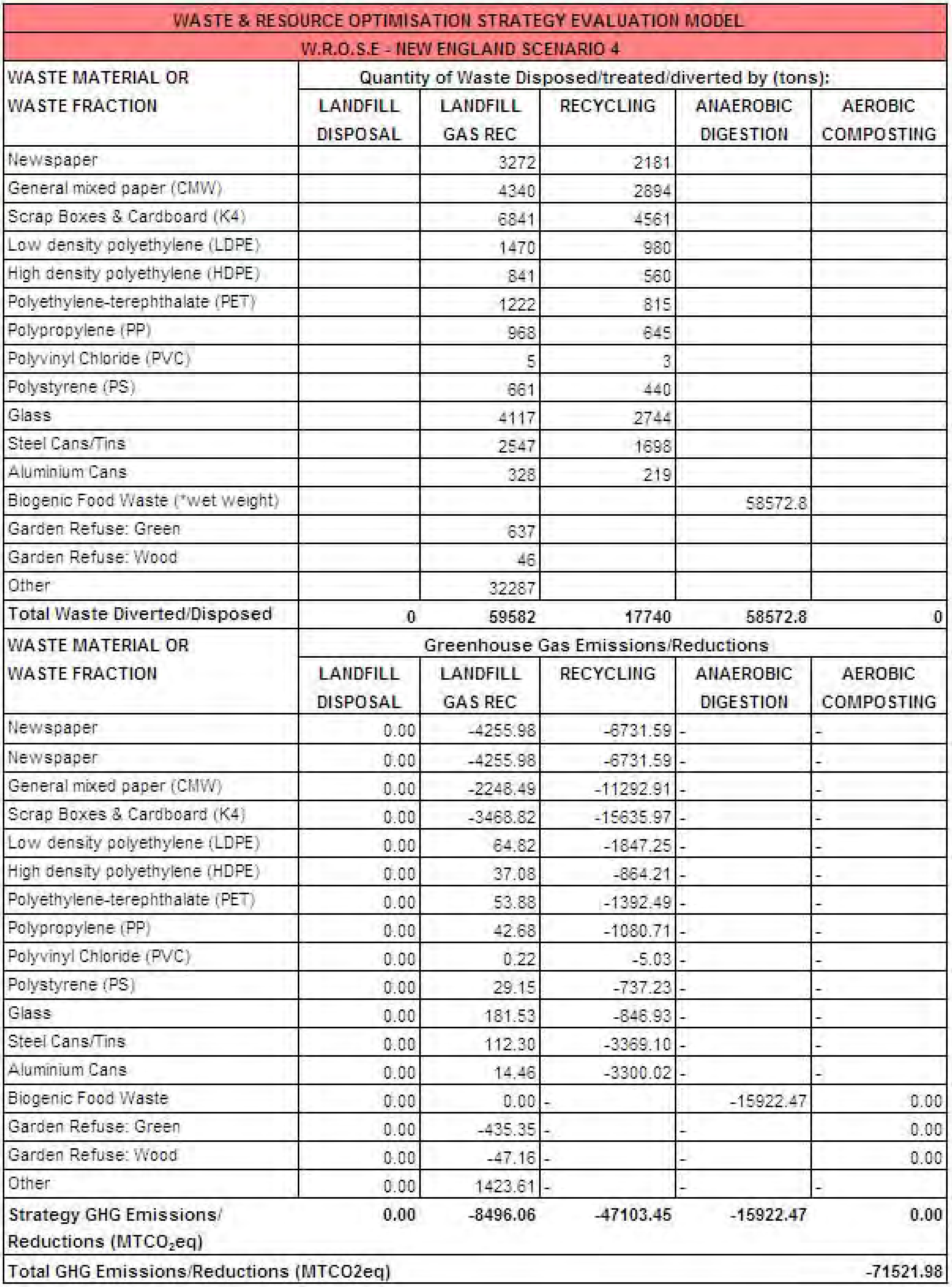
WASTE MATERIAL OR WASTE FRACTION	Greenhouse Gas Emissions/Reductions				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
Newspaper	0.00	-7092.87	0.00	-	-
General mixed paper (CMW)	0.00	-3747.84	0.00	-	-
Scrap Boxes & Cardboard (K4)	0.00	-5781.53	0.00	-	-
Low density polyethylene (LDPE)	0.00	108.03	0.00	-	-
High density polyethylene (HDPE)	0.00	61.77	0.00	-	-
Polyethylene-terephthalate (PET)	0.00	89.82	0.00	-	-
Polypropylene (PP)	0.00	71.12	0.00	-	-
Polyvinyl Chloride (PVC)	0.00	0.35	0.00	-	-
Polystyrene (PS)	0.00	48.55	0.00	-	-
Glass	0.00	302.52	0.00	-	-
Steel Cans/Tins	0.00	187.17	0.00	-	-
Aluminium Cans	0.00	24.12	0.00	-	-
Biogenic Food Waste	0.00	6456.55	-	0.00	0.00
Garden Refuse: Green	0.00	-435.35	-	-	0.00
Garden Refuse: Wood	0.00	-47.16	-	-	0.00
Other	0.00	1423.61	0.00	-	-
Strategy GHG Emissions/ Reductions (MTCO$_2$eq)	**0.00**	**-8331.14**	**0.00**	**0.00**	**0.00**
Total GHG Emissions/Reductions (MTCO2eq)					**-8331.14**

Table D9 – WROSE Input and output screen: New England Road Scenario 3



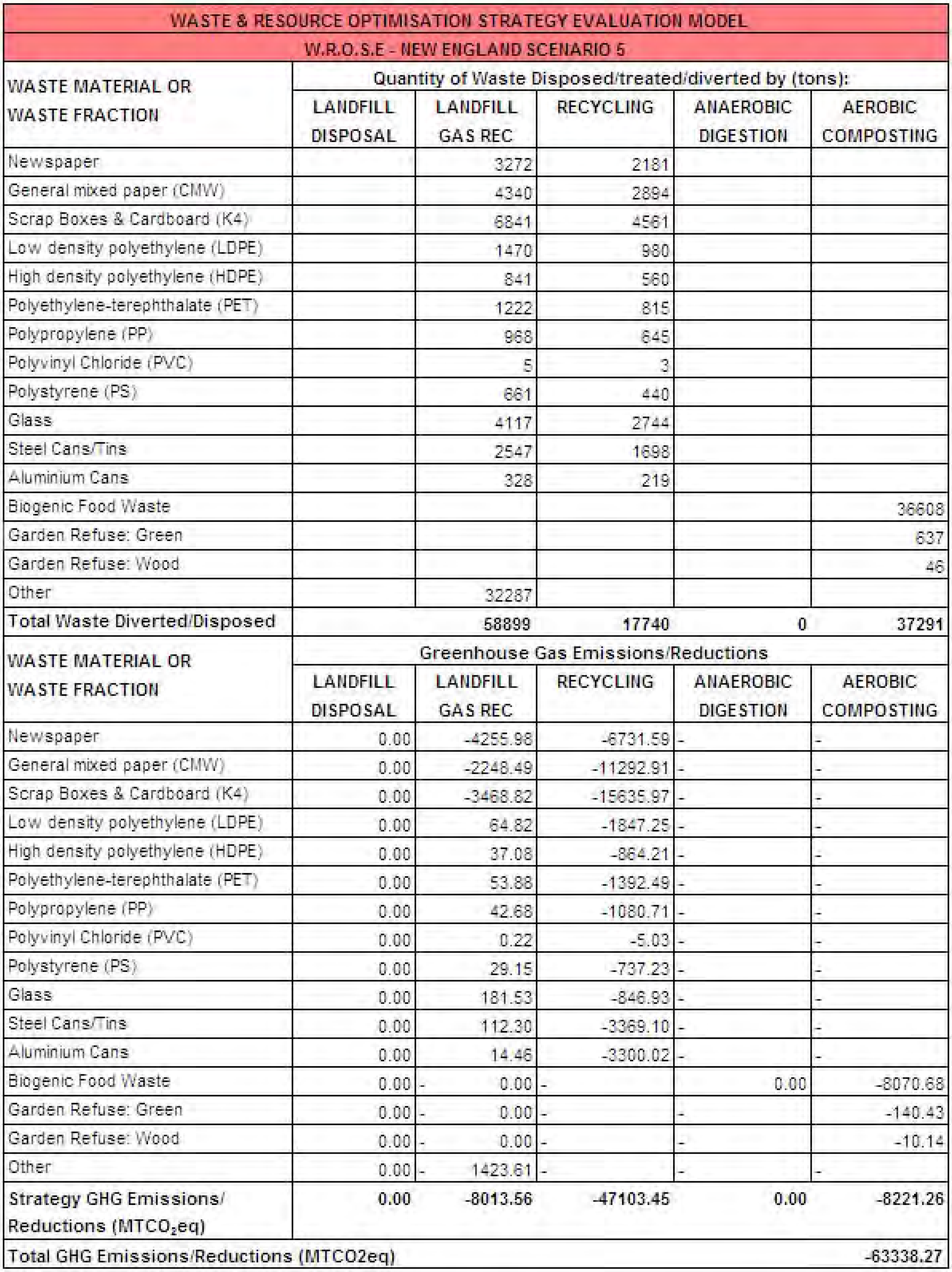
WASTE & RESOURCE OPTIMISATION STRATEGY EVALUATION MODEL					
W.R.O.S.E - NEW ENGLAND SCENARIO 3					
WASTE MATERIAL OR WASTE FRACTION	Quantity of Waste Disposed/treated/diverted by (tons):				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
Newspaper		3272	2181		
General mixed paper (CMW)		4340	2894		
Scrap Boxes & Cardboard (K4)		6841	4561		
Low density polyethylene (LDPE)		1470	980		
High density polyethylene (HDPE)		841	560		
Polyethylene-terephthalate (PET)		1222	815		
Polypropylene (PP)		968	645		
Polyvinyl Chloride (PVC)		5	3		
Polystyrene (PS)		661	440		
Glass		4117	2744		
Steel Cans/Tins		2547	1698		
Aluminium Cans		328	219		
Biogenic Food Waste		36608			
Garden Refuse: Green		637			
Garden Refuse: Wood		46			
Other		32287			
Total Waste Diverted/Disposed		**96190**	**17740**	**0**	**0**
WASTE MATERIAL OR WASTE FRACTION	Greenhouse Gas Emissions/Reductions				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
Newspaper	0.00	-4255.98	-6731.59	-	-
General mixed paper (CMW)	0.00	-2248.49	-11292.91	-	-
Scrap Boxes & Cardboard (K4)	0.00	-3468.82	-15635.97	-	-
Low density polyethylene (LDPE)	0.00	64.82	-1847.25	-	-
High density polyethylene (HDPE)	0.00	37.08	-864.21	-	-
Polyethylene-terephthalate (PET)	0.00	53.88	-1392.49	-	-
Polypropylene (PP)	0.00	42.68	-1080.71	-	-
Polyvinyl Chloride (PVC)	0.00	0.22	-5.03	-	-
Polystyrene (PS)	0.00	29.15	-737.23	-	-
Glass	0.00	181.53	-846.93	-	-
Steel Cans/Tins	0.00	112.30	-3369.10	-	-
Aluminium Cans	0.00	14.46	-3300.02	-	-
Biogenic Food Waste	0.00	- 6456.55	-	0.00	0.00
Garden Refuse: Green	0.00	- -435.35	-	-	0.00
Garden Refuse: Wood	0.00	- -47.16	-	-	0.00
Other	0.00	- 1423.61	-	-	-
Strategy GHG Emissions/ Reductions (MTCO$_2$eq)	**0.00**	**-2039.52**	**-47103.45**	**0.00**	**0.00**
Total GHG Emissions/Reductions (MTCO$_2$eq)					**-49142.97**

Table D10 – WROSE Input and output screen: New England Road Scenario 4



WASTE & RESOURCE OPTIMISATION STRATEGY EVALUATION MODEL					
W.R.O.S.E - NEW ENGLAND SCENARIO 4					
WASTE MATERIAL OR WASTE FRACTION	Quantity of Waste Disposed/treated/diverted by (tons):				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
Newspaper		3272	2181		
General mixed paper (CMW)		4340	2894		
Scrap Boxes & Cardboard (K4)		6841	4561		
Low density polyethylene (LDPE)		1470	980		
High density polyethylene (HDPE)		841	560		
Polyethylene-terephthalate (PET)		1222	815		
Polypropylene (PP)		968	645		
Polyvinyl Chloride (PVC)		5	3		
Polystyrene (PS)		661	440		
Glass		4117	2744		
Steel Cans/Tins		2547	1698		
Aluminium Cans		328	219		
Biogenic Food Waste (*wet weight)				58572.8	
Garden Refuse: Green		637			
Garden Refuse: Wood		46			
Other		32287			
Total Waste Diverted/Disposed	**0**	**59582**	**17740**	**58572.8**	**0**
WASTE MATERIAL OR WASTE FRACTION	**Greenhouse Gas Emissions/Reductions**				
	LANDFILL DISPOSAL	**LANDFILL GAS REC**	**RECYCLING**	**ANAEROBIC DIGESTION**	**AEROBIC COMPOSTING**
Newspaper	0.00	-4255.98	-6731.59	-	-
Newspaper	0.00	-4255.98	-6731.59	-	-
General mixed paper (CMW)	0.00	-2248.49	-11292.91	-	-
Scrap Boxes & Cardboard (K4)	0.00	-3468.82	-15635.97	-	-
Low density polyethylene (LDPE)	0.00	64.82	-1847.25	-	-
High density polyethylene (HDPE)	0.00	37.08	-864.21	-	-
Polyethylene-terephthalate (PET)	0.00	53.88	-1392.49	-	-
Polypropylene (PP)	0.00	42.68	-1080.71	-	-
Polyvinyl Chloride (PVC)	0.00	0.22	-5.03	-	-
Polystyrene (PS)	0.00	29.15	-737.23	-	-
Glass	0.00	181.53	-846.93	-	-
Steel Cans/Tins	0.00	112.30	-3369.10	-	-
Aluminium Cans	0.00	14.46	-3300.02	-	-
Biogenic Food Waste	0.00	0.00	-	-15922.47	0.00
Garden Refuse: Green	0.00	-435.35	-	-	0.00
Garden Refuse: Wood	0.00	-47.16	-	-	0.00
Other	0.00	1423.61	-	-	-
Strategy GHG Emissions/ Reductions (MTCO$_2$eq)	**0.00**	**-8496.06**	**-47103.45**	**-15922.47**	**0.00**
Total GHG Emissions/Reductions (MTCO2eq)					**-71521.98**

Table D11 – WROSE Input and output screen: New England Road Scenario 5



WASTE & RESOURCE OPTIMISATION STRATEGY EVALUATION MODEL					
W.R.O.S.E - NEW ENGLAND SCENARIO 5					
WASTE MATERIAL OR WASTE FRACTION	Quantity of Waste Disposed/treated/diverted by (tons):				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
Newspaper		3272	2181		
General mixed paper (CMW)		4340	2894		
Scrap Boxes & Cardboard (K4)		6841	4561		
Low density polyethylene (LDPE)		1470	980		
High density polyethylene (HDPE)		841	560		
Polyethylene-terephthalate (PET)		1222	815		
Polypropylene (PP)		968	645		
Polyvinyl Chloride (PVC)		5	3		
Polystyrene (PS)		661	440		
Glass		4117	2744		
Steel Cans/Tins		2547	1698		
Aluminium Cans		328	219		
Biogenic Food Waste					36608
Garden Refuse: Green					637
Garden Refuse: Wood					46
Other		32287			
Total Waste Diverted/Disposed		**58899**	**17740**	**0**	**37291**
WASTE MATERIAL OR WASTE FRACTION	Greenhouse Gas Emissions/Reductions				
	LANDFILL DISPOSAL	LANDFILL GAS REC	RECYCLING	ANAEROBIC DIGESTION	AEROBIC COMPOSTING
Newspaper	0.00	-4255.98	-6731.59	-	-
General mixed paper (CMW)	0.00	-2248.49	-11292.91	-	-
Scrap Boxes & Cardboard (K4)	0.00	-3468.82	-15635.97	-	-
Low density polyethylene (LDPE)	0.00	64.82	-1847.25	-	-
High density polyethylene (HDPE)	0.00	37.08	-864.21	-	-
Polyethylene-terephthalate (PET)	0.00	53.88	-1392.49	-	-
Polypropylene (PP)	0.00	42.68	-1080.71	-	-
Polyvinyl Chloride (PVC)	0.00	0.22	-5.03	-	-
Polystyrene (PS)	0.00	29.15	-737.23	-	-
Glass	0.00	181.53	-846.93	-	-
Steel Cans/Tins	0.00	112.30	-3369.10	-	-
Aluminium Cans	0.00	14.46	-3300.02	-	-
Biogenic Food Waste	0.00	- 0.00	-	0.00	-8070.68
Garden Refuse: Green	0.00	- 0.00	-	-	-140.43
Garden Refuse: Wood	0.00	- 0.00	-	-	-10.14
Other	0.00	- 1423.61	-	-	-
Strategy GHG Emissions/ Reductions (MTCO$_2$eq)	**0.00**	**-8013.56**	**-47103.45**	**0.00**	**-8221.26**
Total GHG Emissions/Reductions (MTCO2eq)					**-63338.27**

APPENDIX E - LANDFILL SPACE SAVINGS and TRIAL (IWM) CER ANALYSIS

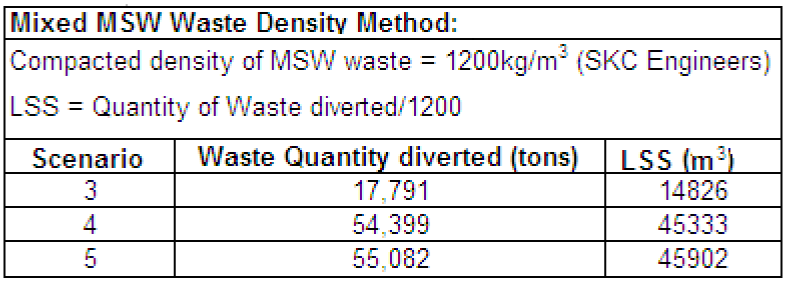
Table E1 – Mariannhill Landfill Space Savings: Mixed MSW Density Method

Mixed MSW Waste Density Method:		
Compacted density of MSW waste = 1200kg/m^3 (SKC Engineers) LSS = Quantity of Waste diverted/1200		
Scenario	**Waste Quantity diverted (tons)**	**LSS (m^3)**
3	*5294	4412
3	**21549	17958
4	70,702	58918
5	79,396	66163

Table E2 – Mariannhill Landfill Space Savings: ERBC and US EPA Landfill Density Methods

Waste Fraction	**LSS Factor (m^3/ton)**	**Amount 9.82% (tons)**	**LSS (m^3)**	**Amount 40% (tons)**	**LSS (m^3)**
Environmental Benefits of Recycling Calculator					
Paper & Card	2.84	1953	5546.52	7943	22558.12
HDPE	5.47	279	1526.13	1136	6213.92
PVC	10.77	107	1152.39	436	4695.72
PP	10.77	250	2692.50	1017	10953.09
US EPA Landfill Density Factor					
Paper & Card	800	1953	4114.86	7943	16735.46
LDPE	670	702	1766.06	2859	7192.54
PET	355	178	845.15	726	3447.08
PP	355	250	1187.01	1017	4828.76
PVC	185	107	974.89	436	3972.44
PS	1015	255	423.46	1037	1722.09
Steel	560	473	1423.69	1927	5800.12
Aluminium	250	113	761.87	460	3101.42
TOTAL RECYCLABLES			**13414.05**		**54606.44**
Food	2000	49153	41425.04		
Garden refuse	1500	8694	9769.48		

Table E3 – New England Road Landfill Space Savings: Mixed MSW Density



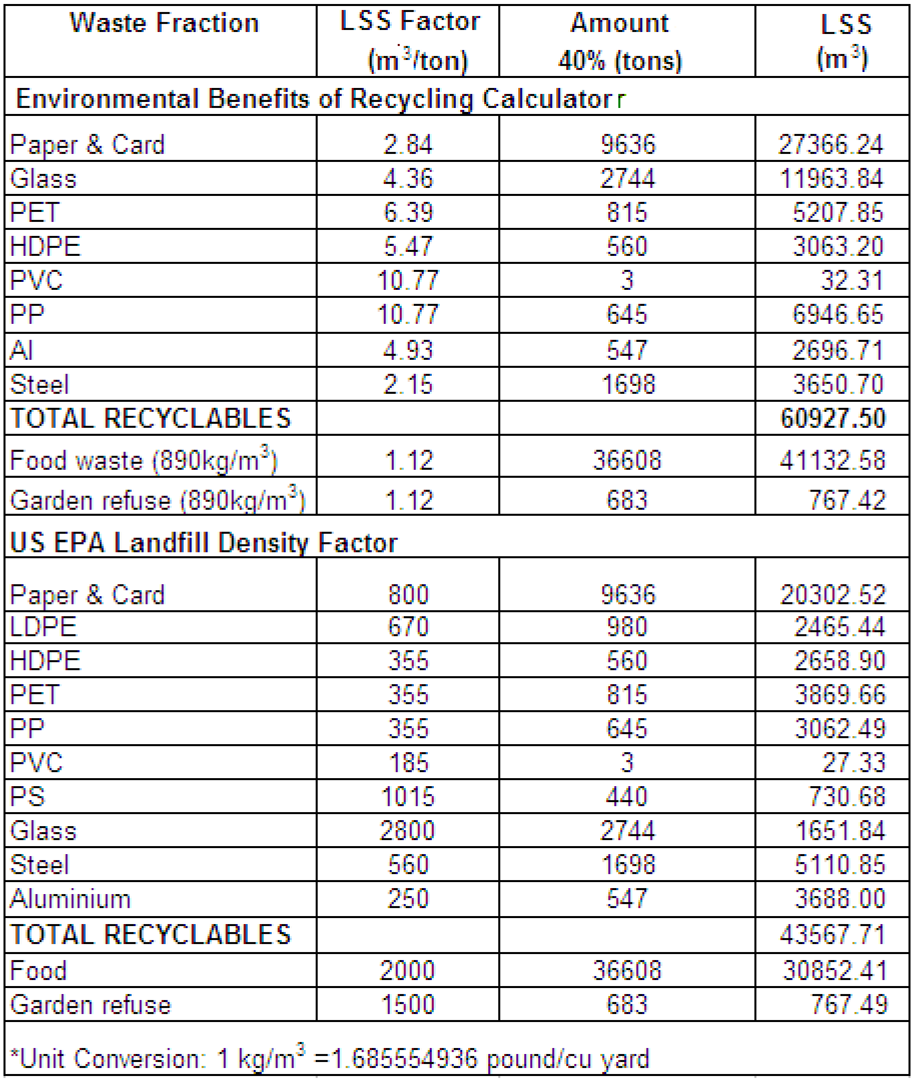
Mixed MSW Waste Density Method:

Compacted density of MSW waste = 1200kg/m^3 (SKC Engineers)

LSS = Quantity of Waste diverted/1200

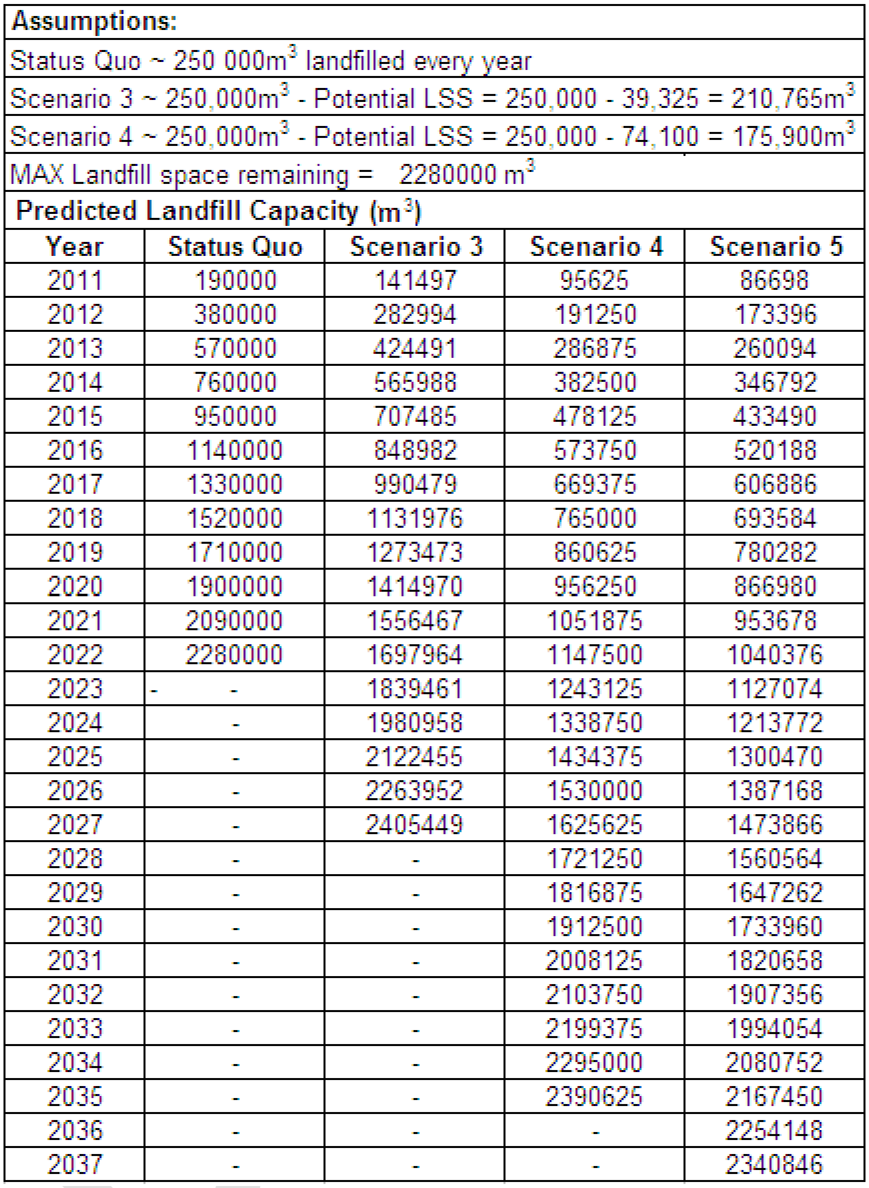
Scenario	Waste Quantity diverted (tons)	LSS (m^3)
3	17,791	14826
4	54,399	45333
5	55,082	45902

Table E4 – New England Road Landfill Space Savings: ERBC and US EPA Landfill Density methods



Waste Fraction	LSS Factor (m^3/ton)	Amount 40% (tons)	LSS (m^3)
Environmental Benefits of Recycling Calculator r			
Paper & Card	2.84	9636	27366.24
Glass	4.36	2744	11963.84
PET	6.39	815	5207.85
HDPE	5.47	560	3063.20
PVC	10.77	3	32.31
PP	10.77	645	6946.65
Al	4.93	547	2696.71
Steel	2.15	1698	3650.70
TOTAL RECYCLABLES			**60927.50**
Food waste (890kg/m^3)	1.12	36608	41132.58
Garden refuse (890kg/m^3)	1.12	683	767.42
US EPA Landfill Density Factor			
Paper & Card	800	9636	20302.52
LDPE	670	980	2465.44
HDPE	355	560	2658.90
PET	355	815	3869.66
PP	355	645	3062.49
PVC	185	3	27.33
PS	1015	440	730.68
Glass	2800	2744	1651.84
Steel	560	1698	5110.85
Aluminium	250	547	3688.00
TOTAL RECYCLABLES			43567.71
Food	2000	36608	30852.41
Garden refuse	1500	683	767.49
*Unit Conversion: 1 kg/m^3 =1.685554936 pound/cu yard			

Table E5 – Calculation of Predicted Airspace by Scenario: Mariannhill Landfill



Assumptions:

Status Quo ~ 250 000m^3 landfilled every year

Scenario 3 ~ 250,000m^3 - Potential LSS = 250,000 - 39,325 = 210,765m^3

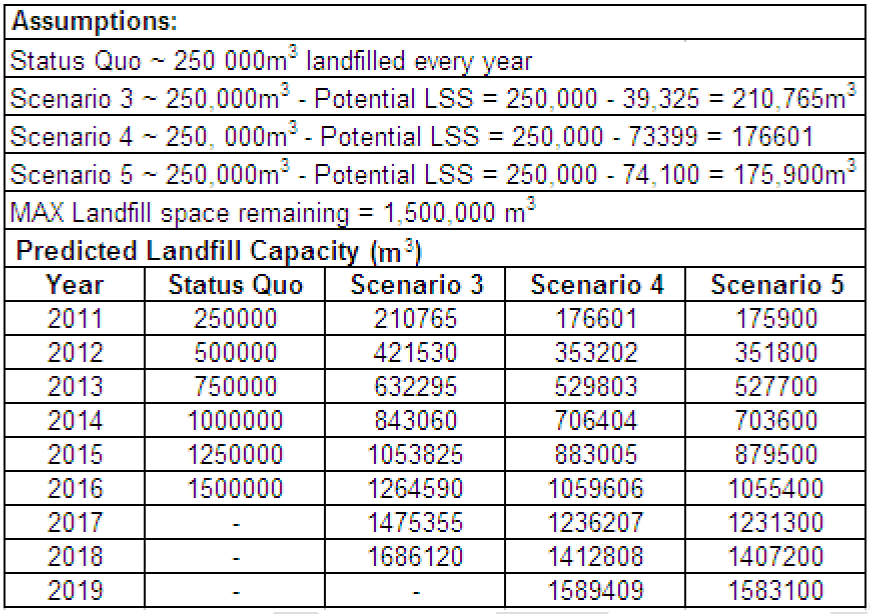
Scenario 4 ~ 250,000m^3 - Potential LSS = 250,000 - 74,100 = 175,900m^3

MAX Landfill space remaining = 2280000 m^3

Predicted Landfill Capacity (m^3)

Year	Status Quo	Scenario 3	Scenario 4	Scenario 5
2011	190000	141497	95625	86698
2012	380000	282994	191250	173396
2013	570000	424491	286875	260094
2014	760000	565988	382500	346792
2015	950000	707485	478125	433490
2016	1140000	848982	573750	520188
2017	1330000	990479	669375	606886
2018	1520000	1131976	765000	693584
2019	1710000	1273473	860625	780282
2020	1900000	1414970	956250	866980
2021	2090000	1556467	1051875	953678
2022	2280000	1697964	1147500	1040376
2023	- -	1839461	1243125	1127074
2024	-	1980958	1338750	1213772
2025	-	2122455	1434375	1300470
2026	-	2263952	1530000	1387168
2027	-	2405449	1625625	1473866
2028	-	-	1721250	1560564
2029	-	-	1816875	1647262
2030	-	-	1912500	1733960
2031	-	-	2008125	1820658
2032	-	-	2103750	1907356
2033	-	-	2199375	1994054
2034	-	-	2295000	2080752
2035	-	-	2390625	2167450
2036	-	-	-	2254148
2037	-	-	-	2340846

Table E6 – Calculation of Predicted Airspace by Scenario: New England Road Landfill



Assumptions:				
Status Quo ~ 250 000m^3 landfilled every year				
Scenario 3 ~ 250,000m^3 - Potential LSS = 250,000 - 39,325 = 210,765m^3				
Scenario 4 ~ 250, 000m^3 - Potential LSS = 250,000 - 73399 = 176601				
Scenario 5 ~ 250,000m^3 - Potential LSS = 250,000 - 74,100 = 175,900m^3				
MAX Landfill space remaining = 1,500,000 m^3				
Predicted Landfill Capacity (m^3)				
Year	**Status Quo**	**Scenario 3**	**Scenario 4**	**Scenario 5**
2011	250000	210765	176601	175900
2012	500000	421530	353202	351800
2013	750000	632295	529803	527700
2014	1000000	843060	706404	703600
2015	1250000	1053825	883005	879500
2016	1500000	1264590	1059606	1055400
2017	-	1475355	1236207	1231300
2018	-	1686120	1412808	1407200
2019	-	-	1589409	1583100

Table E7 – Trial analysis of emissions using IWM model

SCENARIO	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
Scenario Description:	Landfilling	Landfilling and LFG Recovery	Landfilling, LFG Recovery and MRF Recycling	Landfilling, MBT: Anaerobic Digestion and MRF	Landfilling, MBT: Composting and MRF
	EMISSIONS/REDUCTIONS (MTCO$_2$eq/year)				
Mariannhill Landfill	75,308	91,954	69,852 (9.82% RR) 2,015 (40% RR)	-95,185	-63,582
New England Road Landfill	53,328	72,218	-7,767	-90,135	-59,564