Further Development of WROSE, decision-making tool for KZN municipalities

Jimen Reddy

211501957

Supervisor: Prof Cristina Trois

College of Agriculture, Engineering and Science

School of Engineering

Faculty of Civil Engineering

University of KwaZulu-Natal

Durban

South Africa

November 2016

Submitted in fulfilment of the requirements for the degree of Masters of Science in Engineering

Examiners copy

Declaration

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

……………………………… ………………………………

Prof. Cristina Trois Date

I .... declare that

(i) The research reported in this dissertation, except where otherwise indicated, is my original work.
(ii) This dissertation has not been submitted for any degree or examination at any other university.
(iii) This dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
(iv) This dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

a) Their words have been re-written but the general information attributed to them has been referenced;

b) Where their exact words have been used, their writing has been placed inside quotation marks, and referenced.

(v) Where I have reproduced a publication of which I am an author, co-author or editor, I have indicated in detail which part of the publication was actually written by myself alone and have fully referenced such publications.
(vi) This dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the References sections.

……………………………… ………………………………

Jimen Reddy Date

Acknowledgements

I would like to thank my parents and sister for their continuous love and support throughout the past few months, without them, I would not have been able to complete this.

I would also like to thanks Dr Alessio Cibati for his suggestions and feedback on my research, Dr Elena Friedrich for her guidance on the use of emission factors and her help and suggestions on the indicator matrix and Deborah Mkhwanazi for her assistance throughout the year.

And finally would like to thank my supervisor Professor Cristina Trois, for her guidance and support throughout my undergrad and post graduate research and I look forward to working with her in the future.

"The environment is everything that isn't me"
- Albert Einstein

"We do not inherit the earth from our ancestors; we borrow it from our children"
- Native American Indian Proverb

Abstract

Waste management activities produce approximately 4.3% of the total methane emissions in South Africa. If GHG emissions continue to increase without constraint to the year 2030, CO_2 equivalent emissions would likely be more than double the 2010 value. With landfilling being the primary waste disposal strategy employed by South African municipalities the need arises for economically viable waste diversion strategies to be evaluated in the South African context.

The study assessed various waste management strategies that included landfilling, landfill gas with electricity generation/flaring, recycling, anaerobic digestion and composting through the case study evaluation of the eThekwini Municipality, Msunduzi Municipality and Newcastle Municipality. Each strategy was evaluated by further developing the Waste Resource Optimisation Scenario Evaluation (WROSE) decision making tool. WROSE is a waste management decision making tool that provides a methodology for municipalities to evaluate and optimise their waste management strategies to achieve a fully integrated system. WROSE makes use of greenhouse gas emission factors and landfill space saving factors to produce qualitative results, however these factors were developed for international use and have become out dated with the production of validated South African specific factors, The further development takes this into consideration and aims to include various other indicators such as landfill diversion rate and several economic indicators. The further developments aim is to provide a holistic methodology able to fully evaluate a waste management scenario and provide feedback to waste managers and enable them to make informed decisions.

The results established that all diversion scenarios estimated a net reduction of greenhouse gases in comparison with the baseline scenario of landfill disposal. In eThekwini the diversion scenarios produced a greenhouse gas reduction of between -142 454 $MTCO_2$ and -374 436 $MTCO_2$ per a year. In the Msunduzi this reduction was between -25 927 $MTCO_2$ and -64 236 $MTCO_2$ per a year, similarly in Newcastle the reduction was estimated to be between -6 383 $MTCO_2$ and -12 671 $MTCO_2$ per a year. The landfill space savings analysis indicated that these diversion scenarios would also produce large air space savings at the landfills. The landfill diversion rate

evaluation found that a combination of strategies such as recycling, anaerobic digestion and composting produced the greatest diversion rates.

The study found that high capital and operating costs of diversion strategies were the main barrier to implementation in these municipalities. The further development of WROSE results in a powerful tool that can be used by waste managers to make insightful and informed decisions on waste management scenarios however, the multi criteria indicator analysis that was completed to evaluate potential economic, social and environmental indicators needs to be consulted for the expansion of WROSE in the future, to truly evaluate waste diversion strategies.

Table of Contents

List of Figures

List of Tables

List of abbreviations

AD – Anaerobic digestion
BOD – Biochemical oxygen demand
CO_2 – Carbon dioxide
C/N ratio – Carbon/Nitrogen Ratio
CER's – Certified emission reductions
CFC - Chlorofluoro-carbons
COD – Chemical Oxygen Demand
CDM – Clean Development Mechanism
CH_4 – Methane
DEA – Department of Environmental Affairs
DAT – Dome aeration technology
DSW – Durban Solid Waste
DWAF – Department of Water Affairs and Forestry
EIA – Environmental impact assessment
EASEWASTE – Environmental Assessment of Solid Waste systems and Technologies Models
GHG – Greenhouse gases
GWP – Global warming potential
HDPE – High density polyethylene
H_2 – Hydrogen gas
IRR – Internal rate of return
IPCC – Intergovernmental Panel on Climate Change
IPWMP – Integrated Pollution and Waste Management Policy
IWMP – Integrated waste management plan
LFG – Landfill gas
LCA – Life Cycle Assessment
LDPE – Low density polyethylene
LSS – Landfill space savings
MC – Moisture content
MRF – Material recovery facilities
MSW – Municipal solid waste
$MTCO_2eq$ – Metric tons of carbon dioxide equivalents

NERSA – National Electricity Regulator of South Africa

NCCRP – National climate change response policy

NLM – Newcastle Local Municipality

N_2 – Nitrogen gas

O_2 – Oxygen

PET – Polyethylene Terephthalate

PP – Polypropylene

PS – Polystyrene

PVC – Polyvinyl Chloride

REFIT – Renewable energy feed in tariff

UKZN – University of KwaZulu-Natal

UMDM – uMgungundlovu District Municipality

US EPA – United States Environmental Protection Agency

WARM – Waste Reduction Model

WACC – Weighted average cost of capital

WROSE – Waste Resource Optimisation Scenario Evaluation

WSA – Waste stream analysis

Chapter 1 – Introduction

1.1. Introduction

The greenhouse gases (GHGs) that result in the greatest climate change are carbon dioxide, methane and nitrous oxide, all of which are produced from the landfilling of municipal solid waste (Smith et al., 2001). Methane in particular is of a significant importance due to it having a global warming potential of twenty eight times more than carbon dioxide (IPCC 5th Assessment Report, 2014). These emissions, together with the increase in waste generation quantities and limited landfill space, require an improved integrated waste management plan. Improved methods of waste management will lead the way towards a sustainable and efficient city. Landfilling with gas recovery, recycling, anaerobic digestion and aerobic composting are all waste disposal methods that can be effectively used to reduce these greenhouse gas emissions (Jagath, 2010).

Although the waste sector contributes 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 from the South African greenhouse gas mitigation potential analysis completed by the Department of Environmental Affairs (DEA) in 2014, show that if GHG emissions continue to increase without constraint to the year 2030, CO_2 equivalent emissions would likely be more than double the 2010 value. This is shown in Figure 1.1.

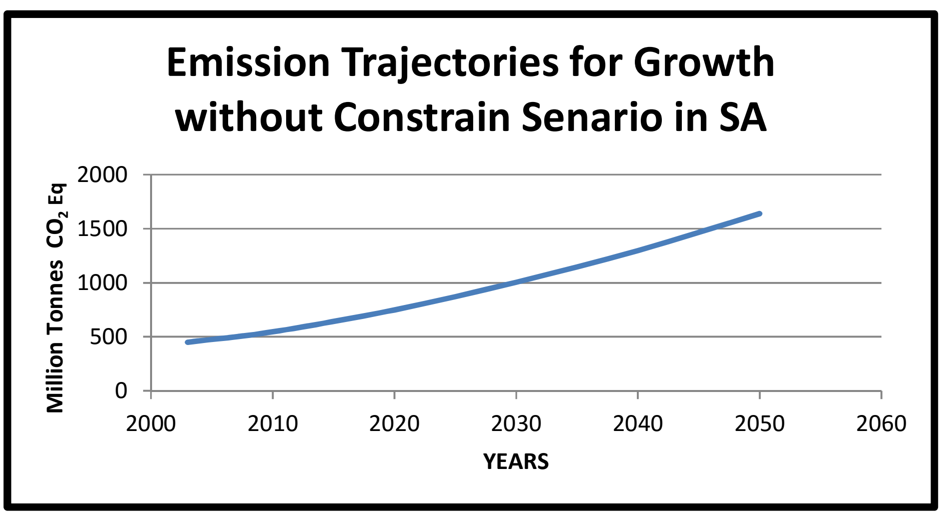


Figure 1.1 – Emission trajectories for growth without constraint in SA (DEA, 2014)

The South African greenhouse gas mitigation potential analysis also provided data suggesting that in the waste sector alone a total of 9.977 Million Tonnes CO_2 equivalents can be reduced by 2020 if all potential mitigating effects are implemented. The report compiled by the DEA in 2014 also shows that landfill gas recovery and electricity generation systems showed the most potential for reduction, with a possible reduction of 4.48Million Tonnes CO_2 equivalents by 2020.

This research intends to provide a comprehensive decision making tool for waste management engineers for alternative integrated waste management strategies. This objective was achieved through the use of various municipalities in KwaZulu-Natal as case studies. The Waste Resource Optimisation Scenario Evaluation (WROSE) model was the decision making tool that was further developed and applied to the EThekwini, Msunduzi and Newcastle municipalities. The WROSE model made use of emission factors to determine GHG impacts and landfill space savings factors to determine the landfill space saved for various waste management scenarios. The model also estimated potential costs and incomes from these scenarios. The further development of the model would take into account various other environmental, economic and social indicators that the WROSE model had not evaluated previously.

The various scenarios that the WROSE model evaluated made use of many alternative waste disposal methods that have not been widely used in South Africa. The alternative waste disposal methods have been thoroughly investigated in the literature review in Chapters 3 through to 6. The methods are named below.

- Mechanical pre-treatment, separation of recyclables and recycling,
- Biological treatment: composting or anaerobic digestion of the wet biogenic fraction, and
- 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 each strategy's implementation requirements, technical feasibility, environmental feasibility and potential environmental impacts, as detailed in the methodology chapter. The selected strategies were then used to develop zero waste scenarios that could be applied to the various municipalities. These scenarios would form the basis of the zero waste models that could be applied to other case studies and be used by waste management engineers.

1.2. Motivation

The motivation of the research stems from several factors including the following:

Large municipalities in South African with limited land available cannot sustain landfilling as a waste management strategy. Along with the landfill space shortages, the decomposing organic waste in landfills leads to the release of soil and water polluting leachate in landfills along with the GHGs (Lou and Nair, 2009). The population in cities is increasing due to urbanization and this leads to an increase in waste. It has been determined that 68% of the South African population will be living in urban condition by 2015 (Friedrich and Trois, 2010). This will have a great impact on current waste management strategies. Urbanisation will greatly worsen the inefficiencies in the local governments' waste management strategies. It will be necessary to develop and understand alternative waste treatment methods.

The disposal of waste in landfills and the organic decomposition that occurs as a result releases significant GHGs into the environment. 90% of waste produced in South Africa is destined for landfills, however only 5% of this waste should actually be landfilled with the rest being recycled or treated by other waste management practices (Lemmer, 2012). The South African waste sector contributes 4.3% to GHG emissions and the government has expressed the need to reduce this (Nahman et al., 2012).

The South African government has pledged under the Copenhagen Accord, to reduce GHG emissions by 34% and 42% below a business-as-usual growth trajectory by 2020 and 2025 respectively. The national climate change response policy (NCCRP) was also implemented by the South African government and is a comprehensive policy framework in response to climate change in the country. The objectives of the NCCRP are aligned to the aims of this study, i.e. to reduce GHG emissions.

The South African government created the Polokwane Declaration in order to develop a zero waste plan by 2022. The Declaration aims to deliver an efficient and sustainable waste management system for South Africa. (Taiwo et al., 2006). However research presented by Taiwo et al. (2006), showed that the Polokwane Declaration proved to be far too ambitious and will not be achieved in the time frame and that, if the target were to be met, significant resources and effort will be needed for progress to occur. A decision making tool that could aid waste management engineers will greatly help reach the goals of the Polokwane Declaration.

Feasibility analysis can be broken down into three broad categories, namely environmental, economic and social. Environmental motivation has been discussed above. The DEA's mitigation report showed that if 100% technical mitigation potential is implemented in the waste sector, the gross domestic product (GDP) of South Africa would increase by R2000 million by 2020. If this were to happen, the result would be extremely positive socially, with 68 000 jobs potentially being created. This is significant motivation for research into alternative waste disposal strategies to be completed (DEA, 2014)

For an effective, efficient and sustainable integrated waste management system to be implemented, waste management engineers need quantitative results that can be used to support decision-making and policy-making. This study hopes to provide a method of determining high quality quantitative results that can be used in decision-making, to achieve zero waste and an efficient use of waste as a resource.

For the development of an accurate waste decision making tool for South Africa, applicable and apt strategies need to be included in the tool. The study aims to provide a method for deciding on correct and accurate waste strategies and scenarios that are applicable to SA municipalities.

1.3. Research Questions, Aims and Objectives

The study is concerned with the development of a methodology that enables municipalities to make informed decisions using results that are scientifically accurate and correct. For this to be achieved the terms of comparison is imperative. The accuracy of this lies in the definition of the strategies and scenarios and their applicability to South African municipalities.

Once the scenarios are identified as relevant through a literature review, the terms of comparison need to be defined in order to develop a multi criteria analysis that satisfies the 3 levels of sustainability (economic, environmental and social)

However, in order to proceed, the original outcomes of the comparison need to be satisfactorily correct and accurate. The measure of the comparison need to be set by the indicators and hence be validated by their nature.

Research Question:

- How best can waste management strategies be evaluated in order to achieve a fully integrated waste management system that is applicable to South African municipalities and enabling these municipalities to make informed decisions aimed at achieving zero waste and resource recovery?

The aims of the research stem from the various motivating factors named in Section 1.2.

Aims:

- To further develop and expand the WROSE decision making tool to include additional environmental and economic indicators that can then be used to evaluate waste management scenarios.
- To determine the most economic and environmentally feasible integrated waste management scenario that can be implemented at three KwaZulu-Natal municipalities.

The above aims will be accomplished by fulfilling the following research objectives

Objectives:

- Review the literature concerning waste management strategies and scenarios in South Africa.
- Research waste management decision making methodologies and select the most applicable methodology for use.
- Identify knowledge gaps in WROSE.
- Evaluate the potential of waste management sustainability indicators which could be included in the WROSE model.
- Upgrading and validating the WROSE model to include additional environmental and economic indicators that could be used to evaluate the waste strategies.
- Producing a Microsoft Excel interface for the WROSE.
- Applying case study data to the updated WROSE tool to produce environmental and economic results and determining the most feasible waste management scenarios.

1.4. Methodological approach

The modelling of zero waste strategies was explored through literature reviews and the use of selected KZN municipalities as case studies. The strategies that were identified made use of landfilling with and without recovery gas systems, recycling, anaerobic digestion and aerobic composting.

The objectives that were set were achieved through a comprehensive literature review and the case studies of the eThekwini, Msunduzi and Newcastle municipalities, which included, data analysis and the modelling of this data. A quantitative and qualitative methodological approach was adopted.

A qualitative multi criteria indicator evaluation matrix was developed and this was used to evaluate potential future indicators that could be used to assess waste management strategies. The matrix evaluated environmental, economic and social sustainability indicators, with six terms of comparison being used such as relevance, effectiveness and consistency. The assessment was completed by waste management experts.

Environmental indicators that were evaluated were GHG impacts, landfill space savings and waste diversion rate. The economic feasibility assessed capital costs, operating costs, income, and economic sustainability.

Various waste management strategies and combinations were evaluated and used to form a total of five scenarios as listed in section 8.2. Using data obtained from the South African Waste Information Centre and waste stream analysis data, the selected waste diversion scenarios were reviewed in terms of the chosen indicators. Alternatively waste stream assessments could have been conducted at the three municipalities, however time was limited and the original waste stream analyses were deemed satisfactory.

Waste management models were researched, that could potentially be used to evaluate the scenarios through the use of the indicators. However, the availability, scope, transparency and last update of the models were the limiting factors for use. Hence, The Waste Resource Optimisation Scenario Evaluation (WROSE) decision making tool was then further developed and used.

The model was updated to use methodologies derived from South African conditions, however where this is not possible, the model reverts to United States Environmental Protection Agency (US EPA) methods. A flow chart of the complete methodology can be seen in Figures 1.2 and 1.3 below.

GHG emissions were evaluated through emission factors derived for landfilling, landfill gas recovery (flaring and electricity generation), recycling and composting by the University of KwaZulu-Natal (UKZN). Emission factors developed by the US EPA were also used in WROSE as a method of comparison.

The average landfill space savings were once again calculated using two different methods: the compacted density of MSW (Matete, 2009) and the US EPA landfill space factors (US EPA, 1994).

The economic assessment included evaluating the capital and operating costs, income generated and financial sustainability. Capital and operating costs for landfill gas recovery systems and composting plants were sourced from studies produced from South African projects. Anaerobic digestion and material recovery facility costs were, however, sourced from international studies as limited South African data were available. Alternatively a detailed cost estimate quotation could have been calculated, however due to WROSE being a model and using multiple variables, cost graphs from literature were used.

The potential revenue that can be generated from each scenario comprises of the sale of recyclables, compost or soil conditioners produced from composting or anaerobic digestion, and electricity produced from landfill gas or biogas. These figures were all sourced from recent local cost studies. Lastly, the financial sustainability was evaluated using a discounted cash flow analysis that calculates the internal rate of return of the project.

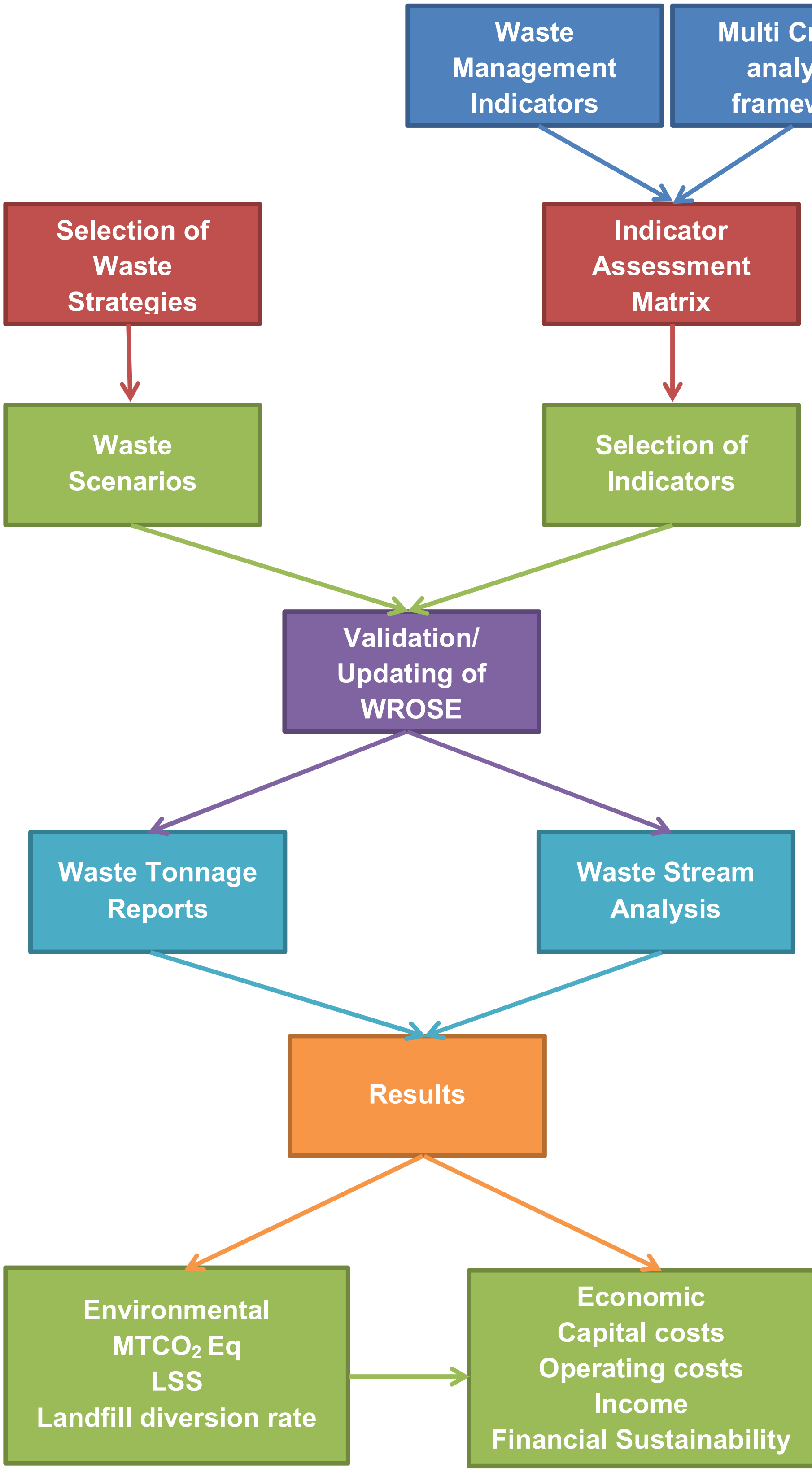


Figure 1.2 – Methodology framework

1.5. Research Framework

The research framework begins with a literature review of waste management in South Africa and various waste management strategies in order to develop the knowledge needed to critically evaluate the strategies and develop methodologies to quantitatively evaluate them. This is followed by case study descriptions of the 3 municipalities in Kwa Zulu Natal. The case studies are used to bring context to the use of the WROSE decision making tool, and simplify the results into qualitative values. The development of the methodology comprising of the indicator matrix is followed by the results and conclusion chapters. A flow chart of the complete research framework can be seen in Figure 1.3 below.

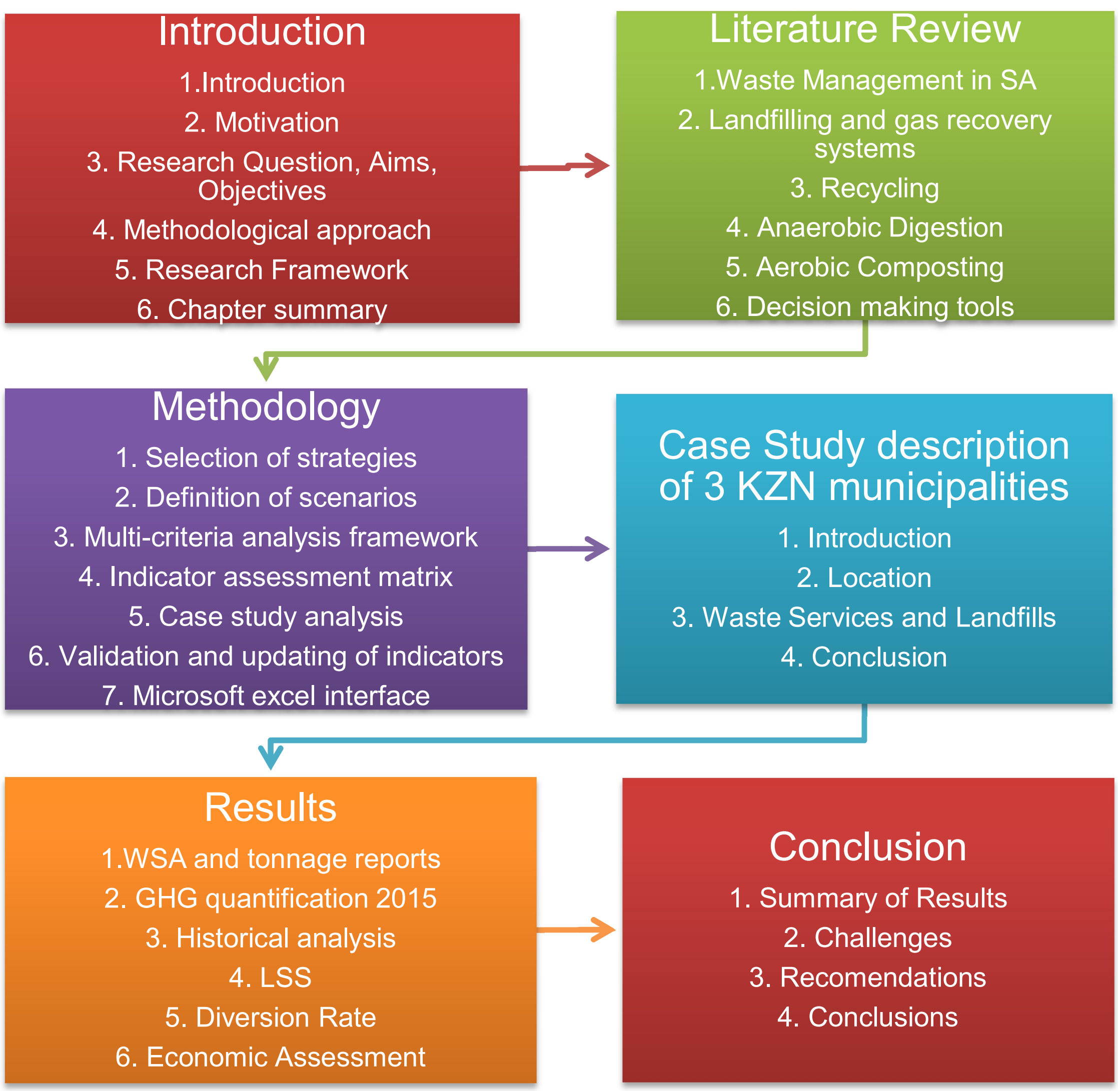


Figure 1.3 – Research framework

1.6. Chapter Summary

This study focuses on the assessment of various zero waste strategies in terms of environmental, economic and social indicators. The zero waste term refers to the strategy of diverting the largest amount of waste possible from landfills. The intention of the study is to produce a working model that could then be used to evaluate municipalities and produce meaningful results that could help determine the most effective zero waste strategy that could be implemented. The WROSE model is the result of multiple past studies conducted by UKZN, with the aim of the model being continuously developed into the future. The results the model produced would ideally help waste management engineers in managing and utilising waste to its full economic and organic potential. The thesis further aims to analyse the shift of waste from being a burden to a potential resource.

Chapters 2 – 6 provide a brief literature review on waste management in South Africa and waste management strategies that will be used in the WROSE model.

Chapter 2 – Waste management in SA

2.1. Introduction

Local government is responsible for waste management at a municipal level, and they are faced with many challenges. The most common of these is equipment failure and poor financial and labour management, together with poor planning at regional and national level. This chapter of the literature review aims to provide an understanding of waste management in the South African context whilst introducing concepts such as zero waste and the South African waste legislation. The discussion on waste management is SA provides a critical background to the development of relevant scenarios that make use of strategies utilised in the South African context.

2.2. Waste

Tschobanoglous et al. (1993) describes waste as any item, material and product that is unwanted or discarded and is no longer useful for its original intended purpose. However in South Africa there is more than one legal definition of waste. This often complicates the classification of materials as waste and creates confusion between private industry and government about waste management issues (Oelofse and Godfrey, 2008). This discrepancy in the definition of waste hinders the implementation of the waste hierarchy that aims to divert waste away from landfills.

There are currently at least three legal definitions of waste in South Africa. The Environmental Conservancy Act of 1989 defines waste in terms of its unwanted or superfluous nature. The Minimum Requirements for Waste Disposal developed by the Department of Water Affairs and Forestry (2006) provides a more recent definition, however it assumes that all waste is hazardous until it is proven otherwise. The requirement to prove that the waste is non-hazardous lies with the generator of the waste, this leads to industrial waste not being re-used as the delisting process involves costly and specialised tests. This restricts the potential of the waste material being re-used.

The most recent definition comes from the National Environmental Management Waste Amendment Act of 2014 that classifies waste into two categories according to the risk it poses: general waste and hazardous waste.

- General waste means waste that does not pose an immediate hazard or threat to health or the environment and includes domestic, demolition, business and inert waste.
- Hazardous waste means any waste that contains organic or inorganic elements or compounds that may, owing to inherent physical, chemical or toxicological characteristics of that waste, have a detrimental impact on health and the environment.

Municipal solid waste (MSW) forms part of the general waste category and comprises of waste generated by residential, commercial, industrial, and institutional activities (Schuberler et al., 1996). MSW is defined as all solid waste generated in a municipality, for which municipal service providers are responsible. However, Trois and Simelane (2010) state the MSW can be classified into two basic fractions, namely wet and dry fractions. The wet fraction is comprised of biogenic waste whilst the dry fraction is comprised of recyclable materials.

The MSW generation rate in South Africa varies between 0.5kg – 2kg per capita per day (DEA, n.d.). This range of values experienced can be attributed to various factors that influence generation rates and compositions including:

- Education and environmental awareness can lead to lower waste generation rates, as there is a higher likelihood of a person recycling if they are aware of the consequences for the environment due to other methods of disposal.
- The dynamic and size of the household is directly related to the quantity of waste produced. Single person households produce less waste whilst multi-person households produce more waste.
- The type of household is also related to the type of waste produced. Apartment blocks will produce little garden waste whilst a stand-alone house with a large garden will produce large amounts of garden refuse.

- The age of the person will also cause a fluctuation in average MSW generation rate, as younger people tend to purchase more pre-packaged goods and food.
- The income of people is another important factor as higher income groups tend to consume more products and hence generate more waste, whilst lower income groups tend to recycle as this can be a source of income.

2.3. Greenhouse gas impacts from waste

Waste management activities produce four primary GHGs, namely, carbon dioxide, methane, nitrous oxide and chlorofluoro-carbons (CFCs) (Smith et al., 2001). The global warming potential (GWP) of these gases is defined as the ratio of the radiative ability that would result from the emissions of one kilogram of a GHG compared to the ability of one kilogram of carbon dioxide over a particular time period (Forster et al., 2007). Carbon dioxide is therefore used as a base unit and all other GHGs are compared to this. Relative contributions to global warming determined by the Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report (2014) shows that carbon dioxide has the greatest relative contribution at 63% with methane only contributing 18% to global warming, however methane is 28 times more potent than carbon dioxide as shown in Table 2.1. Carbon dioxide is primarily produced through the combustion process of fossil fuels used in the transportation of waste, whilst methane is produced during the anaerobic degradation process. Nitrogen oxide is produced in the combustion of waste and during the composting process.

These emissions can result from three forms of activities namely, direct emissions, energy emissions, and transportation emissions. Direct emissions result from waste treatment processes such as landfilling and the incineration of waste. Energy emissions result from waste to energy and anaerobic digestion processes. Transportation emissions result from the transportation of waste between waste management activities.

Table 2.1 – GHG contributions and GWP for CO_2, CH_4, NO_2 and Halocarbons

Greenhouse gas	Contribution	IPCC 2nd Assessment Report (1996) GWP	IPCC 3rd Assessment Report (2001) GWP	IPCC 4th Assessment Report (2007) GWP	IPCC 5th Assessment Report (2014) GWP
Carbon dioxide	63%	1	1	1	1
Methane	18%	21	23	25	28
Nitrous oxide	6%	310	296	298	265
Halocarbons	13%	140-11700	120-12000	124-14800	138-12400

.

2.4. Solid waste management in SA

The United Nations (1997) describes the characteristic activities of solid waste management as

1. “The collection, transportation, treatment and disposal of waste
2. The control, monitoring and regulation of the production of waste
3. The prevention of waste production through in process modifications, reuse and recycling.”

Waste management therefore refers to all the activities that dispose or re-use waste. Figure 2.1 shows a typical waste flow diagram from South African municipalities. Waste is generated and stored at the households until the collection day or until waste is transported to drop-off centres. Waste collection should preferably be collected once a week in order to protect the public form health risks. The collection service type can vary between kerbside collection and collection from a central communal point. Waste receptacles at the generation point should allow for source separation in order to collect recyclables. These storage receptacles include bins with plastic liners, monkey proof bins as well as wheelie bins (CSIR, 2011).

Once collected, transportation of the waste occurs. Transport is an integral part of the waste management process; however, it is very expensive. The cost efficiency of the transport can often determine the feasibility of a waste management scenario. Recyclables may be transported to clean material recovery facilities (MRFS), drop-off centres, and buy-back centres. Mixed waste may be transported to intermediate facilities in the waste management system before being disposed of at a landfill.

The final stage in most waste management systems is landfilling and landfill gas recovery, which may be the cheapest option but it has many disadvantages, such as environmental hazards in the form of leachate and emissions to the air (CSIR, 2011).

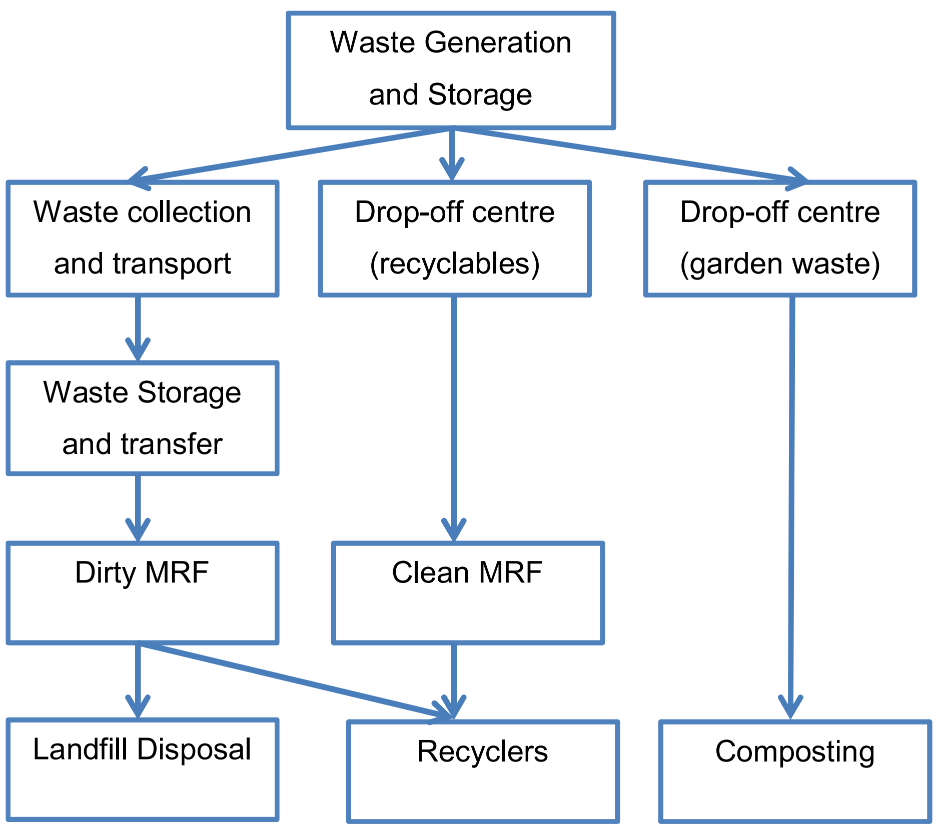


Figure 2.1 – Typical waste flow diagram from South African municipalities (adapted from CSIR, 2011)

Alternative waste management strategies include anaerobic digestion, composting and recycling. Anaerobic digestion can provide municipalities with an effective and sustainable strategy that can be used to reduce greenhouse gases with the possibility of producing electricity and thus generating an income. Aerobic composting is another waste management strategy that can be used to generate an income through the sale of matured compost. Recycling can be used as a supplementary waste management strategy to landfilling, anaerobic digestion and composting. These strategies are further discussed in Chapters 3 – 6

Waste management is a necessity for sustainable development, however in a developing country such as South Africa, it is an escalating challenge due to poor equipment, labour and financial management whilst substandard planning also has a significant effect. Zero waste and the waste management hierarchy are two important principals in waste management that can be used to develop an effective and sustainable waste management strategy.

2.5. Zero waste

The Zero Waste International Alliance (2010) provides the following definition of zero waste:

“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 principal that can be used during the waste management process that encourages efficient processes and minimal wastage. The zero waste principal can also be applied to the design and manufacturing of products where elimination of waste is also encouraged by replacing non-recyclable materials with recyclable materials and replacing toxic products with non-toxic products (Glavic and Lukman, 2007)

Major South African municipalities are starting to engage with the principle of zero waste at a planning level in order to develop policies. This is due to the Polokwane Declaration that aims to develop a zero waste plan by 2022.

Zero waste is a goal that can be ethical, efficient and economical and can be used as a guide to provide sustainable natural cycles where all waste is treated as a resource rather than a burden. Implementing the zero waste principal will eliminate all human made discharges that are harmful to the planet and to animal, plant, and human health (Zero Waste International Alliance, 2010). Theoretically landfills will be rendered obsolete, however residual waste that cannot be reduced, re-used, recycled or recovered will be disposed at a landfill.

2.6. Waste management hierarchy

The internationally accepted waste hierarchy developed by the Council Directive of Waste (1975) is aimed at firstly prevention and the minimisation of waste where possible followed by the recycling and treatment of the waste followed by the last option of landfilling of the waste. This can be seen in Table 2.2.

Table 2.2 – Internationally accepted waste management hierarchy (Council Directive of Waste, 1975)

Cleaner Production	Prevention
	Minimisation
Recycling	Re-use
	Recovery/Reclamation
	Composting
Treatment	Physical
	Chemical
	Biological
Disposal	Landfill

The waste hierarchy adopted by South Africa as seen in the National Waste Management Strategy of 2006 is very similar to the international model and is shown in Figure 2.2. The hierarchy consists of five tiers namely

1. Waste avoidance and reduction – this step aims for products to be designed in a manner that minimises the waste components whilst also reducing the quantity and toxicity of waste during the production process
2. Re-use of waste removes it from the waste stream to be used for a similar or different purpose for which it was made, without the product changing its physical form or properties
3. Recycling involves the separation of waste from the waste stream and re-processing the waste into raw material
4. Recovery involves reclaiming particular components or materials and using the waste as fuel to produce electricity
5. The final tier is treatment and disposal of the waste

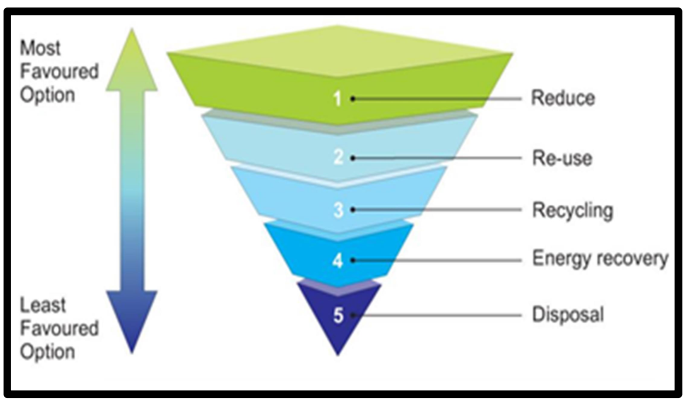


Figure 2.2 – South African waste hierarchy (National Waste Management Strategy, 2006)

The waste management hierarchy was developed to improve the control of waste and decrease environmental impacts through reduction, re-use, recycling, and energy recovery. The implementation of the waste hierarchy depends on its translation into waste legislation and policies. The waste hierarchy should ideally be implemented in all aspects of waste management. The hierarchy should guide waste management engineers in the decision making process.

2.7. Solid waste legislation in SA

Waste in South Africa is currently governed by a number of pieces of overarching legislation including:

The South African Constitution (Act 108 of 1996)
Environment Conservation Act (Act 73 of 1989)
The National Environmental Management Act (Act 107 of 1998)
Waste Act (Act 59 of 2008)

The purpose of waste legislation is to protect and control the utilisation of the environment by supporting the main objectives of waste management. The most recent pieces of legislation in South Africa concerning solid waste is the National Environmental Management Waste Act 59 of 2008 and the Waste Amendment Act of 2014 (RSA, 2014). The Act is the primary piece of legislation governing waste management in SA. It also introduced the concept of reduce, recycle and re-use (the three R's). The Amendment Act of 2014 alters certain definitions, including the definition of waste as pointed out in section 2.2 above. It also establishes the Waste Management Bureau.

In addition to the legislation there are strategies and policies in place including the Integrated Pollution and Waste Management Policy for South Africa, The National Waste Management Strategy, and the Polokwane Declaration on Waste Management.

The Integrated Pollution and Waste Management Policy (IPWMP) for South Africa is a white paper written in 1998 which sets out the stance of the SA government with regards to waste and pollution (RSA, 2000). The main objective of the policy is to reduce pollution and its impact on the environment. Previously the focus was on managing waste once it had been generated. However, the white paper shifted the focus to pollution prevention. The IPWMP also holds any parties responsible for their pollution of the environment and enables the prosecution of those in non-compliance (AGAMA biogas, 2009).

The National Waste Management Strategy translates the IPWMP into action for South Africa and specifies eight goals to be achieved by 2016 (AGAMA biogas, 2009). These goals provide the framework for the development and implementation of green waste technologies (DEAT, 2011). While the long term objective of the strategy is waste prevention and minimisation, short term objectives are included such as waste collection and treatment. These are required due to the inadequate waste management systems in the country.

The South African government also adopted the Polokwane Declaration at the First National Waste Management summit held in Pietersburg in September of 2001. The declaration called for a reduction in waste generation and disposal with the aim to:

- Reduce waste generation and disposal by 50% and 25% respectively by 2012.
- Promote recycling opportunities which are sustainable.
- Engage in activities that will grow the recycling industry by 30% by 2012.
- Have zero waste by 2022.

Protection of the environment against the effects of waste is a high priority, especially in a developing country such as South Africa where the poor enforcement of waste legislation has resulted in impacts on both the environment and human health (AGAMA biogas, 2009).

2.8. Chapter Summary

Waste is produced by human activity and therefore an effective waste management plan is needed in order to offset its production. Ineffective and poor waste management results in severe environmental and health issues. Although waste comprises of unwanted products, it is possible to reuse or convert this waste into useful products or energy by various waste recovery methods and technologies (Ostrem, 2004).

The widespread international adoption of the waste hierarchy gives an indication of the waste problem facing the planet. In order to ensure an effective and coherent implementation of the waste hierarchy, a clear definition of waste is essential. The National Environmental Management Waste Amendment Act of 2014 provides a comprehensive and clear definition of waste.

From the South African context it can be seen that the applicable strategies begins with landfilling followed by recycling. The waste hierarchy opens the possibility of anaerobic digestion and aerobic composting as suitable waste management strategies for the energy recovery and re use of waste

The following chapters discuss these strategies to develop an understanding in order to formulate applicable scenarios that use complimentary waste management strategies. Landfilling is considered the most affordable way to manage waste, but this does not take into account factors such as the environmental and social impact of landfills. The following chapter will discuss landfilling and gas recovery systems.

Chapter 3 – Landfilling and LFG systems

3.1. Introduction

Landfilling refers to the deposition of waste onto land, this includes the filling in of waste into an excavation or the creation of a landfill above grade and then the 'filling' of it. Historically landfilling was the main method of waste disposal, this is because it has always been the cheapest and most convenient waste disposal method.

Landfilling is discussed, as it is currently the main method of waste disposal in South Africa with around 95% of the waste generated in SA disposed of in landfills, whilst the world average is estimated to be 85% (DWAF, 1998). This chapter will discuss the landfilling process along with the waste decomposition process that occurs in landfills.

3.2. Landfilling Process

- **Planning and Selection of site**

The landfilling process effectively begins when it is determined that a new landfill site is required to meet the long term waste disposal requirements of a community, region, town or city (WITS, 2002). The Minimum Requirements for Waste Disposal by Landfill document (DWAF, 1998) guides this planning process.

The Minimum Requirements document classes landfills according to the waste type, size of the waste stream and the potential leachate generation. The classing of landfills is done in order to ensure economic feasibility, suitability to the given circumstances and to protect the environment. Ultimately, the class of the landfill determines the type of lining system required. During this planning stage, the site selection will be governed by the size of the landfill, haul distances, legal requirements and the required lifespan of the landfill. Sites with high water tables, near airports and located within sensitive ecological areas should be eliminated. Once the most feasible site is found, a full environmental impact assessment (EIA) should be completed before construction and issuing of a permit is done (DWAF, 1998).

- **Operation of landfill site**

Sanitary landfills are operated according to two basic principles, namely compaction and covering of the waste on a daily basis. Waste is placed and compacted using purpose built landfill compactors. Compaction reduces voids in the waste resulting in less infiltration and migration of the leachate. Compaction also maximises airspace and improves the overall stability of the landfill. Each day the waste is covered with sand and soil in order to minimise the odour and reduce the amount of litter scattered by wind. The general aesthetics of landfills are also improved with daily coverings (DWAF, 1998). The correct application of compaction and covering prevents the majority of short-term adverse impacts resulting from landfilling.

- **Management of emissions and waste treatment**

Leachate is prevented from entering the natural environment through the construction of a lined landfill. A typical landfill lining can be seen in Figure 3.1. Lining systems vary depending on site conditions and the class of landfill. They typically consist of an impervious layer either made of clay or a synthetic material such as high density polyethylene (HDPE). A geosynthetic can also be used as a lining (Rowe, 1998). The lining also must include a drainage system for the leachate. Once collected, the leachate must be treated, this can be done on site through a sequencing batch reactor, leachate recirculation or through the use of aerobic lagoons. Alternatively the leachate can be sent to a sewer treatment works if a sewer line is located in the vicinity of the landfill.

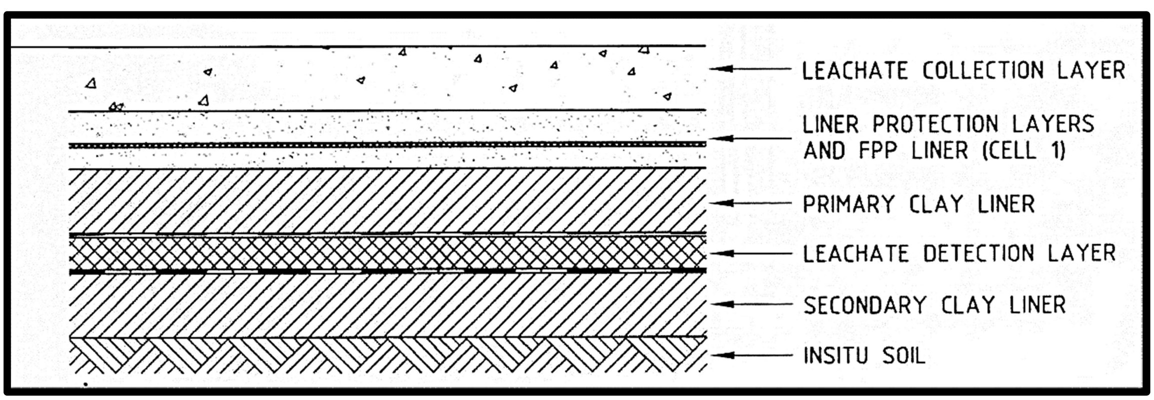


Figure 3.1 – Typical landfill lining (Rowe, 1998)

Lined landfill sites help contain and control landfill gases. Passive venting is commonly used for shallow landfills, whilst active abstraction of landfill gas occurs when gas is extracted via vertical wells in the landfill. These wells are generally spaced approximately 50m apart. The wells and pipe network are then connected to a blower that maintains a negative pressure at the well points. Once collected the landfill gas can be flared off with no recovery of energy occurring. It can be used to produce heat through direct burning. Alternatively, the landfill gas can be used as a fuel to power either a mechanical engine or a turbine to produce electricity.

- **Closure of a landfill**

Landfills are constructed to pre-determined levels and once this level has been reached it is required to be capped off and closed. The Minimum Requirement for Waste Disposal by Landfills (DWAF, 1998) states that the closure of sites includes drainage maintenance, leachate management and capping of the landfill with an impervious layer in order to prevent moisture access and hence to limit the amount of leachate produced. Top soiling and vegetating of the landfills top layer is also required. The landfills permit holder is responsible for the care of the landfill for a period of 30 years after closure. This care can include monitoring of the groundwater quality and the integrity of the capping system.

3.3. Decomposition process

All landfills undergo biological degradation, this is due to the large constituent of putrescible domestic waste found in them. A combination of physical, chemical and biological processes occur in the decomposition process that results in liquid (leachate) and gas emissions. Leachate is an aqueous solution that is the product of water percolating through decomposing waste. The composition of leachate is highly variable and dependant on a number of variables including moisture content, age of the waste and the waste composition. Landfill leachate is also considerably stronger than sewage and municipal waste water. Landfill gas is also a product of the decomposition process and consists primarily of methane and carbon dioxide with trace amounts of other gases. However the gas compositions change over time due to the sequence of waste decomposition (Trois, 2014). Experience from full scale landfills has shown that changes in landfill gases and leachate characteristics may be theoretically modelled as occurring in 5 stages (Christensen and Kjeldsen, 1992). These stages can be seen in Figure 3.2 and Figure 3.3

The first stage takes place in aerobic conditions as bacteria in the air decomposes the waste. This stages takes place within the first few months and can last up to a year. Stage 2 takes place in anaerobic conditions and acideogenic decomposition of the waste takes place, which causes a slow rate of energy release (Bove and Lunghi, 2006). Hydrogen, carbon dioxide and water are all produced during this stage. The leachate created produced is of an acidic nature.

Stage 3 is an acetogenic stage, which results in the oxidation of acids into acetic acids. Oxygen and hydrogen is created during this stage. In stage 4, methanogenesis occurs and results in the creation of methane from the products created during acetogenesis. The last stage is the maturation stage and is characterised by low gas production.

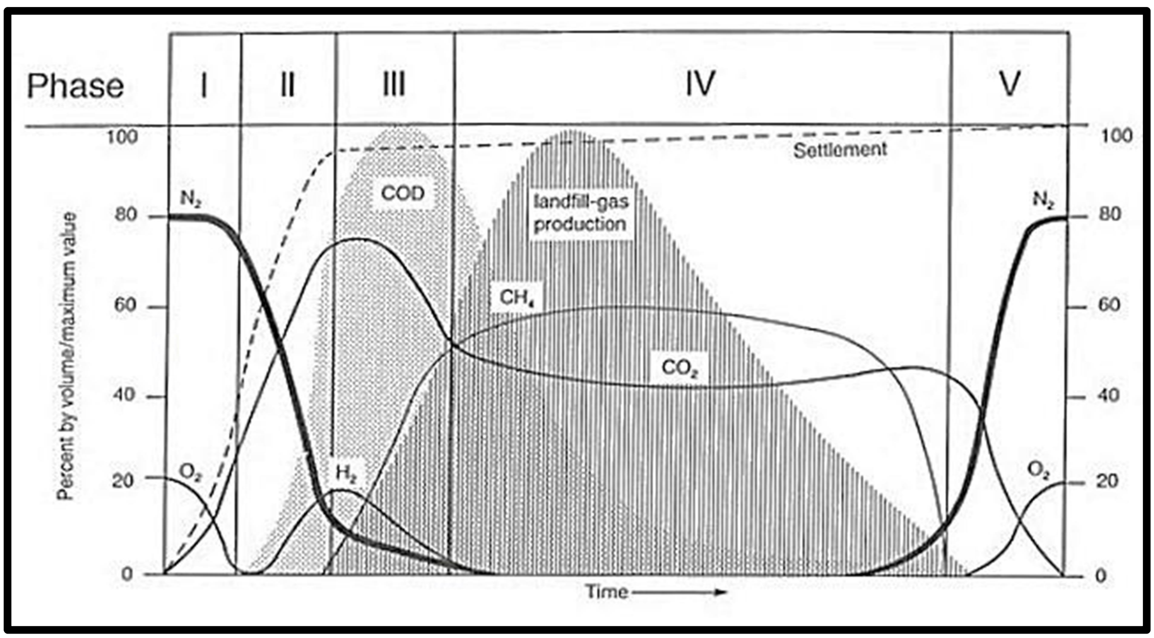


Figure 3.2 – Landfill gas decomposition process (Christensen and Kjeldsen, 1992)

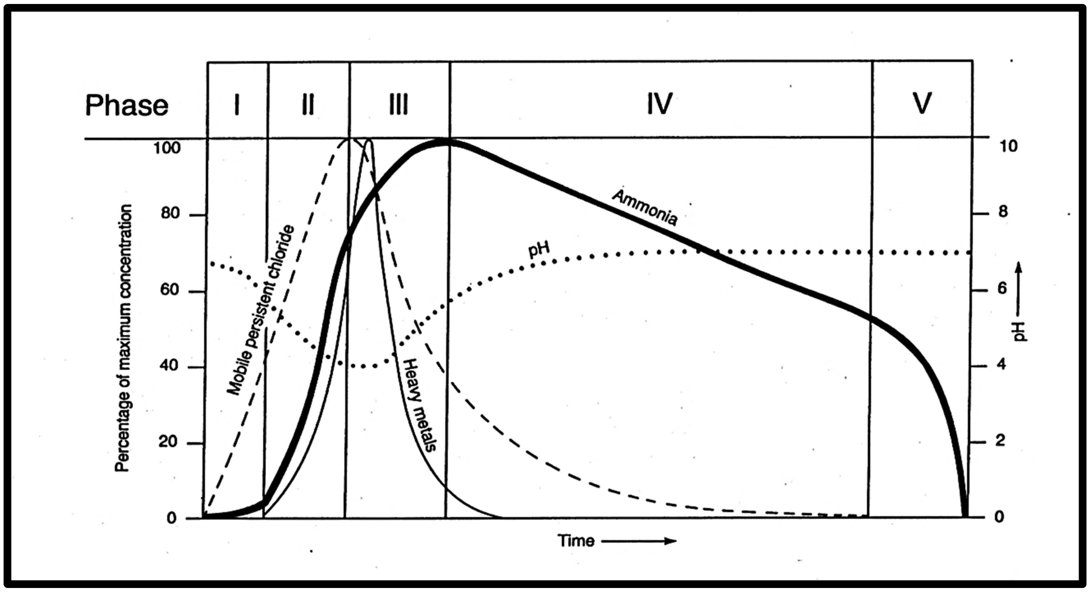


Figure 3.3 – Landfill leachate decomposition process (Christensen and Kjeldsen, 1992)

3.4. Landfill gas characteristics

- **Gas production rate**

Landfill gas production occurs in the acetogenic phase and increases through to the stable methanogenic phase, where, once reaching its peak, the gas production rate is decreased through to the mature phase of the landfill where the rate is negligible.

- **Methane**

No methane (CH_4) is produced in the anaerobic phase due to the inadequate amounts of carbon dioxide (CO_2) in solution which is required to act as an hydrogen (H_2) acceptor (McCarthy, 1963). Similar to the gas production rate, the onset of the acetogenic phase results in measurable quantities of methane being produced. The onset of this phase is likely to be related with the pH of the refuse becoming sufficiently neutral for growth of methanogenic bacteria to occur. During this phase the acids that had accumulated in the anaerobic phase are converted to methane and carbon dioxide by the methanogenic bacteria (Christensen and Kjeldsen, 1989, Barlaz et al., 1989). In the stable methanogenic phase, the methane production rate will reach its maximum level before levelling off and decreasing thereafter as the pool of soluble substrate of carboxylic acids decreases. As this happens, air will encroach into the landfill through the cap and into the actual waste mass. At some point of the mature phase, almost all of the methane produced will be oxidized in the waste body. This results in the average methane content within the landfill continuously decreasing.

- **Hydrogen Gas**

Hydrogen gas (H_2) production is noticeable in the anaerobic phase before declining at phase 3. This is due to the methanobacterium, which are capable of using H_2 at a very rapid rate (Toerien and Hattingh, 1969). The H_2 level does not increase during the following phases.

- **Carbon Dioxide**

During the aerobic phase of the landfill, carbon dioxide (CO_2) is produced in approximate molar equivalents to the oxygen (O_2) that is consumed. During phase 2, a CO_2 bloom is observed and the peak CO_2 concentration occurs. In the following acetogenic and methanogenic phases, CO_2 concentrations are reduced to their lowest levels. CO_2 concentrations can be expected to increase towards the end of phase 4 through its production in the methane oxidation reaction.

- **Nitrogen gas**

During the aerobic phase very little Nitrogen gas (N_2) is displaced. N_2 is drastically reduced in phase 2, but some N_2 is produced through denitrification. During phase 3 and 4, the N_2 concentrations are reduced to terminal concentrations. Air intrusion during the mature phase will increase the nitrogen content of the landfill.

- **Oxygen**

During the initial aerobic phase of the landfill, oxygen (O_2) present in the void spaces of the recently buried waste is rapidly consumed, which results in the production of CO_2. This phase lasts only a few months because oxygen is not replenished once the refuge is covered. As oxygen sources are depleted, the waste becomes anaerobic, which supports the fermentation reactions. During the following phases oxygen will be nearly undetectable due to its rapid consumption. As mentioned above, air will encroach in the landfill through the cap during the mature phase of the landfill, and this will increase the oxygen concentration of the waste body.

3.5. Leachate characteristics

- **Chemical Oxygen Demand (COD)**

In the 2nd and 3rd phase, the highest biochemical oxygen demand (BOD) and COD concentrations in the leachate will be measured as shown in Figure 3.2 (Barlaz and Ham, 1993; Reinhart and Grosh, 1998). The BOD to COD ratio in the acetogenic phase has been reported to be above 0.7 by Robinson (1995). The COD and BOD concentrations then begin to decrease in the acetegenic phase once it has peaked. The BOD to COD ratios will also decrease as carboxylic acids are consumed.

In the methanogenic phase, some COD is present in the leachate, but it is mostly recalcitrant compounds such as humic matter and fulvic acids (Barlaz and Ham, 1993; Christensen et al., 1994). The BOD to COD ratio will generally fall below 0.1 in this phase because carboxylic acids are consumed as rapidly as they are produced.

BOD and COD concentrations are likely to decrease slowly through the mature phase until a BOD of near zero and a COD that will consist of recalcitrant humic matter are all that remain. BOD and COD concentrations can be seen in Table 3.1.

- **Ammonia**

In phase 2 and 3, a high production of ammonia is observed due to the hydrolysis and biodegradation of organic matters by microorganisms. During the 4th methanogenic phase, sulphates and nitrates are reduced to sulphides and ammonia, respectively.

- **pH**

In the second acidogenic phase, the hydrolytic, fermentative, and acetogenic bacteria dominate, resulting in an accumulation of carboxylic acids, and a pH decrease. The pH then increases in phase 3 as acids are consumed. The conclusion of this phase is associated with the pH of the waste becoming sufficiently neutralised for the limited growth of methanogenic bacteria. In the stable methanogenic phase, the pH continues to increase to steady concentrations.

- **Heavy metals**.

Heavy metals occurring in landfills include cadmium, chromium, copper, lead, nickel and zinc. Average metal concentrations are fairly low and can be seen in table 3.1. This has been shown by several major studies in which researchers have reported metals concentrations from full-scale landfills, test cells, and laboratory studies. These studies conclude that heavy metals in landfill leachate at present are not a major concern (Christensen et al., 1999; Reinhart and Grosh, 1999; Revans et al., 1999; Kjeldsen and Christophersen, 2001).

Table 3.1 – Leachate characteristics (Pohland et al., 1988)

TABLE 2 - Changes in Landfill Leachate Characteristics from Residential-Type Solid Waste (from Pohland (9))

Leachate Parameter	LEACHATE COMPOSITION		
	Initial*	Intermediate**	Final***
pH	5.3	6.1	6.7
Total Alkalinity, mg/l $CaCO_3$	8,300	4,283	1,338
COD, mg/l	40,210	9,464	350
BOD_5, mg/l	20,437	5,800	88
TOC, mg/l	10,938	2,957	307
Total Volatile Acids (TVA), mg/l HAc	15,611	4,710	ND
Total Kjeldahl Nitrogen, mg/l N	825	374	20
Ammonia Nitrogen, mg/l N	645	111	9
Total Phosphorus, mg/l P	4.93	0.83	0.27
ORP, mv E_c	--	-15	-91
Specific Conductance, µmho/cm	11,850	6,250	1,080
Chloride, mg/l	862	505	178
Sulfate, mg/l	750	110	ND
Calcium, mg/l	2,850	360	260
Magnesium, mg/l	264	153	71
Manganese, mg/l	73.7	1.0	1.6
Sodium, mg/l	1,175	650	515
Potassium, mg/l	1,070	611	311
Iron, mg/l	900	157	39
Zinc, mg/l	2.65	0.1	0.5
Cadmium, mg/l	0.2	ND	ND
Chromium, mg/l	0.4	ND	0.3

*After onset of acid fermentation with daily recycle.
**At onset of methane fermentation with daily recycle.
***After methane fermentation with daily recycle.
ND = nondetectable.

3.6. Landfill variables

As a landfill progresses towards the final maturation phase the solid waste and refuse is subjected to the physical, chemical and biological factors that occur within a landfill. The age and characteristics of landfilled waste, and the site-specific external operational conditions also significantly impact the waste. Environmental conditions which most significantly influence biodegradation in landfills are discussed below.

Moisture is one of the most important factors in waste stabilisation and leachate production. Moisture stimulates the methanogenic bacteria, whilst also being a reactant in the hydrolysis reactions. In addition, it transports nutrients and enzymes throughout the landfill and dilutes inhibitory compounds.

The availability of free oxygen dictates the type of decomposition occurring, namely, aerobic or anaerobic. During aerobic decomposition organic matter is transformed to CO_2 and H_2O, whilst during anaerobic decomposition organic acids, ammonia, methane and carbon dioxide are produced. The phases discussed above are due to the reductions in the quantity of oxygen available.

Temperature in the landfill site is a largely uncontrollable factor that influences the leachate and landfill gas quality. The temperature also fluctuates with seasonal variations. Bacterial growth and chemical reactions are affected by the temperature. Decreases in temperature will decrease bacterial growth due to enzyme deactivation and cell wall rupture. Solubility of salts such as NaCl increase with temperature however some compounds found in leachate (e.g. $CaCO_3$) show a decrease in solubility with an increase of temperature. These are further summarised in Table 3.2.

Table 3.2 – Summary of influencing factors on MSW degradation in landfills (Yuen et al., 2004)

Sl.No.	Influencing factors	Criteria/Comments	Reference
1.	Moisture	Optimum: 60% and above	Pohland (1986); Rees (1980)
2.	Oxygen	Optimum redox potential for methanogens:	
		-200 mv	Farquhar & Rovers (1973)
		-300 mv	Christensen & Kjelden (1989)
		< -100 mv	Pohland (1980)
3.	pH	Optimum pH for methanogenesis:	
		6 to 8	Ehrig (1983)
		6.4 to 7.2	Farquhar & Rovers (1973)
4.	Alkalinity	Optimum alkalinity for methanogenesis: 2000 mg/L.	Farquhar & Rovers (1973)
		Maximum organic acid concentration for methanogenesis: 3000 mg/L	Farquhar & Rovers (1973)
		Maximum acetic acid/alkalinity ratio for methanogenesis: 0.8	Ehrig (1983)
5.	Temperature	Optimum temperature for methanogenesis;	
		40°C	Rees (1980)
		41°C	Hartz *et al* (1982)
		45 (34 – 38°C)	Mata-Alvarez *et al* (1986)
6.	Hydrogen	Partial hydrogen pressure for acetogenesis: $<10^{-6}$ atm	Barlaz *et al* (1987)
7.	Nutreints	Generally adequate	Christensen & Kjelden (1989)
8.	Sulphate	Increase in sulphate decrease in methanogenesis	Christensen & Kjelden (1989)
9.	Inhibitors	Cation concentration producing moderate inhibition (ppm)	McCarty & McKinney (1961)
		Ammonium (Total) : 1500 – 3000	
		Sodium : 3500 - 5500	
		Potassium : 2500 – 4500	
		Calcium : 2500 – 4500	
		Magnesium : 1000 – 1500	
		Heavy metals: No significance influence	Ehrig (1983)
		Organic compounds: Inhibitory effect only in significant amount.	Christensen & Kjelden (1989)

3.7. Landfilling Problems

Landfilling impacts may be divided into short term and long term impacts. Short term impacts include problems such as an odour, noise pollution, air pollution, flies and windblown litter. However, these problems should cease with the closure of the landfill.

Long term impacts include pollution of the ground water and the water course by leachate. The leachate has high levels of ammonia, which is toxic to the environment. Organic matter in the leachate also creates septic conditions. Landfill gas generation results in air pollution, which in turn creates a greenhouse effect on a global scale. These problems often arise due to incorrect landfill site selection, design and operation. These problems may persist long after the landfill closes. The impacts are shown in Figure 3.4 together with their associated impact range (Kjeldsen, 1996).

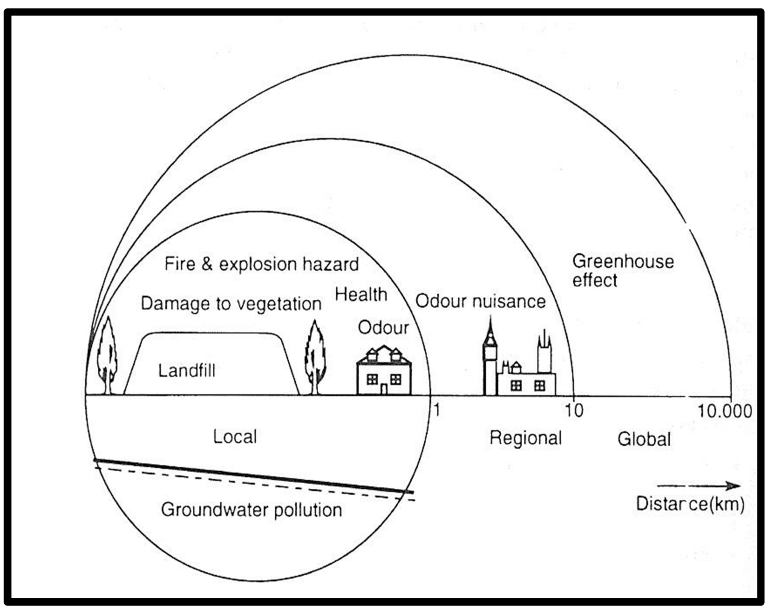


Figure 3.4 – Landfill impacts with associated range (Kjeldsen, 1996)

3.8. Chapter Summary

Landfilling begins with the site selection and planning and, once this is done, operation on site can begin. This includes compacting and covering of the waste on a daily basis. Leachate from landfills can either be treated on site or transported to a waste water works, whilst the landfill gas can be extracted through passive or active venting and flared or used to generate electricity. Closure of a landfill requires capping the area with an impervious layer to limit leachate generation. Re-vegetation of the top layer is also required.

Physical, chemical and biological decomposition processes occur in a landfill and can be theoretically modelled in five idealised stages. Leachate and landfill gas generation varies in these stages and can be seen in Figures 3.2 and 3.3.

Short term impacts of landfilling, such as odour and flies, affect the social circumstances of the surrounding area, however the long term impacts of leachate and landfill gas affect the environment on a global scale.

From the above discussion it was shown that landfilling is the status quo when it comes to waste management in majority of municipalities and thus should be used as the benchmark condition against which other strategies should be compared.

The landfilling process and problems associated with it are discussed to develop the working knowledge needed to further develop WROSE with regard to landfilling. Landfill gas and leachate characteristics also provided potential indicators in which other strategies can be quantitatively compared to

There will always be a residue of waste that will have to be landfilled, no matter what waste minimisation and volume reduction technologies are used. Hence, landfills will always be needed. Landfilling is environmentally acceptable if properly implemented, however, if not carried out to high standards, it has the potential to adversely impact on the environment.

Chapter 4 - Recycling

4.1. Introduction

Recycling and reuse of waste is no longer optional but essential to address the problems associated with waste management. Recycling is the reprocessing or reuse of used and waste material into new materials and products. This all-encompassing definition can be applied to many waste management strategies, such as anaerobic digesting and composting which can also be viewed as the recycling of organic waste. Recycling is an integral part of the waste hierarchy and plays an essential role in the development of any zero waste model as shown in Figure in 2.1.

The International Solid Waste Association (1992) has named five types of recycling that are differentiated according to the product, these are namely

- The use of an item, more than once, for the same purpose for which it was originally used for.
- The use of an item, in its original form, but for another purpose.
- Production line process waste returned into mainstream production line feedstock to produce an item.
- The treatment of the materials from one product to produce raw materials for other products.
- The conversion of waste material into energy.
- The separation of waste at the source followed by collection and transportation is also regarded as part of recycling.

The United Nations (2007) formal definition of recycling states that recycling is any reintroduction of waste materials in a production process that diverts it from the waste stream. Both processing as the same type of material and for different proposes are included. The following chapter will discuss the recycling process of glass, metals, paper, plastic and electronic waste. Variables in the recycling industry such as open and closed loop recycling are also studied. Finally recycling methods such as buy-back and drop-off centres are discussed to give a conclusive overview of various factors that affect the recycling trade.

4.2. Recycling process

4.2.1. Glass

New glass is made of four raw materials namely quartz, lime, soda ash and sand. If recycled glass from the waste stream is added to the production process the need for energy is reduced from 14.1GJ/ton for glass made with virgin material to 9.23GJ/ton (Matete, 2009). One ton of recycled glass can be used to produce one ton of glass, but 1.2 tons of virgin raw material is required for one ton of new glass. Recycling of glass therefore not only reduces the energy needed but also the amount of raw material whilst also accelerating the production process due to the lowered melting point of the recycled glass.

Glass containers are made in three different colours, green, brown and clear. When separated correctly they can achieve a much higher price than unseparated and contaminated glass. Glass containers are completely recyclable and can easily be remanufactured without any appreciable loss of material or degradation of quality.

Almost all glass is recyclable with the exception of window glass, light bulbs and mirrors which cannot be recycled as they are chemically treated. Glass also poses a problem when incineration is the method of disposal, as it interferes with the burning process (Bagghi, 2004).

The Glass Recycling Company (2015) has reported that in South Africa the glass-recycling rate has increased from 18% to 40.6% in the last 7 years. Glass recycling has resulted in a reduction of 220 000 CO_2 emissions in the last year.

4.2.2. Metal

Recyclable metal consists of beverage or soft drink cans, non-perishable food tins, scrap metal and construction steel. Beverage cans are made from aluminium, while the food tins, scrap metal and construction material are predominantly made from steel. Up to 95% less energy is required for manufacturing aluminium cans from recycled material compared to the production from virgin material. The recovered aluminium is melted in a furnace and mixed with other metals to form an alloy suitable for use. Steel goes through a sorting process first, followed by a heat treatment to remove any paint still on the material and is finally melted and cast into steel ingots. Steel waste can be recycled many times without losing quality and strength (Smith et al, 2001). The scrap steel industry in South Africa is worth between R15 and 20 billion, and this equates to three million tons of scrap metal being recycled a year (Metal Recyclers Association Of South Africa, 2012).

4.2.3. Paper

There are three predominant types of paper that can be recycled: newspaper, cardboard and office paper. Recycled paper is firstly de-inked to remove any traces of grit and ink from the original content. It is then bleached and water added to form a pulp. Virgin pulp which is produced from un–recycled wood pulp, is then added to the recycled pulp, to improve the quality. Paper is not infinitely recyclable because the recycled pulp fibres become shorter and weaker after recycling, hence the need to include virgin pulp in the process (Bagghi, 2004). For every ton of paper that is recycled, 17 trees, 54% of the process water, 2.5 barrels of oil and 64% of the process energy is saved (Recycling Revolution, 2010).

Currently, paper recycling technology has advanced to the point where recycled paper pulp is competitively priced against virgin pulp material (Bagghi, 2004). However there are problems with certain papers, coloured paper must be separated from white paper before de-inking and glue on paper must be removed before de-inking. 62.1% of recoverable paper was recycled in South Africa during 2013. This has increased from 43.5% during the year 2009 (Paper Recycling Association of South Africa, 2013).

4.2.4. Plastic

There are six types of resin that are primarily used in disposable plastic packaging. They are all given a particular resin code that is determined by their composition and hence their melting point. These codes placed on the packaging help differentiate the particular resin from others when sorting occurs. Sorting between groups of resin must be done before recycling. Table 4.1 shows the recovery rates for each resin, adapted from the South African Plastic Recyclers Organisation (2012).

Table 4.1 – Shows the various resins available in SA (Adapted from South African Plastic Recyclers Organisation, 2012)

Plastic derivative	Common use	Tons recycled	Recovery rate
Low density polyethylene (PE–LD)	Film waste and irrigation pipes sold back to respective industries	98 971	28.54%
Polyethylene Terephthalate (PET)	PET beverage bottles recycled into tapes and fibres	50 280	31.75%
Polypropylene (PP)	Yogurt and margarine tubs recycled into chairs	47 080	18.10%
High density polyethylene (PE–HD)	PE–HD crates closed loop recycling	45 950	23.00%
Polyvinyl Chloride (PVC)	Construction pipes, doors and windows recycled into flooring, mud flaps and gumboots	16 812	10.34%
Polystyrene (PS)	Foamed cups, takeaway containers into coat hangers and seed trays	3 394	8.1%

4.2.5. Electronic waste

Electronic waste, also referred to as e-waste, is used to describe old and unwanted electronic devices. E-waste includes computers and appliances. E-waste is a relatively new problem and has significantly increased since the development of the personal computer. E waste contains both valuable and hazardous waste that can be recovered through proper recycling. The hazardous components need to be treated correctly before being disposed of safely (EWASA, 2008).

4.3. Process variables

4.3.1. Closed loop/open loop

Closed loop recycling refers to the reprocessing of waste material into raw material that can be used in the manufacturing of products that are similar to the original waste product (DEAT, N.D.) An example of this is wine bottles being reused after washing and sterilisation has taken place (Bagghi, 2004).

Open loop recycling refers to the reprocessing of waste material into products different to the original waste. An example of this is scrap metal that can be easily separated from municipal solid waste due to its magnetic properties and then recycled into steel cans for the packaging of food, paint and aerosols (Bagghi, 2004).

4.3.2. Single/double/multi stream

A single stream system occurs when all the recyclables are combined in a single collection receptacle by the waste generator i.e. paper, glass, cans are collected in a single mixed form.

Duel stream occurs when recyclable materials are kept separate in two categories. In one category, all fibres such as paper and cardboard are kept together and in another category, containers such as the plastic, glass and aluminium cans, are collected together.

Multi-stream recycling is a collection method where the generators of waste are required to source separate in three or more categories of recyclables into separate collection receptacles. From here, the material is transported to a multi-stream material recovery facility (MRF). These MRFs require less mechanical equipment than single stream MRFs as the material has been pre-sorted. The multi-stream MRFs require more manual sorting and hence require less investment in capital costs (Lakhan, 2015).

4.3.3. Buy-back and drop-off

Buy-back centres obtain recyclables from waste collectors or informal recyclers and are often operated by entrepreneurial individuals. The success of these centres is highly dependent on their location, so as to reduce transportation costs. Buy-back centres can be located close to commercial and industrial centres to capture this market or they can be placed near low income areas where their occupants are dependent on income from the recycling of waste (DEAT, n.d.).

Drop-off centres provide containers for the public to deposit recyclable waste. These drop-off centres are often located at a central point accessible to a large part of the community. Drop-of centres rely heavily on public participation as no compensation is offered for recycling.

4.3.4. Informal recycling

This form of recycling takes place on landfill and dumping sites and is performed by the low income group. Scavenging and waste picking through refuse bags and bins also fall in the informal recycling category. The waste products are then reused for personal use, converted into useful items or sold to buyback centres for an income. This form of recycling is extremely dangerous and hazardous to scavengers as they do not make use of personal protection equipment (DEAT, n.d.).

4.3.5. Material recycling facilities

Material recovery facilities (MRFs) are buildings where recyclable items are stored for sorting and distribution. In these facilities, recyclables are separated and prepared for marketing. The items can be sorted by hand or mechanically. If hand sorting occurs then a conveyor belt system is implemented with several workers collecting different types of items. If a mechanical system is used, then conveyor belts, trammel screens, magnetic systems and eddy current machines can be used in synchrony to separate and sort the waste. In MRF's, material is either positively sorted or negatively sorted. In a positive sorted scenario, the selected target waste is physically removed from the comingled waste such as when magnets are used to remove ferrous materials. The negatively sorted material refers to the material which was not removed during the positive sort, and ideally this material should be the material with the largest volume (Cimpan et al., 2014). MRF's are categorised according to three types of incoming waste streams.

1. Multi-stream collection of recyclable items and garbage separately. Residents need to separate each item and place them in separate containers for collection.
2. Single stream collection. Resident place all types of recyclables in a single container and household waste separately in another container. Subsequently, sorting of specific recyclable fractions is needed at the MRF.
3. Unsorted collecting of mixed waste. The residents do not need to separate household waste and recyclable waste. The organic fraction is separated from the recyclable fraction at the MRF.

(Beck, 2006)

This form of recycling relies heavily on public participation for the separation of dry waste and wet waste. However the benefit of this is that it allows recycling to occur at a much larger scale. Public participation also allows for a much lower construction and operating cost of the MRF as less machinery is needed if completed by the public.

4.4. Chapter Summary

The greatest barrier to achieving a successful recycling program is the limited amount of source separation that occurs. If source separation were to be implemented on a large scale, recycling has the potential to become a feasible and sustainable industry.

Recycling cannot be treated as a collective solution to the management of the recyclable fraction. Recycling may not eliminate the need for landfills but it does help extend the life of existing landfills and delays the need of new landfills. Recycling should be viewed as an overall environmentally friendly low cost waste management strategy (Matete, 2009)

The above research provides the recycling strategy with sufficient importance to apart from landfilling strategies form the basis of alternative waste management scenarios. Material recovery facilities and the discussion on various recyclable material provided insight into the potentially profitable economic aspect of recycling and hence a viable indicator that can be used across potential waste management strategies.

Chapter 5 – Anaerobic Digestion

5.1. Introduction

Anaerobic digestion (AD) is a biological process in which biodegradable organic matter such as food waste is broken down by microorganisms in the absence of oxygen, into biogas and a stable solid. The biogas produced consists of methane, carbon dioxide, and small amounts of other gases (Yang et al., 2004). The biogas which is produced is then used in the generation of electricity and the digestate produced can be further processed into compost through an aerobic process.

The anaerobic digestion process occurs naturally on landfill sites, wetlands and bogs where very little or no oxygen is present (Ostrem, 2004). Anaerobic digesters are controlled and optimised versions of the naturally occurring systems, which allow for the biogas and digestate to be produced more efficiently (Monnet, 2003; Ostrem, 2004).

Anaerobic digestion meets the criteria of the waste hierarchy of waste diversion from landfills and energy generation. AD also uses waste as a resource with the production of biogas and digestate that can be used in other applications, with potentially economic benefits.

This chapter discusses the process of AD and biogas production which can be divided into 4 stages, namely, pre-treatment of the waste, digestion, biogas to electricity conversion and digestate use (Das, 2012). Design and process variables of anaerobic digestion are also researched and presented below.

5.2. Process of anaerobic digestion to biogas

5.2.1. Pre-treatment

Pre-treatment of the waste will be dependent on the type of waste used for the feedstock, for example, manure needs to be mixed whilst municipal solid waste will need to be sorted and shredded (Das, 2012). The feedstock might also need to be chopped up into smaller parts to prevent clogging and to help with the biological digestion. The purpose of a pre-treatment is to mix different feedstock, to add water or to remove undesirable materials such as large items and inert material that will not decompose. This allows a better digestate quality and hence a more efficient system (Monnet, 2003). Feedstock that contains sand and heavier material will need to be pre-treated as sand should not enter the digester, as it will silt up and cause the digester to be inefficient (The Anderson Centre, 2010).

5.2.2. Digestion

The digestion stage takes place in the digester. During the digestion stage micro-organisms break down the organic material in the absence of oxygen, to produce methane and carbon dioxide. The digestion stage can further be broken down into four biological processes, namely, hydrolysis, acidogenesis, acetogenesis and methanogenesis. Figure 5.1 shows the four biological processes that occur in anaerobic digestion.

Hydrolysis is the process whereby complex insoluble molecules in the substrate are converted to soluble molecules such as simple sugars, amino acids and fatty acids (Monnet, 2003). The hydrolytic process can be limiting and thus chemicals can be added at this stage to decrease the digestion time whilst also increasing the methane yield (Verma, 2002).

The acidogenisis process further breaks down the soluble molecules formed during the hydrolysis step into simple organic compounds. Volatile fatty acids, ammonia, carbon dioxide and hydrogen sulphide are created by acidogenic bacteria in this step.

Acetogenisis is the third step that occurs. The simple molecules that were created in the previous two steps are now transformed into acetic acid and carbon dioxide and hydrogen.

In the final methanogenic step, the hydrogen released during the acetogenesis process bonds with the carbon to make methane. If oxygen becomes available at this stage then the hydrogen and carbon will bond to this and produce carbon dioxide and water rather than methane (Ostrem, 2004).

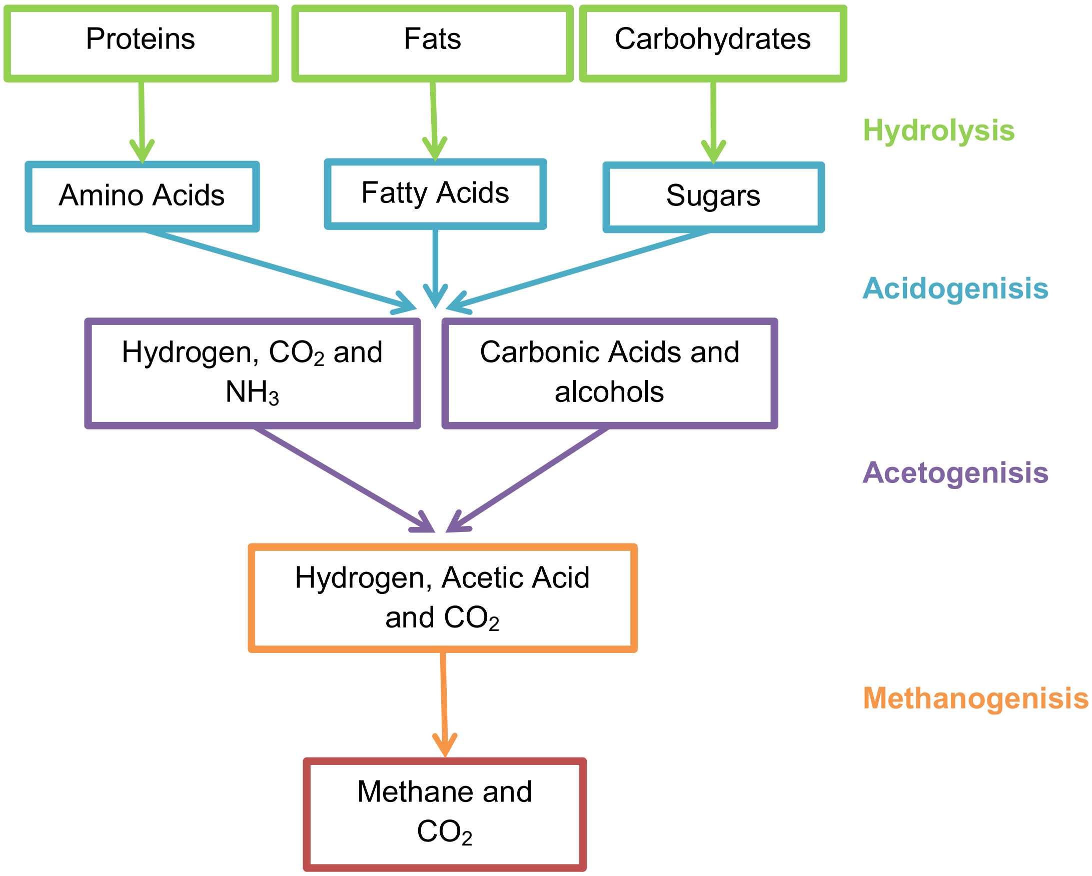


Figure 5.1 – The four biological processes that occur in anaerobic digestion

Making these processes all occur in a controlled environment is imperative to maximising the output of methane. This takes place over a period of 6 - 60 days, which is known as the retention time.

5.2.3. Biogas to electricity

AD is an attractive option to manage organic waste as it produces biogas and digestate. As said above, biogas consists of primarily 60% methane and 40% carbon dioxide with trace amounts of hydrogen sulphide and ammonia (The Anderson Centre, 2010). Biogas is a colourless, flammable and stable end product (Igoni et al., 2007). Composition of this biogas is directly related to the composition of the waste used in the digester.

Biogas can be used to generate electricity, heat or a combination of both. The unrefined gas can be used to produce electricity in a generator or for applications designed for natural gas systems however the biogas will be required to be upgraded for some gas appliances that require gas of a higher standard than that of biogas. A number of gas upgrading systems have been developed, these include carbon dioxide removal systems and hydrogen sulphide removal systems. These systems create a purified form of biogas called bio-methane which consist of 97% methane that can be used in the heating of boilers, combined heat and power systems, and fuel for vehicles (Monnet, 2003).

The electricity produced from the biogas is often used to power the anaerobic digestion process, whilst the remaining energy can be used elsewhere on the site or be sold back to the national energy grid.

5.2.4. Digestate uses

The anaerobic process removes the carbons, hydrogen and oxygen from organic material however, essential plant material such as nitrogen, phosphorus and potassium remains in the digestate, which can be classified as immature compost (Ostrem, 2004). Similarly to the biogas component, the fertilizing agents in the digestate vary depending on the feedstock composition. The use of the digestate depends on the quality and the type of plant producing it.

Small agricultural digesters for example can use the digested slurry without further treatment as a fertilizer on the farm. However anaerobic digestion effluents are not generally suitable for putting directly onto the land. They are too wet and contain volatile fatty acids. Also a problem occurs if digestion has not occurred within the thermophilic range of temperatures, as the effluents will then not be hygienised. (Mata Alvarez et al., 2000). Therefore large-scale commercial plants that use municipal solid waste may process the effluent to a higher quality to increase its value and appeal to the fertilizer market (Monnet, 2003).

Further processing of the digestate can include turning the digestate into compost. This option allows for the complete breakdown of the organic material. Composting is the biological decomposition of solid waste under controlled aerobic conditions (Calreycle, 2013). It can be used to improve soil structure and provide plants with nutrients (Cole, 1994). This compost can also be used as a landfill cover. Aerobic treatment such as compost creation produces large and uncontrolled emissions of volatile compounds, such as ketones, aldehydes, ammonia and methane.

These biological and physical processes that encompass anaerobic digestion require careful management of the variables that can influence the output. These variables are the temperature, moisture content, continuous or batch systems, number of digesters and the tank layout. These variables all have a different effect on the processes and can be used to maximise the output (The Anderson Centre, 2010).

5.3. Anaerobic digestion design variables

5.3.1. Temperature

Anaerobic digesters can be classified by temperature. Mesophilic and thermophilic systems exist as shown in Figure 5.2. The main difference between them is the operating temperatures with mesophilic operating at 25 – 45^{o}C whilst thermophilic systems operate at 50 – 60^{o}C. Mesophilic systems have a much longer retention time of 18 - 60 days compared to thermophlic systems which have a retention time of 10 - 18 days. Due to the slow retention time, biogas production is much slower per unit of feedstock in mesophilic systems. Thermophilic systems kill pathogens more efficiently however, they are much more expensive to construct and also use more energy to run. They can be feasible in hotter climate areas due to the higher operating temperature (The Anderson Centre, 2010). A comparison is shown in Table 5.1.

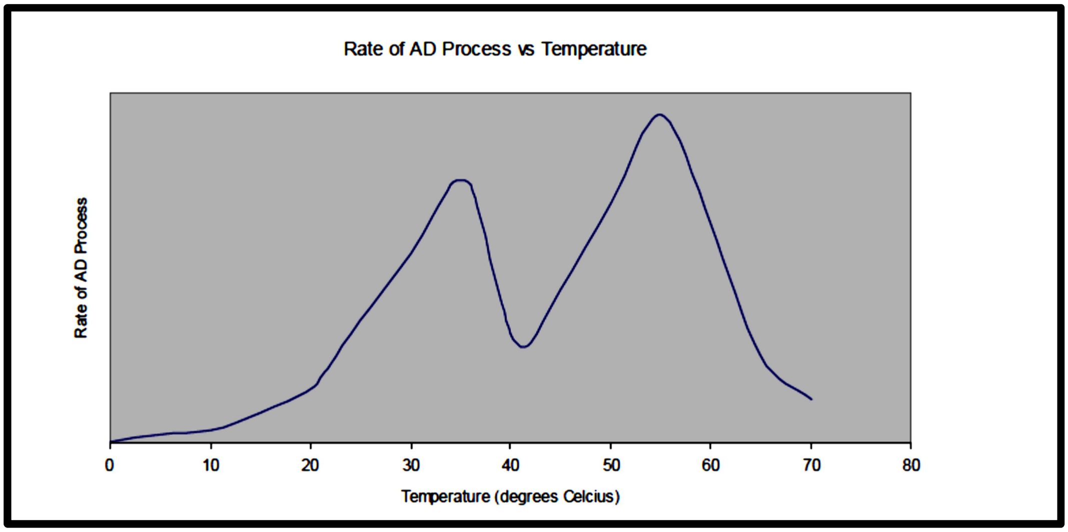


Figure 5.2 – Shows the rate of reaction vs temperature in anaerobic digestion (Ostrem, 2004).

Table 5.1 – Comparison between mesophilic and thermophilic digestion (The Anderson Centre, 2010)

	Mesophilic	Thermophilic
Temperature	25-45 Degrees Celsius	50-60 Degrees Celsius
Digestion period	18-60 days	8-18 days
Gas production /unit feedstock	Slower	Faster
Space required /unit feedstock	High	Low
Pathogen Kill	Good	Better
Management requirement	Lower	Higher
Capital Cost per m3 capacity	Cheap	Expensive
Operating Cost	Cheap	Expensive

5.3.2. Moisture content

The moisture content refers to whether the feedstock is wet or dry. Wet digestion is considered to have 5% – 15% dry matter whilst dry digestion is considered to have 15% – 50% dry matter. Wet digestion means the digestate is treated as a liquid and can therefore be pumped. During dry digestion the digestate is treated as a solid and will therefore be shovelled (The Anderson Centre, 2010). Table 5.2 shows a comparison between moisture content variables.

Table 5.2 – Comparison between Wet and Dry Digestion (The Anderson Centre, 2010)

	Wet	Dry
Dry Matter	5 - 15%	15% to 50%
Gas production /unit feedstock	Lower	Higher (more dry matter)
Space required	More	Less (depends on system)
Feedstock digestion	Less volume reduction	More volume reduction
Operating Cost	Dearer	Cheaper, less water to heat
Maintenance	More moving parts	Fewer moving parts, but must be much stronger
Digestate	More water effluent	Less water to store
Set-up capital cost	Lower	Higher
On Farm	Handles slurry not straw	Handles stackable feedstock
Suitability	Ideal for slurry & vegetable waste	Ideal for drier silages & straw based feedstock

5.3.3. Continuous flow/batch process

Wet systems tend to use a continuous flow system whereby digestate is removed every few weeks and the process is restarted. Dry systems are however often used in batch systems where multiple digesters are in operation and it is possible to stagger the batching process to allow a constant yield of biogas (The Anderson Centre, 2010).

5.3.4. Number of digesters

Multiple digesters can be used to achieve different conditions in each digester that has been optimised for each of the biological processes explained above. This method allows for optimum gas production as the feedstock is completely digested. With this increase in the number of digesters there is a dramatic increase in capital and operating costs (The Anderson Centre, 2010).

5.3.5. Tank layout

Most digesters are vertical towers with feedstock entering in one side and digestate exiting through the other side, however horizontal tank digesters also exist. In this system, flow enters one side and the speed at which it leaves can be controlled by the rate the system is fed. This guarantees that the feedstock does not leave the system early or spends too much time in the tank (The Anderson Centre, 2010).

5.4. Anaerobic digestion process variables

5.4.1. pH

The pH of a digester is the primary measurement of the health of the digester. A stable pH indicates the system is in equilibrium, but a falling pH can indicate an acid accumulation and system instability. An acceptable pH range is 5.8 – 8.5 however the closer the value is too neutral the higher the probability that the methanogenic bacteria will function at optimum levels (Ostrem, 2004).

If a large amount of fresh waste were to be introduced into the digester, acid would begin to accumulate and acidogenic bacteria would begin to thrive and produce large amounts of acid whilst killing off methanogenic bacteria. This creates a cyclic effect as the decreasing amount of methanogens will in turn lead to an increase in acid, as methanogens are responsible for consuming acid. This acidic process can be remedied by the addition of water to the digester.

On the other hand, a high methanogenic bacteria count can lead to a basic pH where a high concentration of ammonia exists. An increase in pH to above 8 will hinder the production of acidogenic bacteria. This basic process can be remedied by the addition of fresh feedstock (Ostrem, 2004).

5.4.2. Temperature

As discussed above, two ranges of temperatures exist, namely, mesophylic (25 – 40^{o}C) and thermophylic (50 – 65^{o}C). Anaerobic bacteria thrive within these two ranges of temperature. A thermophylic system allows a higher rate of degradation of organic material, but due to the higher temperature needed, it requires a large amount of energy. It is also highly sensitive to changes in the equilibrium of the system and to toxins in the substrate.

Mesophylic bacteria are however much stronger and can handle changes in the environment. This allows a mesophylic system to be very stable. The temperature needs to be maintained in anaerobic digesters. This can be done in many ways including insulation, water baths and solar heating (Ostrem, 2004).

5.4.3. Carbon/Nitrogen ratio

The Carbon/Nitrogen Ratio (C/N ratio) is an indicator of the relative amounts of carbon and nitrogen in the feedstock before digestion occurs. The C/N ratio can be monitored either through testing or by keeping track of the types of waste entering the digester and knowing the make-up of the feedstock.

The optimum C/N ratio is between 20 and 30. If a feedstock is high in carbon, a high nitrogen containing manure can be added to increase this ratio. A low C/N ratio means too much nitrogen exists in the system; this can cause ammonia to accumulate which would lead to pH values above 8.5 and a low quality of digestate will occur. A high C/N ratio means extra carbon exists; this will lead to an increased use of nitrogen by the methanogenic bacteria and hence a lower gas production (Ostrem, 2004).

5.4.4. Retention time

The time from when feedstock enters a digester to the time the digestate leaves the digester is known as the retention time. It is determined by the time the organic material takes to digest. This retention time is measured when a suitable COD/BOD is measured from the effluent leaving the digester.

The longer a feedstock is kept in the digester the more complete the digestion process will be and hence a better digestate will be produced. The rate of the digestion reaction is inversely proportional to the retention time, hence an optimum retention time needs to be found that is cost effective whilst also producing a suitable quality digestate.

It has been shown that volatile suspended solids in a digester could be reduced by 64 – 85% after only 10 hours, however retention times of 10 days were found to be necessary for complete digestion to occur (Chang et al., 1997; Vlyssides and Karlis, 2003).

Reducing the retention time results in the need for a smaller digester, and hence leads to a large cost saving. A shorter retention time will also result in a higher production rate but with a lower level of degradation.

Retention time can be reduced through the use of low amounts of solids and mixing of the digester. The decreasing of the solids content allows the bacteria to access the substrate easily because it is in a liquid form. The bacteria react better in a liquid form because the reactions require water to be completed. A low solids content also aids in mixing

Mixing increases the substrates surface area available for the bacteria to react with and hence reduces the retention time. A digester that is not mixed properly will lead to huge layers of undigested material leaving the digester (Ostrem, 2004).

5.4.5. Organic loading ratio

The organic loading rate determines the amount of volatile solids that are placed in the digester. A high organic loading rate will result in high volatile solids and hence a higher demand of bacteria needed to process the material. As explained in the pH section, an increase in the organic loading rate would increase the acidogenic bacteria which would then produce acid and increase the pH and kill the methanogenic bacteria. Hence, the organic loading ratio needs to be carefully managed together with the other variables associated in the anaerobic digestion process that can be seen in Figure 5.3.

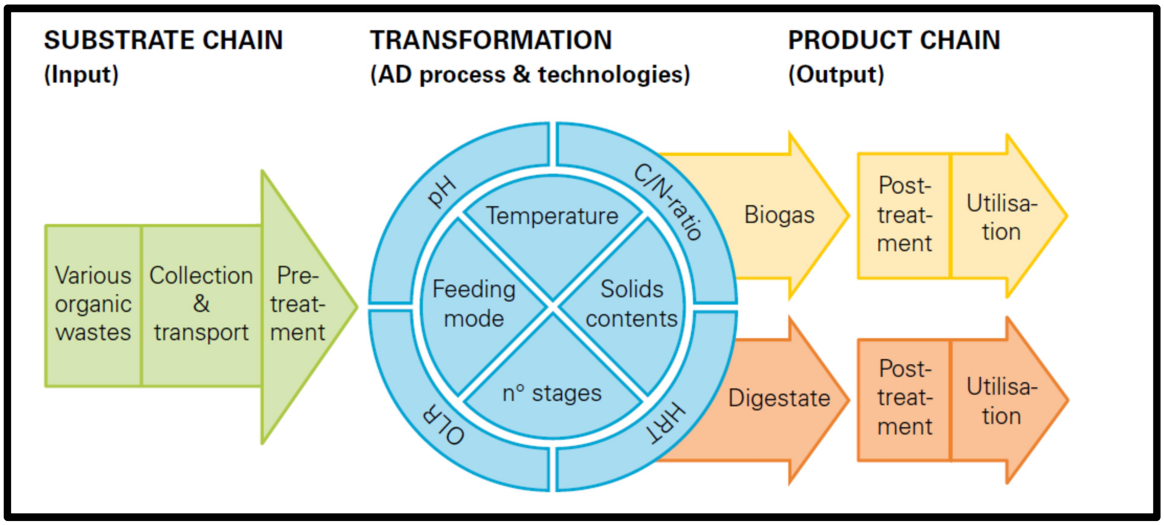


Figure 5.3 – Shows the complete anaerobic digestion process including process and design variables (EWAG, 2014)

5.5. Advantages and Disadvantages

5.5.1. Economic

Advantages

- Anaerobic digesters can be used to make a profit through the production of biogas and digestate.
- It is a cheaper option of waste removal as opposed to incineration
- Waste will always be available to use in an anaerobic digester hence fuel security will be good.

Disadvantages

- Capital and maintenance costs of anaerobic digesters can be high.
- Only large plants are economically feasible due to the large amount of biogas needed to produce sufficient electricity.
- High project failure rate in the past.

(BioProducts Association 2007; Stuart, 2002)

5.5.2. Environmental

Advantages

- Anaerobic digestion is a renewable energy source.
- Use of this technology will lead to a cleaner environment as it will remove waste normally diverted to a landfill.
- Nutrient rich solids left can be processed into fertilizer.
- In the anaerobic digestion process, pathogens are killed and hence diseases do not spread to animals, plants and humans.
- Less nitrate removal.
- Carbon saving.
- The biological processes in AD also kills any seeds in the feedstock which eliminates the spread of weeds, alien and invasive species of plants.
- Rodent control is better than in other forms of disposal such as the collection of waste for landfills.
- Waste going through a digester removes harmful material that could pollute water supplies if it had been through waste in a landfill.

Disadvantages

- AD also produces emissions that can be harmful to the environment and humans and thus needs to be controlled.

(BioProducts Association 2007; Stuart, 2002)

5.5.3 Technical

Advantages

- Low sludge production occurs in the process.
- Biogas is produced during the process that can be used to generate electricity
- Decentralised electricity.
- Consistent power can be generated and the plant would not be dependent on Eskom's national grid. The plant would also not be affected by load shedding.
- Produces a physical fuel that can be stored and used during high peak demand time.

Disadvantages

- There is risk of fire and explosion on the plant due to the biogas, however this occurs at all biogas production plants.
- Process is highly sensitive to changes in condition such as temperate and pH. This would need to be managed very carefully in order for the digester to work properly.
- Running of the plant is a complicated process and needs to be run by trained specialists. The cost of which further drives up the maintenance costs.
- The operation and maintenance of the anaerobic digestion plant is extremely time consuming.
- Hydrogen sulphide produced with the biogas is extremely corrosive and noxious and needs to be removed before being used in a generator.
- Moisture present in the biogas reduces its calorific value and hence the generator's performance.
- Large plots of available land are needed to construct the digesters, but this will be dependent on the type of system used, i.e. the number of tanks.

(BioProducts Association 2007; Stuart, 2002)

5.5.4. Social

Advantages

- The establishment of an AD plant will create a good environmental image for the operators.
- Less smell - up to 80% less than other disposal methods such as landfills.
- New jobs will be created in its construction, maintenance and operation.

Disadvantages

- Noise pollution will occur from the generators, pumps and compressors all needed in the operation of an AD plant
- The digester components will create a visual impact on the surrounding area. Large digester tanks will create a contrast with the rest of the area.
- Vehicle movement will cause an undesirable impact on surrounding communities, roads will be degraded from the increased loads from the trucks transporting waste and noise will also be generated from the continuous movement of the vehicles.

(BioProducts Association 2007; Stuart, 2002)

5.6. Chapter Summary

Anaerobic digestion is a biological process that uses organic waste to produce renewable energy in the form of biogas. The use of biogas to produce electricity reduces the dependency on fossil fuels.

The energy generated from anaerobic digestion is not sufficient to power an entire town or city however; it can be viewed as an additional form of renewable energy.

Digestate produced from the process of anaerobic digestion can also be used to generate an additional income through the sale of it as a soil conditioner or fertilizer.

Anaerobic digestion also diverts waste from landfills thus reducing ground contamination and odours. These two characteristics of landfills can be viewed as the most destructive.

Anaerobic digestion facilities provide many advantages however they require a significant capital investment, whilst landfilling is still considered the most cost effective method of waste disposal (Ostrem, 2004).

Anaerobic digestion was evaluated due to the successful diversion of the biogenic fraction from the waste stream. The advantages and disadvantages discussed the potential use of AD as a viable strategy that can be used in South Africa and evaluated with the WROSE decision making tool. Once again, the process of the strategy was researched in order to develop an overarching background to the strategy. AD process and design variables were discussed in order to determine potential indicators that can be used to evaluate other strategies

Chapter 6 – Aerobic Composting

6.1. Introduction

Aerobic composting is a biological process in which the biological degradation of biogenic waste, in the presence of oxygen, takes place. The process produces carbon dioxide, ammonia, water and humus or compost thus ensuring a stabilisation of the biogenic waste.

Composting is used as a method of disposing of food waste and recycling organic waste in order to improve soil structure and fertility (Li et al., 2013). Importantly the final product is stable, free of pathogens and plant seeds whilst being beneficial when added to the land (Saravannan et al., 2003).

The stable humus like substance that is produced is most commonly used as a soil amendment or as an organic fertilizer (Tiquia, 2010; Coelho et al., 2011; Lashermes et al., 2012). Compost is therefore defined as the solid particulate material, which has been sanitised and stabilised as the result of composting (Haug, 1993; Joint Research Centre, 2008). Compost can be used in a wide array of applications, including landfill cover material and fertilizer for agricultural and horticultural purposes.

Compost improves the physical properties of the soil it is applied to. The soil increases in water content and in the ability to retain water. Furthermore the soils aeration and permeability are increased when compost is applied. The soil is also able to filter water better when compost has been used (Polprasert, 1996).

As with anaerobic digestion, composting uses waste as a resource with the production of compost able to create an income, similarly it satisfies the waste hierarchy and diverts waste away from landfills and aids towards the goal of zero waste

An added benefit of compost usage is that a reduced amount of chemical fertilizers is therefore needed. This chapter will discuss the composting process along with the variables affecting the composting process.

6.2. Aerobic composting process

Composting is a two-stage treatment process for organic waste. Once MSW is collected, it should be sorted and the organic waste should be separated from plastics and metals, and the organic waste can then be shredded to the optimal size. The organic waste may then be composted in open windrows or closed vessels for approximately 4 weeks. During this process, the aeration and moisture content should be controlled (Paul et al., 2007). Following this, the compost should be stored in windrows for two to three months in order to fully mature.

The biological process of aerobic composting consists of four stages: an initial stage where readily degradable organic waste is decomposed; mesophilic and thermophilic stages characterised by large bio-oxidative activity; and lastly a maturation stage in which the humus is produced (Sharma et al., 1997).

The phases have been outlined below and are defined by the respective stages of the temperature range:

Stage 1. Latent/initial phase: this initial phase allows for the micro-organism population to grow, adapt and acclimatise to the existing environmental conditions.
Stage 2. Mesophilic growth phase: micro-organism populations continue to increase and grow, as temperatures rise to the mesophilic range.
Stage 3. Thermophilic phase: The temperatures increase to the thermophilic temperature range resulting in waste stabilisation and effective pathogen destruction occurring at this temperature.
Stage 4. Maturation phase: biological activity reduces and temperature decreases to the mesophilic range. At this stage the oxygen requirement is lowered and ammonia is converted into nitrates via nitrification. Humificiation which is the production of humus occurs at this stage.

(Polprasert, 1996)

6.3. Composting process variables

6.3.1. Oxygen

Composting is an aerobic process and therefore by definition requires oxygen. The consumption of oxygen is the highest at the beginning and slowly decreases as the process continues to the final product. Reducing the oxygen supply to the compost will slow down the composting process, anaerobic conditions will occur and with it unpleasant odours. If this occurs, anaerobic micro-organisms will form intermediary compounds such as methane, hydrogen sulfide, and organic acids. Physically turning the compost will maintain an aerobic system which will in turn limit odours. An oxygen content greater than 15% is required and excessive temperatures are an indication that the materials are not receiving adequate oxygen.

6.3.2. Temperature

The temperature change is an indicator of the microbial activity occurring during the composting process and consequently can be used to determine at which stage the composting is occurring. Maintaining an optimum temperature of between 50 – 60^{o}C, will allow for quicker and more complete composting to occur (Li et al., 2013). The optimum temperature during the thermophylic stage also significantly affects the ability of the compost to effectively destroy the pathogens present in the compost. Lopez–Real and Foster (1985) determined that only 3 – 4 days at 55^{o}C was needed to effectively kill of any pathogens present. The temperature also influences the decomposition rate of the compost.

6.3.3. Moisture content

Moisture content (MC) content greatly affects the physical and chemical properties of the waste material and it was proved by Liang et al. (2003) that it was the dominant factor affecting aerobic microbial activity. The moisture content is responsible for the transportation of the dissolved nutrients that are required for metabolic activities of the micro-organisms. A high MC, which occurs in food waste, will result in a very long treatment time and a low degradation efficiency. The optimum moisture level for different composting mixtures varies between 50 – 55% (Liang et al., 2003).

6.3.4. pH

Short chained organic acids and ammonia present during the composting process contribute towards the pH variations that can occur in composting (Conghos et al., 2003). A pH of between 6.5 and 8 can be considered optimum (Couth and Trois, 2012). Smars et al. (2002) also conducted composting experiments with organic household waste and found that the highest degradation occurred when the pH was between 6 and 8. A low pH value can prevent microbial activity and hence impede the progress of the composting. Similarly, a high pH can also impede the composting reactions (Li et al., 2013). As a variation of pH affects the composting performance, it is suggested that adding an additive such as fly ash would help in maintaining the pH at a certain level in order to enhance the efficiency of the process.

6.3.5. Carbon/Nitrogen ratio

The Carbon/Nitrogen ratio is extremely significant as these elements are the two most important factors in proper microbial development (Couth and Trois, 2012). The carbon is the main provider of energy to the process whilst the nitrogen produces the protein required for microbial growth (Norbu et al., 2005). A Carbon/Nitrogen ratio of between 25:1 and 30:1 should be achieved for successful composting (Couth and Trois, 2007). However, if the carbon content is excessive, then the rate of decomposition will decrease. Similarly, if the nitrogen content is excessive then the composting pile will release a malodorous smell.

6.3.6. Particle size

Waste should be shredded to reduce its particle size in order to increase the reaction rate, due to the greater surface area available. Shredded waste also allows micro-organisms to digest a larger amount of waste material and increase the growth population rate. Reduction of particle size also results in more heat being produced and this, together with the increased micro-organism growth and reaction rate all improve the overall efficiency of the aerobic composting process. A particle size of between 25 and 75mm was determined to be an optimal size by Tchobanogloues et al. (1993). By shredding the MSW to reduce the particle size, a homogenous mixture is formed which in turn prevents anaerobic pockets forming (Lou and Nair, 2009).

6.3.7. Aeration

Aeration of the waste is required in order for the even and uniform distribution of the micro-organisms and the nutrients available (Tchobanogloues et al., 1993). The aeration allows the waste to be exposed to air, thus minimising the anaerobic reactions and reduces the production of methane. Odours produced by the composting process are also minimised with the use of an efficiently designed aeration system that ensures waste is turned periodically. Odours can also be minimised with the use of bio-filters to filter the air (Ostrem, 2004). A composting summary can be seen in Figure 6.1.

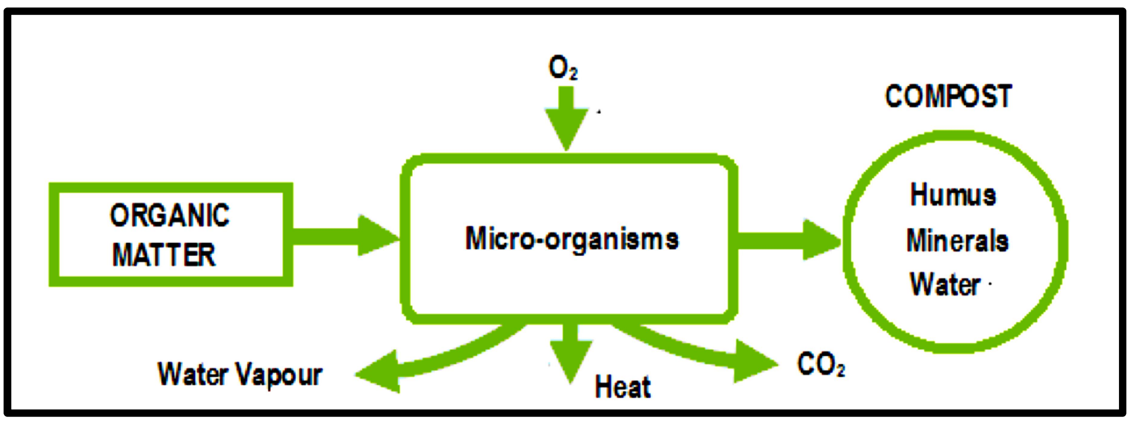


Figure 6.1 – Composting process and variables relationship (Ostrem, 2004)

6.4. Advantages and disadvantages.

6.4.1. Economic

Advantages

- Very little capital and operating costs needed.
- Land required is minimal.

Disadvantages

- Revenue will rarely cover operating costs.
- Difficulty in securing finances due to low income.

6.5.2. Environmental

Advantages

- Increases diversion rate from landfilling as up to 80% of low and medium income waste streams are compostable.
- Provides a valuable soil amendment that is integral in sustainable agriculture.
- Reduces methane generation from landfills.
- Reduces landfill space.
- Climate is optimum for composting in developing countries such as SA.
- Enhances the effect of fertilizers.
- Helps reduce soil erosion when added to soil.
- Viability of weed seeds are reduced.
- Pathogens are destroyed in a properly managed composting system.

Disadvantages

- Nutrient values of compost is significantly lower than chemical fertilizers.
- Highly variable nutrient composition compared to chemical fertilizers.
- Slow release of nutrients does not meet nutrient requirement resulting in nutrient deficiency.
- Long term application of compost results in salt, nutrients or heavy metal accumulation.

6.5.3. Technical

Advantages

- Can reduce transport requirements to landfills as mass and volume are also reduced.
- Flexible in implementation at different social levels – can be applied to households and at municipal levels.
- Improved handling of waste as compost reduces moisture content.

Disadvantages

- Potential problem controlling contaminants i.e. poor feedstock results in poor quality composts.
- Developing and operating successful composting programs is difficult i.e. developing markets and end users.
- Non existing standards for finished compost quality.

6.4.4. Social

Advantages

- Addresses health problems that arise from organic waste such as dengue fever.
- Possible to involve informal waste sector in the collection, separation and composting of waste.
- Creating of jobs from new composting plants.

Disadvantages

- Nuisance potential such as odour and rats possible.

Compiled from research by Hoornweg et al., (2000), Black and Miller, (1998), Finck, (1982), Hoitink and Fahy, (1986), Risse and Faucette, (2000), and US EPA, (1993).

6.5. Chapter Summary

Finding landfill sites is becoming a growing problem in most countries. In addition to the fact that people do not want to live near a landfill, they also occupy valuable land, and require large quantities of loose soil, to cover the garbage received every day (Adhikari et al., 2008). From this the need arises for alternative waste disposal methods, composting being one alternative.

Composting is considered more favourable than landfill disposal and gas collection options, as the waste is converted into a useable product and not left as a burden for future generations (Couth and Trois, 2012).

Composting provides a cheap alternative to anaerobic digestion and landfilling for the biogenic fraction of waste and was thus included in the evaluation of literature review. A basic knowledge of the method is developed throughout the chapter, with the advantages and disadvantages together with the process variables providing prospective indictors to be used in WROSE.

The benefits of composting are vast and include a reduction of waste otherwise destined for landfills, recovery of organic materials and production of soil enhancer and organic fertilizer. A reduction of ground and surface water pollution also occurs when composting is used (Paul et al., 2007). Composting of municipal solid waste does occur in Africa. Garden refuse, which has been separated from the main waste stream, is known to be composted in Cape Town and Johannesburg in South Africa (Coetzee et al., 2007). However, a poor quality of compost is produced as the garden refuse used, often arrives on site contaminated by plastic refuse bags or other waste fractions.

Chapter 7 – Decision Making Tools

7.1. Introduction

This chapter discusses the concepts and methods of decision making tools followed by the various different tools to assist environmental decisions making for municipal solid waste management.

The chapter critically assess decision making tools in order to determine a methodological approach to achieve the aims set out for this study.

These tools for environmental decision making include environmental impact, technology and risk assessment, and life cycle assessment. The chapter concludes with the discussion of the environmental technology assessment tool WROSE, in order to determine the weaknesses and strengths of the tool required for the further development.

7.2. Environmental Decision Making Tools

Three decision support tool methodologies that are commonly used for waste management are discussed below. These are sustainable/environmental technology assessments, environmental impact assessment and life cycle assessment

7.2.1. Sustainable/Environmental Technology Assessment

Sustainable/environmental technology assessment is a method of identifying the potential impacts from the use of new technology (IETC, 2003). An extremely large range of sustainable technology is available for use in waste management, however these technologies are best suited to specific scenarios and situations with the technology selection dependant on the following:

- Socio economic environments
- Culture
- Technical expertise

- Legislation
- Environmental considerations

(IETC, 2003)

This is required as it provides decision makers with a clear understanding of how strategies perform under different conditions. Sustainable technology assessment uses economic, environmental and social indicators to analyse potential options. Sustainable technology assessment allows decisions makers to identify the correct technology needed to satisfy their context. (IETC, 2003)

The international environmental technology centre (IETC) lists the eight functions of sustainable technology assessments, they are as follows:

- "the identification and development of socially desirable and useful technologies;
- support for relevant stakeholders in the creation of their approaches for the development of technologies;
- the assessment at an early stage of possible problems and disadvantageous consequences;
- supporting decision makers by identifying and assessing issues and problems;
- the enlargement of the knowledge base on these technologies, which strengthens policy making related to scientific and technological advancements;
- contributing to long term policies by providing information on possible developments and alternatives;
- promoting accountable and reliable science; and
- promoting public acceptance of technology-related progress"

(IETC, 2003)

7.2.2. Environmental Impact Assessment (EIA)

The US EPA (2010) defines Environmental Impact Assessments (EIA) as

"The process by which the anticipated effects on the environment of a proposed development or project are measured. If the likely effects are unacceptable, design measures or other relevant mitigation measures can be taken to reduce or avoid these effects" (US EPA, 2010)

Decisions are made on the acceptability of the likely impacts. EIA's can be used to determine the impacts on natural resources such as waterways, ecosystems, human health and safety (Maharaj, 2014)

Environmental impact assessments regulations in South Africa fall under sections 24(5) and 44 of the National Environmental Management Act, 1998 (Act No. 107 of 1998).

The EIA process consists of a scoping phase, impact assessment phase, environmental impact report and decision making phase, this is illustrated in Figure 7.1

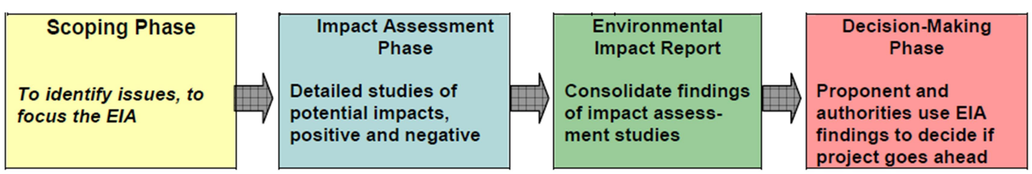


Figure 7.1. – EIA Process (L&W Environmental, 2002)

.

7.2.3. Life Cycle Assessment

Life cycle assessments quantify the consequences of producing and using a product from cradle to grave. LCA are defined in the ISO 14040 and 14044 standards, which outline the different stages of a LCA and how these stages are to be carried out. Similarly to sustainability/environmental technology assessments, LCA's produce quantifiable data, that can be used in determining where large environmental loads occur (Christensen, 2011).

The four iterative stages of LCA are:

1. Goal and scope definition

    This is the first step, and a goal is used to set the scope of the model, and if done correctly, leave no decisions to be made in subsequent stages (Baumann and Tillman, 2004). The ISO standards require that the goal be unambiguous, state the reason for carrying out the study and the intended audience

2. Life cycle inventory analysis

    The analysis consists of three activities

    - Use of the system boundaries from the goal definition to construct a flow chart
    - Collect data for the activities involved in the system, including documentation
    - Calculate the environmental loads of the system

3. Life cycle impact assessment

    The impact assessment translates the loads calculated in the inventory analysis and into environmental impacts grouped into three categories namely, natural resource use, ecological consequences and human health.

4. Interpretation of results and sensitivity analysis

    This phase aims to produce results based on the previous stages. Baumann and Tillman (2004) state that the results can be evaluated through the following checks:

- "Completeness Check - Check for data gaps in the LCI or completeness of the LCIA
- Consistency Check - Check for appropriateness of life cycle modelling and methodological choices
- Uncertainty Analysis - Check for the effect of uncertain data
- Sensitivity Analysis - Identification and check of critical data
- Variation Analysis - Check effect of alternate scenarios and models
- Data quality assessment - Assess the degree of data gaps, approximate and appropriate data"

All the tools discussed above are capable of providing decision making support, however in the South African context only environmental impact assessments are mandatory by legislation, with the other methodologies being used optionally

7.3. Decision Making Tool Alternatives

- **Waste Reduction Model (WARM)**

The WARM model was developed by the US Environmental Protection Agency (EPA) to help solid waste managers to track and report GHG emission reductions. The model calculates GHG emissions for landfilling, landfilling with gas recovery (electricity generation and flaring), recycling, combustion and composting. The model calculates emissions in metric tons of carbon equivalent (MTCE), metric tons of carbon dioxide equivalent ($MTCO_2E$), and energy units (million BTU) across a range of 54 material types. WARM uses GHG emission factors that were developed following a life-cycle assessment methodology. The WARM model is available as a web based interface as well as a Microsoft excel spreadsheet interface and was last updated in March 2015. The Input screen can be seen in Figure 7.2.

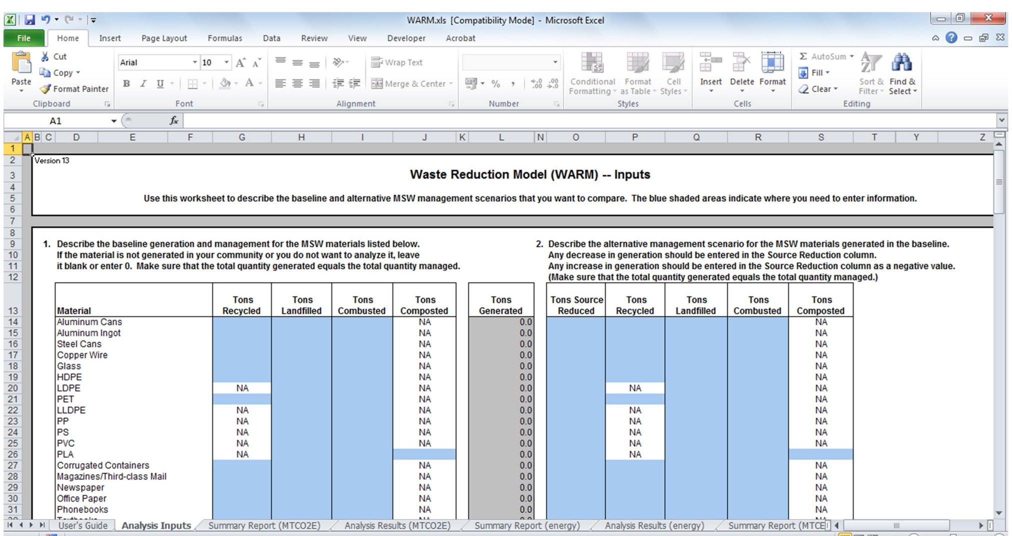


Figure 7.2 – WARM (US EPA, 2015)

- **Environmental Assessment of Solid Waste Systems and Technologies Models (EASEWASTE, EASETECH)**

The Easetech model was developed by the Technical University of Denmark and was based on the previous version called Easewaste, which was released in 2004 and updated to Easetech in 2012. The model aims to perform a life cycle analysis of complex waste management systems. Easetech focuses on material flow modelling, using flow compositions as the basis for the LCA calculations (Clavreul et al., 2013). It is pre-loaded with elemental waste stream databases that are then used to set up scenarios on the graphic user interface. Easetech can be used to evaluate landfills, LFG recovery systems, recycling, anaerobic digestion and aerobic composting. Easetech is not freely available and authorisation for use of the model requires training at the university itself, therefore the model cannot be used. The Input screen can be seen in Figure 7.3.

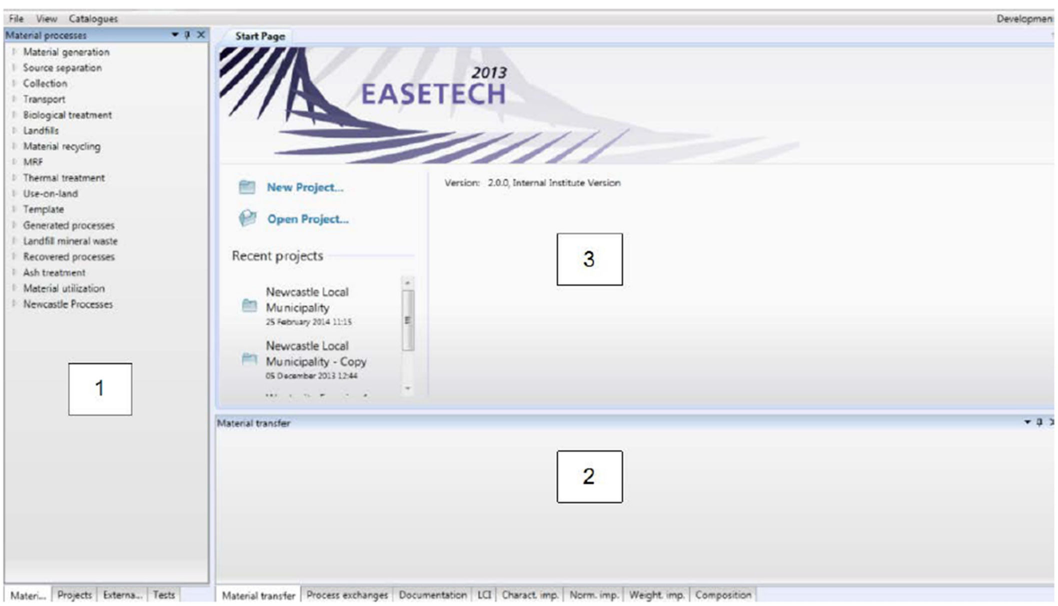
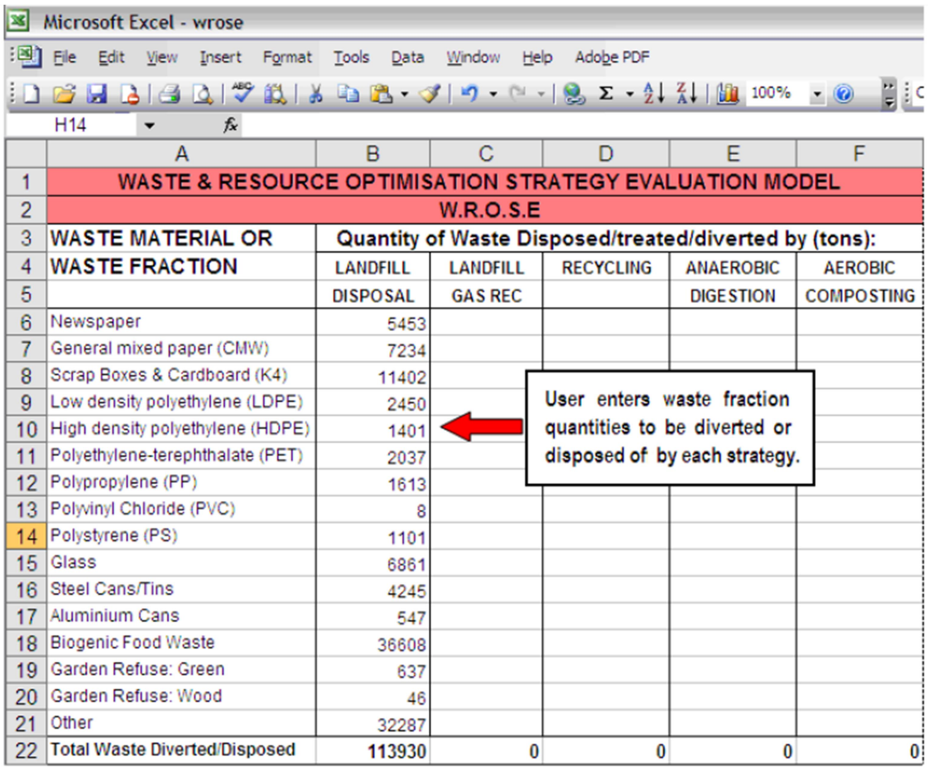


Figure 7.3 – EASETECH (Maharaj, 2014)

- **Waste and Resource Optimisation Scenario Evaluation (WROSE)**

WROSE falls into the category of sustainability/environmental technology assessment tool. WROSE was developed by UKZN to evaluate GHG emissions for various waste management strategies including landfilling, LFG recovery, recycling, anaerobic digestion and aerobic composting. Waste quantities disposed of are input and the GHG emissions and reductions are automatically generated as $MTCO_2eq$. The model uses emission factors developed by the US EPA (2006) and Jagath (2010). Landfill space savings as well as a basic economic evaluation is also included in the model. The WROSE model uses a Microsoft excel spreadsheet interface and was last updated in December 2010. The Input screen can be seen in Figure 7.4.



	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

Figure 7.4 – WROSE (Jagath, 2010)

The WROSE decision making tool was last updated in 2010 and is therefore severely outdate.

- Emission factors used by WROSE to calculate greenhouse gas emissions in metric tons of CO2 equivalents were developed by the US EPA in 2006 and have since been revised and updated to more accurately represent waste management activities
- Emission factors for the South African contexts have also been subsequently released rendering the old WROSE out dated.

- WROSE simply compares CAPEX/OPEX for each strategy without taking into consideration the time value of money and the internal rate of return, this flaw makes WROSE inaccurate in the current waste management climate as valid economic data is required for unambiguous decision making
- Recycling, composting and digestate costs have all changed since 2010 once again causing inaccuracy in the model
- Landfill gas recovery with flaring emission factors have been developed since the last updates. These have been developed for international use and for the South African context.
- Renewable energy feed in tariffs (REFIT) were introduced into SA since the last update further increasing the income that could be possible generated from waste management.

The above points rendered WROSE out dated, and provided a platform for the potential update for the tool.

- **Comparison**

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

- The developer determines if the methodology is from a reputable source.
- Availability of the models and whether they are freely available for public use or the conditions required for their use.
- Scope of the model determines the specific waste management options and strategies that can be evaluated by the model.
- User friendliness of the model and methodology by providing detailed instruction manuals, and online support. User interface can determine the user friendliness.
- Transparency of the model's calculations, emissions factors and other parameters used to quantify GHG emissions.
- Methodology used, for example if life cycle analysis is used in the model.
- The last update, determines if the methodology has not been superseded by newer research and if it is up to current standards.

This comparison can be seen below in Table 7.1.

Table 7.1 – Decision making tool comparison

Model/ software	Developer	Availability	Scope	Interface/ user friendliness	Transparency	Methodology	Last updated
WARM	US EPA	Freely available	AD not evaluated	MS Excel spread sheet, User manual online, support available	Emission factors available from support documents	GHG Emission factors for waste management derived from US emission date	March 2015
Easewaste/Easetech	Technical University of Denmark	Freely available after extensive training at DTU	All major waste management strategies evaluated	GUI, user manual available	Not transparent	Life cycle analysis, using Danish emission data	2012
WROSE	UKZN	Freely available	Landfilling, LFG Recovery systems, recycling AD AC	MS Excel, no manual available	Completely transparent	GHG emission factors for waste management derived from US emission data	December 2010

7.4. Chapter Summary

This chapter is aimed at developing a knowledge of decision making tools in order to determine the best methodology on how to evaluate waste management strategies through the use of these tools.

Three methodologies of assessing waste management were discussed and evaluated namely, Life cycle analysis, Environmental impact assessments and Sustainability/environmental technology assessment. The research further discussed individual decision making tools namely, WARM, EASETECH and WROSE from which a summary on Table 7.1 was compiled. It found that WROSE was the most flexible in terms of development, and completely transparent. The WARM model provided a potential problem with anaerobic digestion not being evaluated. EASETECH although providing all the necessary evaluations was not freely available without intensive training.

As discussed the WROSE decision making tool is out dated, with several components needing replacing. The opportunity also exists to increase the scope of WROSE to include other indicators that can quantitatively assess various waste management strategies. This is discussed further in chapter 8 and 9

Chapter 8 – Methodology

8.1. Introduction

The aims and objectives of this research is to develop a waste management decision making tool able to quantify the environmental, economic, social impacts of zero waste management in order to aid waste managers and engineers. The methodological approach used to achieve the aims and objectives outlined in the first chapter includes the following components:

1) Selection of MSW strategies: the selection of zero waste strategies suitable for MSW management in South Africa

2) Development of waste management scenarios: incorporating these strategiesto form coherent waste management scenarios suitable and applicable for SA.

3) Multi criteria analysis framework: definitions of the sustainability/feasibility criteria and environmental, economic and social indicators.

4) Indicator Assessment Matrix: selection of various indicators that will be used to evaluate the different zero waste scenarios.

5) Case study analysis: the application of the selected indictaors to the case study data.

6) Validation/updating of selected indicators: the methodologies of either updating existing indicators in WROSE or the validation of new indicators to be applied.

7) Development of WROSE Microsoft Excel interface: into a completely integrated user friendly interface.

The following sections details the development of the zero waste model, environmental and economic models and indicator matrix used to evaluate indicator suitability.

8.2. Selection of MSW strategies

A zero waste model has been developed that would simulate several scenarios that may be implemented or are currently implemented at municipal level to effectively divert waste from landfills.

Various waste management strategies were identified and assessed according to their environmental impact, economic feasibility, social implementation ability and institutional and technical feasibility. These strategies presented in Table 8.1 would then be implemented together to form several waste management scenarios.

Table 8.1 – Waste management strategy summary

Waste Management Strategy	EVALUATION CRITERIA			
	Environmental impacts	**Economic feasibility**	**Social Implementation**	**Institutional/ technical feasibility**
Source Separation	Initial separation reduces contamination of other wastes and hence increases the quality of the waste	Economic impact of separate bins, refuse bags and collection services	Public participation required, along with separate bins and refuse bags. Weekly collection services will be required	Technically feasible as source separation of paper is used in most areas of eThekwini
Thermal Treatment	Reduction in emissions through energy recovery. Emission of pollutants and heavy metals occur during thermal treatment	Significant capital investment required	Separation of combustible waste required at either source or after collection	Further research into technologies such as pyrolysis. Not widely implement in SA
Landfilling	Negative impact to the environment. Emissions released to atmosphere and leachate to surroundings	No addition capital required as, it is the current disposal strategy in SA	No public participation needed, as normal unsorted waste can be used	Current disposal strategy in majority of SA

Landfill Gas Recovery	Reduction in emissions through energy production and flaring	Landfill gas recovery systems and electricity generation equipment will be needed	No public participation needed, as normal unsorted waste can be used	Technically feasible as landfill gas recovery has been implement in eThekwini
Recycling	Preserves natural resources. Increases carbon sequestration	Recycled material sold at significant cost compared to virgin material	Public participation will be required if source separation is used. No public participation will be needed if a dirty MRF is used	Incentives to strengthen recycling market. Recycling centres and programs in place currently
Anaerobic Digestion	Reduction in emissions through biogas and energy production. Production of digestate for use as fertilizer and soil conditioner	Significant capital investment	Separation of biogenics required	Legislation and incentives to create market for AD products
Aerobic composting	Production of compost results in reduced use of chemical fertilizers	Capital costs varies depending on type of composting method	Separation of biogenics required	Technically feasible as composting is a well developed process
Material Recycling facility	MRF preserves natural resource if final waste is recycled	MRF capital and operating costs	No public participation is needed if unsorted, untreated waste is used in MRF	Technically feasible as MRF is currently operated in eThekwini

The above assessment was adapted and based on the following sources: Jagath (2010); 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:

1. Landfilling
2. Landfilling with landfill gas recovery through flaring
3. Landfilling with landfill gas recovery through electricity generation
4. Recycling of the recyclable dry fraction through the use of an MRF

5. Anaerobic digestion of the wet biogenic fraction
6. Aerobic composting of the biogenic fraction

Source separation and thermal treatment strategies were not considered for the model as they are not financially feasible in South African municipalities (Douglas, 2007). Thermal treatment also produces pollutants through the treatment of MSW (Smith et al., 2001).

8.3. Development of waste management scenarios

The six waste management strategies were used to develop scenarios that would be used to evaluate the municipalities against environmental and economic indicators. The scenarios for assessment include elements of current waste disposal methods in SA such as landfilling and landfill gas recovery, as well as potential disposal strategies. A summary of the strategies used in each scenario is shown in Table 8.2 and a detailed description is discussed below

Table 8.2 – Scenario Summary

Scenario	Waste Management Strategy					
	Landfill Disposal	Landfill gas recovery/ flaring	Landfill gas recovery/ elec gen	Recycling MRF	Anaerobic Digestion	Aerobic Composting
1	●					
2A		●				
2B			●			
3A			●	●		
3B			●	●		
4			●	●	●	
5			●	●		●

.

8.3.1. Scenario 1: Landfill disposal of unsorted, untreated MSW

This scenario evaluates the status quo at most municipal landfills in South Africa. All MSW is disposed of, untreated and unsorted, into a landfill. Scenario one provides a baseline to compare the efficiency of the other scenarios. Figure 8.1 illustrates a schematic of scenario 1.

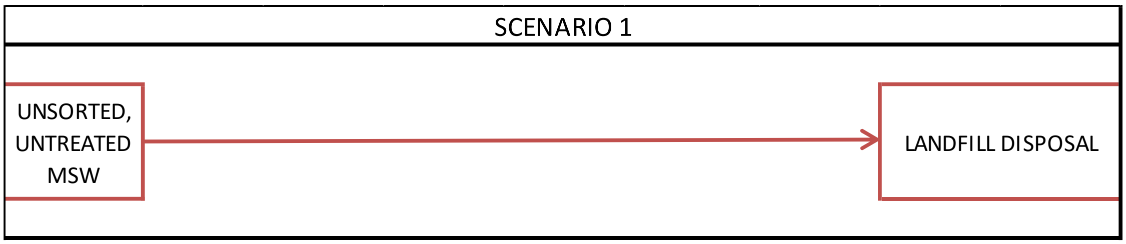


Figure 8.1 – Scenario 1

8.3.2. Scenario 2: Landfill disposal of MSW with gas recovery

Scenario 2 evaluates the effectiveness of landfill disposal with gas recovery systems in place. MSW is disposed of, untreated and unsorted, into a landfill, and landfill gas is produced through the degradation of organic material. Scenario 2A evaluates flaring of the landfill gas whilst 2B evaluates electricity generation from landfill gas. Figures 8.2 and 8.3 show the schematic of scenarios 2A and 2B. These scenarios are the status quo of the landfills in the EThekwini Municipality as mentioned in Chapter 9.

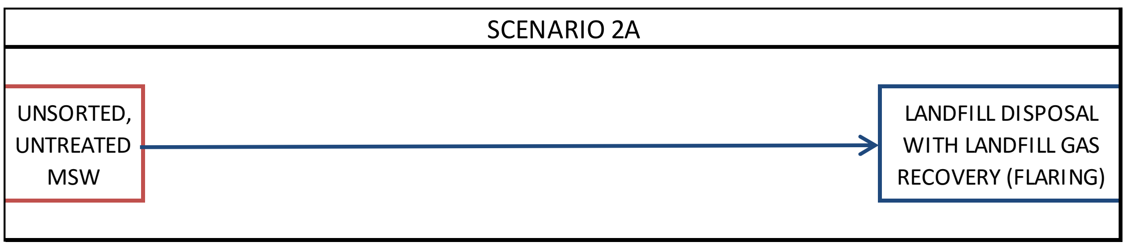


Figure 8.2 – Scenario 2A

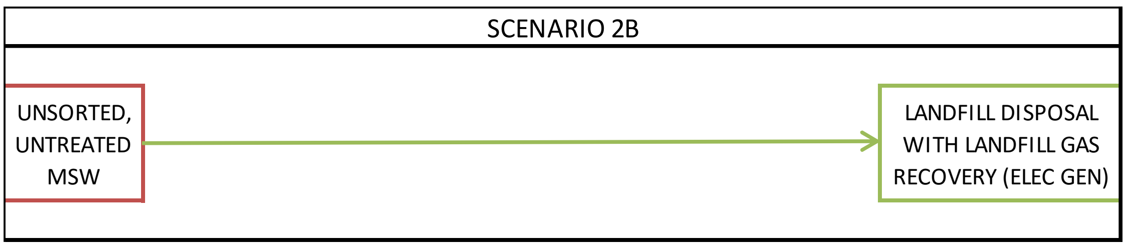


Figure 8.3 – Scenario 2B

8.3.3. Scenario 3: Recycling with landfill gas recovery

Scenario 3 consists of unsorted, untreated MSW being put through mechanical pre-treatment, with the biogenic and residual waste being landfilled (with gas recovery and electricity generation), whilst the recyclable fraction is sold to recycling companies. Scenario 3A evaluates the system with the current recycling recovery rate being applied, whilst scenario 3B uses a potentially achievable recycling recovery rate. In accordance with the Polokwane Declaration, the achievable recycling recovery rate should be an increase of 30% (Austin and Gets, 2009). Figures 8.4 and 8.5 show the schematic of scenarios 3A and 3B.

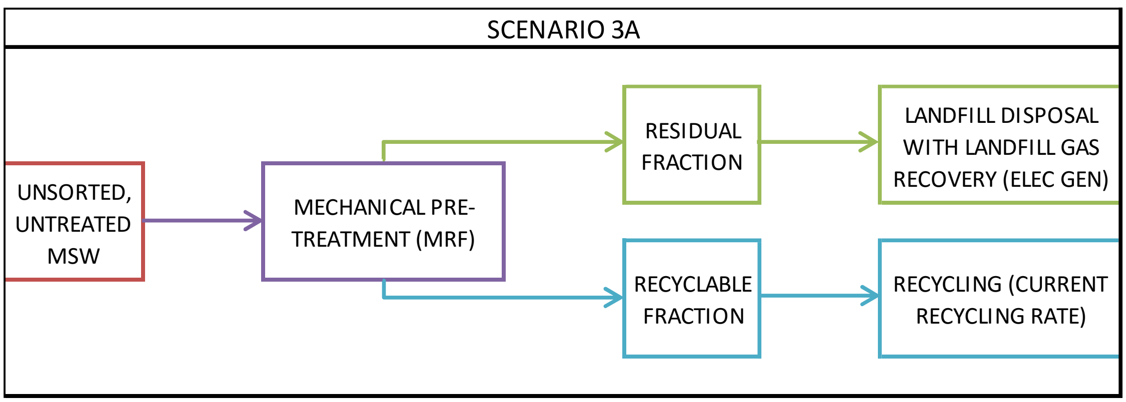


Figure 8.4 – Scenario 3A

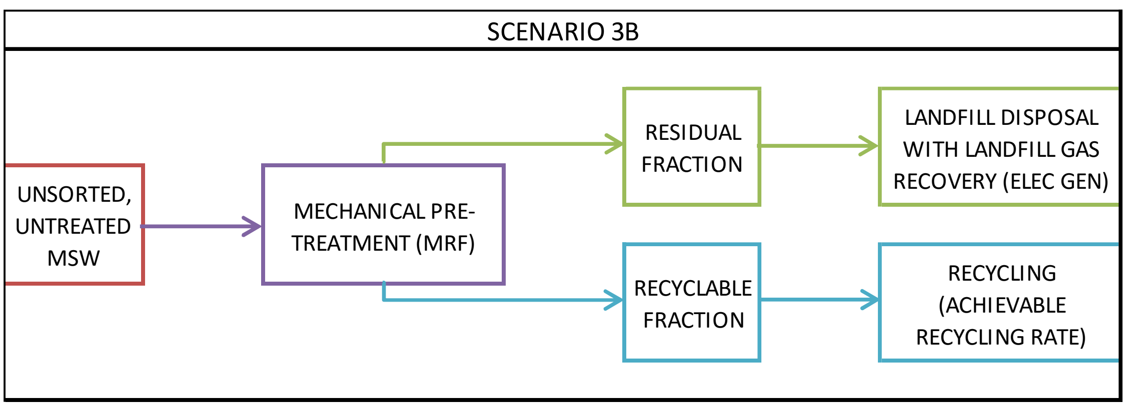


Figure 8.5 – Scenario 3B

8.3.4. Scenario 4: Recycling with anaerobic digestion

Unsorted, untreated MSW is mechanically pre-treated in an MRF with the waste stream being separated into residual, recyclable and biogenic fractions. The residual fraction is then landfilled with a gas recovery system that is used to produce electricity. The recyclable fraction is sorted, baled and sold to recycling companies, whilst the biogenic fraction is anaerobically digested to produces biogas and hence electricity. Figure 8.6 shows the schematic of scenario 4.

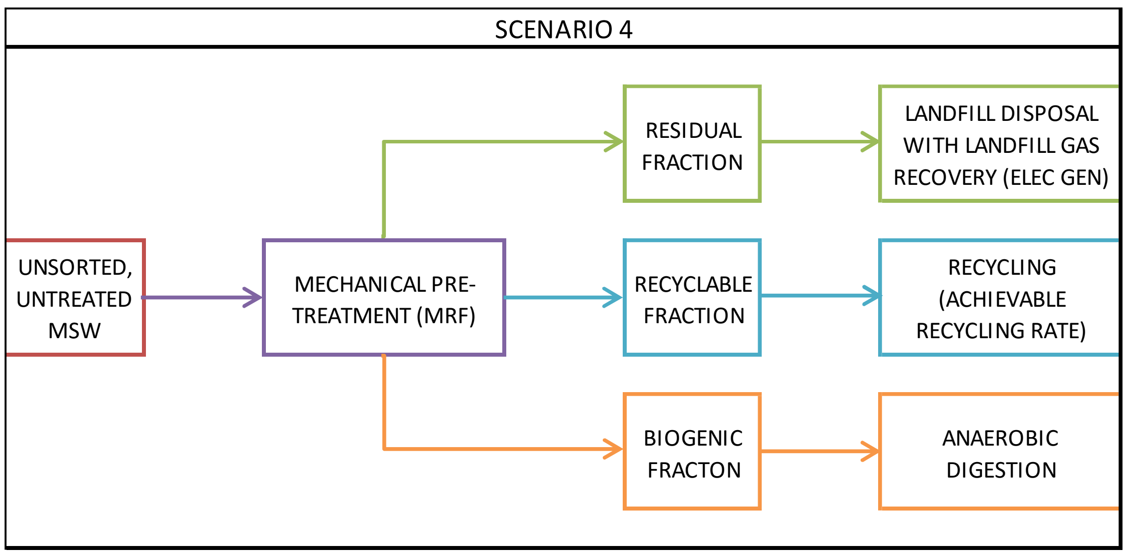


Figure 8.6 – Scenario 4

8.3.5. Scenario 5: Recycling with aerobic composting

Scenario 5 evaluates the use of an MRF to mechanically pre-treat MSW waste. The residual waste is diverted to a landfill with a gas recovery and electricity generation system, whilst the recyclable fraction is sold to private recycling companies. The biogenic waste fraction is aerobically composted which can then be sold to the public. Figure 8.7 shows a schematic of scenario 5.

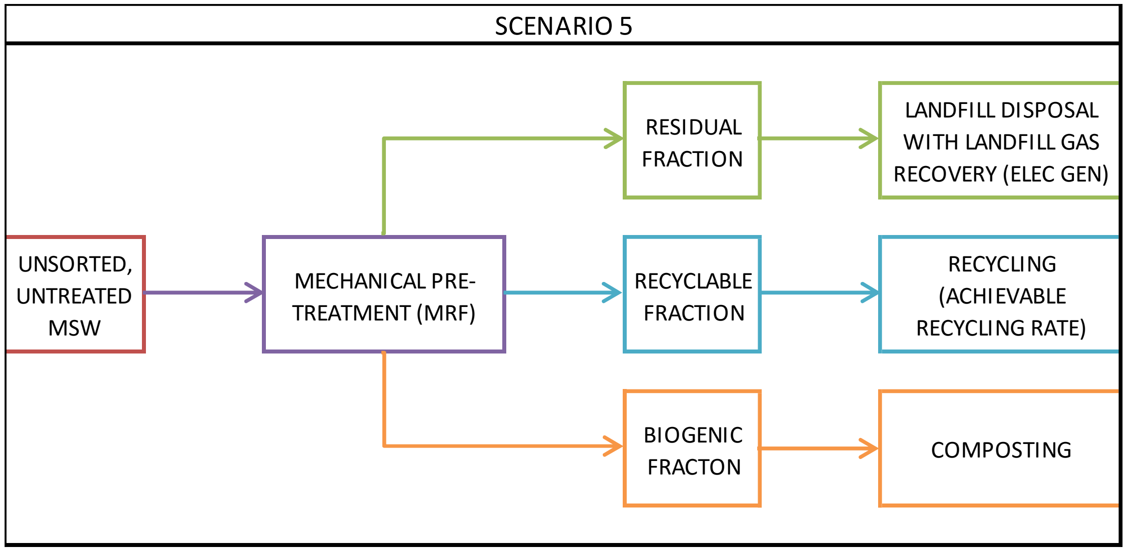


Figure 8.7 – Scenario 5

8.4. Multi Criteria analysis framework

Indicators of sustainability help quantify impacts, whilst also aiding in important decision-making. These indicators are often based on the concept of the "three pillars" of sustainability i.e. environmental, economic, and social (US EPA, 2012).

The WROSE model evaluated five indicators in the previous model, namely greenhouse gas emissions, landfill space savings, capital costs, operating costs and income. The indicators will be used to evaluate the five scenarios explained above, and will then be used to determine the most feasible scenario that can be applied in reality. These indicators address the environmental and economic sustainability. The social aspect of sustainability had not been assessed by WROSE, and therefore it was required to evaluate the potential of other indicators that could be included in WROSE in the future.

There is a range of other significantly important indicators that must be considered when evaluating the sustainability of waste management strategies. The key indicators of sustainability used in the indicator assessment together with their definitions are:

Possible Indicators

Environmental

Global warming potential (MTCO_2eq) – The amount of metric tons of carbon dioxide equivalents i.e. greenhouse gases emitted from the different scenarios.
Landfill Space Saving (m^3) – The amount of space saved through the diversion of waste for scenarios 3 – 5.
Acidification potential (SO_2eq) – used as a measure of terrestrial acidification of the environment through the emission of sulphur dioxide.
Eutrophication potential (NO_Xeq) – quantifies the nutrients enrichment through the emissions of NO_X.
Ozone depletion potential (CFC–11eq) – used as a measure of stratospheric ozone depletion.

Waste Diversion Rate (%) – All waste diverted from landfilling compared to the total amount of waste generated for each scenario.
Water Consumed (litres) – Water used by the different scenarios.
Energy Consumed (GJ/MW) – Energy used by the different scenarios.

Economic

Capital Cost (Rands) – Fixed once off costs incurred to start a project.
Operating Cost (Rands) – Related to the operation of a project in order to maintain its existence.
Income (Rands) – Income generated from each strategy through the sale of compost, electricity and recyclable material.
Financial Sustainability (IRR %) – Long term feasibility, viability and autonomy.
Sensitivity To Variables – Stability of the project when variables are changed.

Social

Jobs Creation – Number of jobs created by implementing the different strategies and scenarios.
Noise Generation (Decibels) – Noise generated from each strategy
Public Acceptance and Social Perception (Qualitative) – perception of people in the case study area that accept and are satisfied with each strategy.
Cleanliness and Smell (Qualitative) – Smell, general cleanliness of the different scenarios.
Social Participation Required (Qualitative) – social participation required for each scenario i.e. source separation, community composting.

The above mentioned waste management indicators were compiled from various studies namely: Baner et al. (2009), Chester et al. (2008), Jagath, (2010), Maharaj (2013), Friedrich, (2013), Matete, (2009), Armijo et al. (2011), Luoranen et al. (2009), Rigamonti et al. (2009) and Villeneuve et al. (2009).

Sustainability/feasibility Criteria

The following is a list of selection criteria that was used to choose sustainability performance indicators. The set of indicators should be:

"Relevant to the interests of the intended audiences, reflecting important opportunities for enhancement of social and environmental conditions as well as economic prosperity.

Meaningful to the intended audiences in terms of clarity, comprehensibility and transparency.

Comprehensive in providing an overall evaluation of progress with respect to sustainability goals.

Transferable, scalable and consistent across different sites or communities and adaptable at regional, state, or local levels.

Practical/Actionable in allowing cost-effective, non-burdensome implementation to address factors.

Intergenerational/Durable, reflecting fair distribution of drawbacks and benefits among different generations whilst having a long term relevance."

(Fiksel, 2009; NRC, 2011)

8.5. Indicator Assessment Matrix

Waste management experts, Dr Alessio Cibati and Dr Elena Friedrich evaluated the indicators of sustainability in a series of semi-formal interviews. Indicators were ranked from 1 to 3 according to the corresponding selection criteria as shown above, with 3 being the best for that criteria.

Following the indicator assessment, and knowledge gaps determined in Chapter 7, global warming potential, landfill space savings, waste diversion rate, capital and operating costs, income, financial sustainability, and sensitivity to variables were chosen to be evaluated with regard to the scenarios. Full results of the indicator assessment can be seen in the Results Chapter.

8.6. Case study analysis

In order to validate the indicators, case studies were used. These were the EThekwini Metropolitan Municipality, Msunduzi Local Municipality and the Newcastle Municipality. Each municipality were used as case studies for different reasons, these are outlined in Chapter 9 Case Study Descriptions. The selected indicators of comparison were then applied to the case study data in the below mentioned methods

8.7. GHG emissions update

The waste management scenarios were firstly evaluated according to the emissions or reduction of GHGs. The GHGs are measured in metric tons of carbon dioxide equivalents ($MTCO_2eq$). GHG emissions of other gases are converted in $MTCO_2$ by multiplying the global warming potential of the particular gas. For example, methane has a global warming potential of 28, and is therefore 28 more times harmful than CO_2.

The challenge of evaluating GHG emissions is that many assumptions are made that are based on factors and conditions that occur throughout the life cycle of discarded waste. Countries such as Australia, United States of America and Canada have calculated and formulated emissions databases and factors for material groups and specific waste management methods that quantify the GHG emissions and reductions (Smith et al., 2001).

Many of the models, databases and factors use Life Cycle Assessment (LCA) principles to quantify emissions and reductions generated throughout a system's life span (Friedrich and Trois, 2010). LCA is a methodology used to evaluate and analyse the environmental impacts of products, processes or systems. These system life spans may include acquisition of virgin materials, manufacturing processes, transportation and distribution through to product use and disposal by the user (Craighill and Powell, 1996).

Models that were identified and evaluated for use in this study were the Waste Reduction Model (WARM), Environmental Assessment of Solid Waste systems and Technologies Models (EASEWASTE) and the Waste and Resource Optimisation Scenario Evaluation (WROSE).

8.7.1. Selected Methodology

Each methodology and model evaluated Chapter 7 had limitations and downfalls. The WARM model did not evaluate anaerobic digestion whilst EASETECH was not freely available. The WROSE model was extremely out-dated and it was necessary for it to be improved. A unique approach was used, where the WROSE model was updated to include new US EPA emission factors and South African emission factors. A new economic analysis was developed for WROSE using a discounted cash flow methodology with updated capital and operating costs and incomes, this can be seen in section 8.10.

8.7.2. US EPA emission factors

An emission factor is a term used to present the amount of GHG's released per unit of energy, mass of volume. The US EPA emission factors are derived using IPCC guidelines, through a streamlined life cycle analysis. The GHG life cycle is considered from the point the waste is discarded by the waste generators, to the point it is disposed of, treated or recycled. Table 8.4 shows the old (2006) and new (2015) US EPA emission factors used in the 2010 and updated version of WROSE.

Table 8.3 – US EPA emission factors (US EPA, 2015)

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL										
W.R.O.S.E										
WASTE MATERIAL OR	US EPA EMISSION FACTOR MTCO2/SHORT TON									
WASTE FRACTION	LANDFILLING		LANDFILL GAS REC/FLARING		LANDFILL GAS REC/ELEC GEN		RECYCLING		ANAEROBIC COMPOSTING	
	2006	2015	2006	2015	2006	2015	2006	2015	2006	2015
newspaper	0.48	-0.21	0	-0.73	-1.18	-0.94	-2.8	-2.75	0	0
general mixed paper (CWM)	1.35	1.59	0	0.4	-0.47	-0.1	-3.54	-3.53	0	0
scrap boxes and cardboard (K4)	1.49	1.68	0	0.46	-0.46	-0.08	-3.11	-3.12	0	0
low density polyethylene (LDPE)	0.04	0.04	0	0.04	0.04	0.04	-1.71	-1.71	0	0
high density polyethelene (HDPE)	0.04	0.04	0	0.04	0.04	0.04	-1.4	-0.88	0	0
Polyethelene terephthalate (PET)	0.04	0.04	0	0.04	0.04	0.04	-1.55	-1.13	0	0
polypropylene (PP)	0.04	0.04	0	0.04	0.04	0.04	-1.52	-1.52	0	0
polyvinyl chloride (PVC)	0.04	0.04	0	0.04	0.04	0.04	-1.52	-1.52	0	0
polystyrene (PS)	0.04	0.04	0	0.04	0.04	0.04	-1.52	-1.52	0	0
glass	0.04	0.04	0	0.04	0.04	0.04	-0.28	-0.28	0	0
steel cans/tin	0.04	0.04	0	0.04	0.04	0.04	-1.8	-1.81	0	0
aluminium cans	0.04	0.04	0	0.04	0.04	0.04	-13.67	-9.11	0	0
biogenic food waste	1.43	1.54	0	0.64	0.16	0.43	0	0	-0.2	-0.15
garden refuse green	0.06	-0.16	0	-0.49	-0.62	-0.57	0	0	-0.2	-0.12
garden refuse wood	0.07	-0.26	0	0.64	-0.93	-0.82	0	0	-0.2	-0.12
other	0.04	0.04	0	0.4	0.04	0.4	0	0	0	0

The US EPA emission factors work with the imperial system of units and therefore waste quantities need to be input as short tons. One short ton is equal to 2000 pounds or 0.907 metric tons. It should also be noted that a negative emission factor indicates a net reduction in emissions whilst a positive value indicates a net emission of GHGs.

8.7.3. Anaerobic digester factors

The GHG emission factors for anaerobic digestion was taken from work completed by Jagath (2010) titled "An assessment of carbon emission reduction potential through zero waste activities in South African municipalities". Although the emission factor for AD has been obtained from a different source, it has been determined using the same principles of life cycle analysis and IPCC guidelines for GHG accounting used by the US EPA in determining their emission factors.

The emission factor was based on emissions including direct emissions from the process; energy emissions during operation of the plant; collection and transportation of the waste to the AD plant; and emissions from the digestate produced (Jagath, 2010). The resulting factor is shown in Table 8.5.

Table 8.4 – AD emission factor (Jagath, 2010)

Parameter	Calculated factor ($MTCO_2EQ/TON$)
Direct emissions	+0.0011
Energy emissions	- 0.23157
Transportation emission factor	+0.0030
Digestate emission factor	- 0.0443
Resultant emission factor	**- 0.2718**

GHG emission savings and reduction are due to energy recovery and the generation of electricity as well as the substitution of inorganic fertiliser by compost (Jagath, 2010). The modelling process requires the wet weight to be entered into the WROSE model, therefore, $0.6m^3$ of water per ton of the biogenic fraction was assumed (Jagath, 2010).

Typical anaerobic digestion factors derived from various factors are compared below in Table 8.6. It shows that the Jagath (2010) emission factor falls well within the range of the other values.

Table 8.5 – AD emission factor comparison (Jagath, 2010)

Source		**Emission factor $MTCO_2EQ/TON$**
Anaerobic digestion and digestate use: accounting of GHG's and global warming contribution	Moller et al. (2009)	- 0.375
Potential for GHG abatement from waste management and resource recovery activities in Australia	Wamken ISE (2007)	- 0.8856
Determination of the impact of waste management activities on GHG emissions	ICF Consulting (2005)	- 0.1
Waste management options and climate change	Smith et al. (2001)	- 0.165
An assessment of carbon emission reduction potential through zero waste activities in South African municipalities	Jagath (2010)	- 0.2718

8.7.4. South African Emission Factors

Emission factors are increasingly being used to calculate the GHG emissions from the waste sector, however these factors are calculated for developed countries and are lacking for developing countries such as South Africa. Friedrich and Trois (2013) developed emission factors for the landfilling, recycling and composting of municipal solid waste in South Africa and are seen in Table 8.7.

The development of the South African emission factors was based on a carbon balance approach and was performed by conducting a series of streamlined life cycle assessments for each of the waste management strategies.

Table 8.6 – South African Emission factors (Friedrich and Trois, 2013)

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL						
W.R.O.S.E						
WASTE MATERIAL OR WASTE FRACTION	SOUTH AFRICAN EMISSION FACTORS MTCO2EQ/TONS					
	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper	1.0163	0.1012	-0.1445	-1.6103	0	0
general mixed paper (CWM)	1.0163	0.1012	-0.1445	-0.5685	0	0
scrap boxes and cardboard (K4)	1.0163	0.1012	-0.1445	-0.5177	0	0
low density polyethylene (LDPE)	1.0163	0.1012	-0.1445	-0.8594	0	0
high density polyethelene (HDPE)	1.0163	0.1012	-0.1445	-0.7194	0	0
Polyethelene terephthalate (PET)	1.0163	0.1012	-0.1445	-1.8324	0	0
polypropylene (PP)	1.0163	0.1012	-0.1445	-0.7894	0	0
polyvinyl chloride (PVC)	1.0163	0.1012	-0.1445	-0.98	0	0
polystyrene (PS)	1.0163	0.1012	-0.1445	-0.98	0	0
glass	1.0163	0.1012	-0.1445	-0.2901	0	0
steel cans/tin	1.0163	0.1012	-0.1445	-2.5869	0	0
aluminium cans	1.0163	0.1012	-0.1445	-19.1107	0	0
biogenic food waste	1.0163	0.1012	-0.1445	0	-0.27184	0.185
garden refuse green	1.0163	0.1012	-0.1445	0	0	0.185
garden refuse wood	1.0163	0.1012	-0.1445	0	0	0.185
other	1.0163	0.1012	-0.1445	0	0	0
Ethekweni Collection and transport EF	0.01134					
Msunduzi Collection and transport EF	0.01026					
SA AVG (Newcastle) Collection and transport EF	0.0146					

The calculations to determine the total metric tonnes of CO_2 equivalents can be seen below

Landfilling and landfilling with gas recovery (flaring and electricity generation)

Landfilling with and without gas recovery systems requires a transportation emission calculation to be determined along with the individual waste fraction emissions. The total emissions resulting from landfilling will be the sum of the transportation emissions and the individual waste fraction emissions. Transportation emission factors vary with each municipality, and are shown in Table 8.7.

Transport Emissions = Total Waste Quantity (tons) x transport factor ($MTCO_2eq$/ton)
Individual waste fractions = total waste quantity (tons) x waste composition (%)
Individual waste emissions = Individual waste fractions (tons) x landfilling emission factor ($MTCO_2eq$/ton)

Total emissions ($MTCO_2eq$) = Transport Emissions + Individual waste emissions

Recycling, composting, anaerobic digestion

The recycling, composting and anaerobic digestion emission factors have transportation emission factors incorporated into them, and therefore do not require this additional calculation. However the AD emission factor requires a wet waste quantity, and this calculation is shown below.

Individual Recycling fractions (tons) = total waste quantity (tons) x recycling rate (%) x waste composition (%)
Individual AD fraction (tons) = (total waste quantity x 1.6) x waste composition (%)
Individual AC fraction (tons) = total waste quantity (tons) x waste composition (%)

Total waste emission ($MTCO_2eq$) = Individual waste fractions (tons) x Recycling/AD/AC emission factor (MTCO2eq/ton)

8.8. Landfill space savings update

Landfill space saving calculations can be used to determine the amount of air space that is saved through the diversion of waste by recycling, composting and anaerobic digestion. The WROSE model uses two different methodologies to empirically calculate the landfill space savings that occur from waste diversion. The site conditions, degree of compaction and efficiency of the compaction effect the actual airspace saved. Due to these variables, two different methodologies were decided upon. As used above an internationally recognised methodology developed by the US EPA was used as well as a South African methodology.

8.8.1. US EPA Landfill Density Factors

The US EPA methodology provides density factors for a wide range of waste materials that can be diverted from landfills and hence save airspace and extend the life span of the landfill. Table 8.8 shows the landfill density factors used in the WROSE model, include the US EPA factors.

Table 8.7 – US EPA landfill density factor (US EPA, 2015)

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E			
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)		
WASTE FRACTION	MIXED MSW DENSITY (TONS/M3)	US EPA LANDFILL DENSITY FACTORS (LB/CU)	US EPA LANDFILL DENSITY FACTOR (TONS/M3)
newspaper	1.2	800	0.4744
general mixed paper (CWM)	1.2	800	0.4744
scrap boxes and cardboard (K4)	1.2	800	0.4744
low density polyethylene (LDPE)	1.2	670	0.39731
high density polyethelene (HDPE)	1.2	355	0.210515
Polyethelene terephthalate (PET)	1.2	355	0.210515
polypropylene (PP)	1.2	355	0.210515
polyvinyl chloride (PVC)	1.2	185	0.109705
polystyrene (PS)	1.2	1015	0.601895
glass	1.2	2800	1.6604
steel cans/tin	1.2	560	0.33208
aluminium cans	1.2	250	0.14825
biogenic food waste	1.2	2000	1.186
garden refuse green	1.2	1500	0.8895
garden refuse wood	1.2	1500	0.8895
other	1.2	1500	0.8895

The US EPA landfill density factors are expressed in pounds per cubic yard. 1 pound per cubic yard = 0.59327 kg/m^3 was used to convert to metric units.

Individual waste fraction (tons) = total waste fraction (tons) x waste composition (%)
LSS (m^3) = individual waste composition (tons) x US EPA Landfill density factors (Tons/m^3)

8.8.2. Mixed MSW Density Methodology

Matete (2009) approximated the LSS for various zero waste scenarios by dividing the total waste quantity of waste diverted by the compacted density of mixed MSW. This methodology uses a single value for the density of waste as opposed to the US EPA methodology that has multiple values for each waste fraction. This methodology can be explained by the equation below

LSS (m^3) = Total waste quantity diverted (tons)/ Average compacted density of mixed MSW (tons/m^3)

The compacted density of mixed MSW is approximated to be 1.2 tons/m^3 (SKC engineers, 2004).

8.9. Landfill diversion rate validation

The landfill diversion rate was approximated by calculating the total amount of waste diverted from landfilling divided by the total amount of waste entering the waste stream. The diverted waste could be due to waste being diverted to recycling, anaerobic digestion, composting or a combination thereof. The calculation can be seen below:

Diversion rate (%) = Total quantity of waste diverted (tons) / total quantity of waste entering waste stream (tons)

8.10. Economic analysis and validation

8.10.1. Capital and Operating costs and Income

8.10.1.1 Landfilling with gas generation

Disposal costs in landfills vary with the amount of waste being disposed, yet landfilling is still the least expensive method of disposal (Smith et al., 2001; Ostrem, 2004). SKC Engineers (2002) found the actual operating cost of landfill disposal to be between R150 – R180/m^3. This is equivalent to an average cost R138/ton of waste.

Capital and operating costs of landfilling were not included in the economic analysis as it was considered the base scenario and all infrastructure was expected to be existing. However the capital and operating costs for landfill gas generation systems was evaluated. Parkin (2011) produced capital and operating costs for landfill gas recovery systems based on the eThekwini landfill gas to energy project for the Mariannhill and Bisasar Road landfills. Capital costs were found to be R11million per 1MW whilst operating costs are R1.1 million per 1MW per year. The Mariannhill landfill operated a 1MW system and processed 450 tons refuse per day with a peak of 700 tons/day.

Based on the renewable energy feed in tariff (REFIT) stipulated by the National Electricity Regulator of South Africa (NERSA), the sale price of electricity amounts to R0.90/kWh for landfill gas recovery systems.

8.10.1.2. Material recovery facility

The throughput capacity of MRF's were calculated directly from the WROSE inputs of tonnage values and recycling rates. The capital costs and operating costs were then approximated using work completed by Chang et al. (2005). The study produced a linear relationship between the capital and operating costs and the design capacity (tons per day) which can be calculated from throughput. This is shown in Figure 8.8.

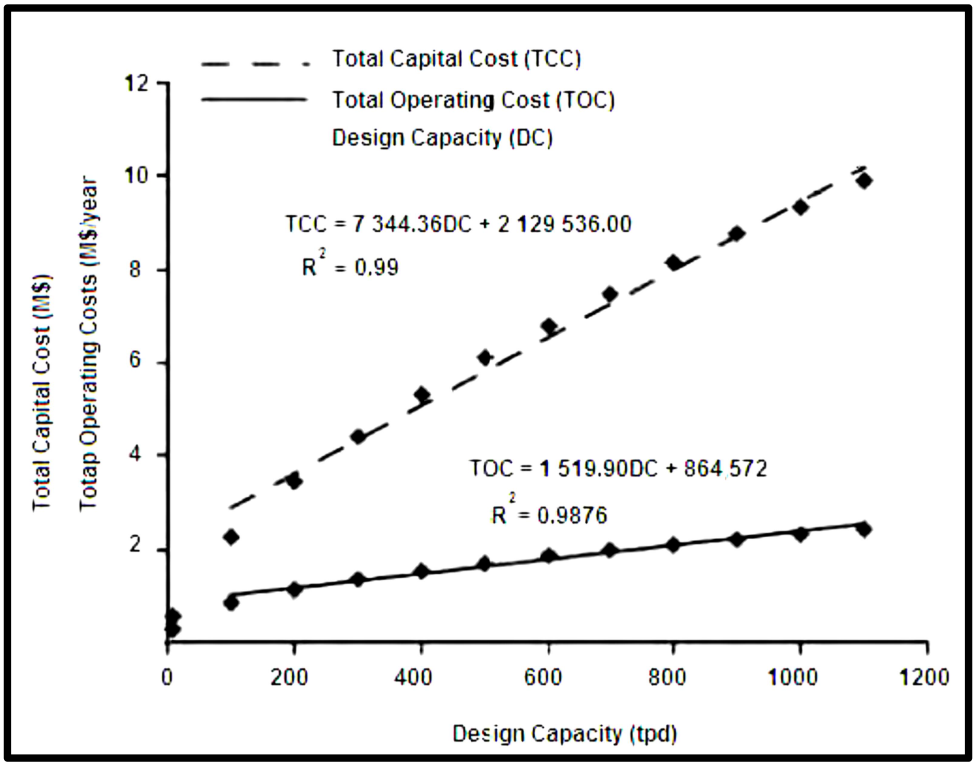


Figure 8.8 – MRF cost curves (Chang et al., 2005)

Sale of these recyclables to local recycling companies would then provide the income for the project and would have to offset the capital and operating costs. The sale prices of recyclables were required to be updated from the old version of WROSE. Original values were sourced from GreenEng (2010) and City of Cape Town IWMP (2004) and can be seen in Table 8.8. The updated values were sourced from a local company, Sibanye Recycling and can also be seen in Table 8.8. The old and new values were found to be very similar although they were taken 5 years apart. It also showed in both cases that recycled plastics provided the greatest income per ton of material.

Table 8.8 – Recyclable income costs

	Green Engineering (2010)	Sibanye Recycling (2015)
	Sale price/ton	**Sale price/ton**
Newspaper	R 500	R 400
CWM	R 500	R 100
K4	R 600	R 500
LDPE	R 1 500	R 2 500
HDPE	R 2 700	R 2 500
PET	R 2 500	R 1 500
PP	R 2 000	R 3 500
PVC	R 1 000	R 1 500
PS	R 1 000	R 1 500
Glass	R 380	R 380
FE Cans	R 1 060	R 1 000
AL Cans	R 1 060	R 4 000

Using the capital and operating costs, and the income generated, the internal rate of return (IRR) would then be calculated to determine if the project would be feasible. Alternatively, in another scenario, the selling price of the recycled material could be set at a specific level in order to meet the required IRR for a viable project.

Using this information a completely integrated economic methodology was developed for WROSE, where the values input earlier (waste tonnages, recycling rates) in the evaluation were then used to calculate the economic feasibility for a MRF without additional inputs.

8.10.1.3. Anaerobic digestion

Rapport et al. (2008) produced capital and operating cost curves from data by Tsilemou et al. (2006) and Clark et al. (2000). These graphs are illustrated in Figure 8.9 and Figure 8.10. Tsilemou et al. (2006) evaluated the capital and operating costs of 16 different anaerobic digestion plants (AD), whilst Clark et al. (2000) based their analysis on seven AD plants. The coefficient of determination (R^2) is also shown for the data, with the data from Tsilemou et al. (2006) providing a high R^2. For this reason, the regression lines for Tsilemou et al. (2006) were used to approximate the capital and operating costs.

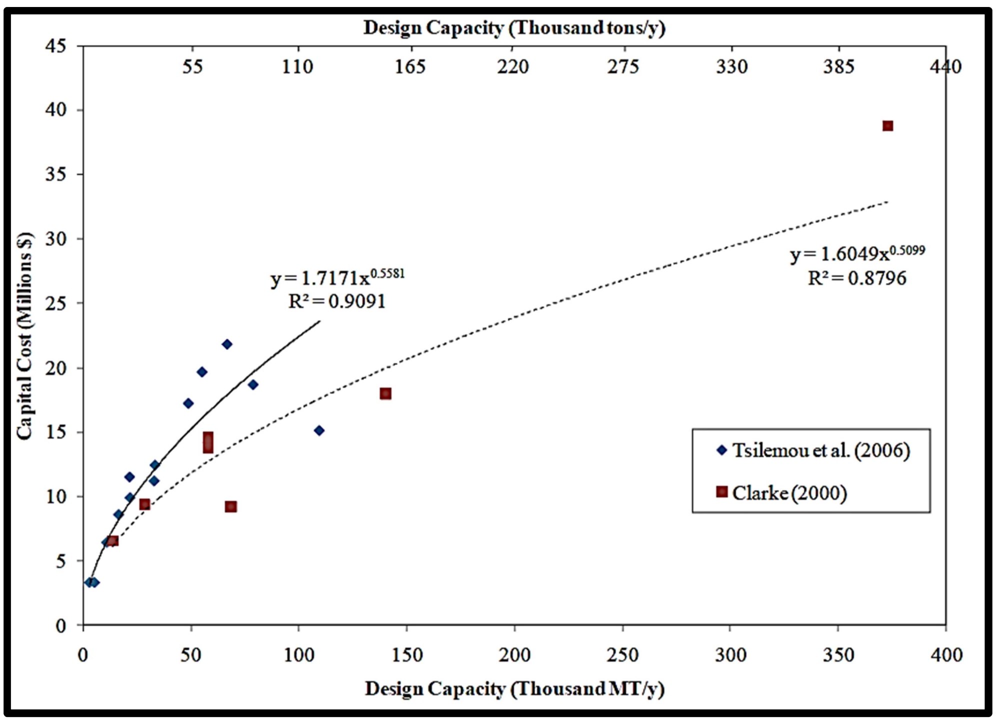


Figure 8.9 – AD capital costs (Rapport et al., 2008)

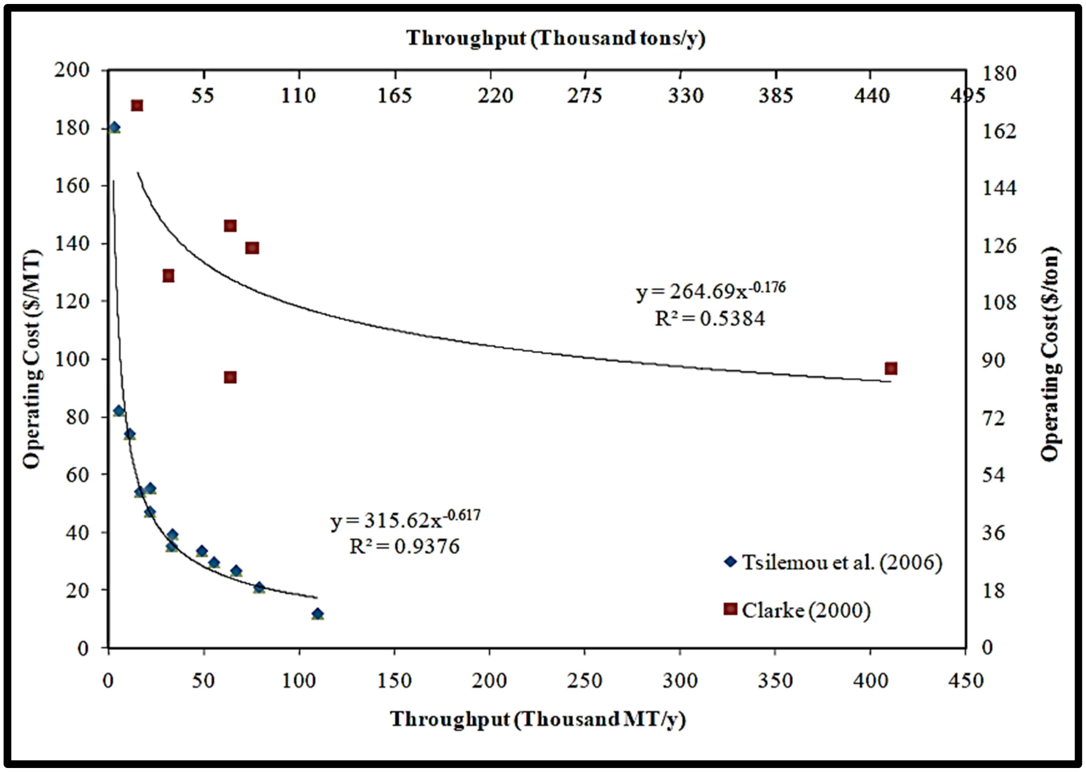


Figure 8.10 – AD operating costs (Rapport et al., 2008)

Income from AD can be generated through the sale of electricity and digestate. Figure 8.11 shows the methodology used to determine the sizing of the generator needed for the AD. The generator sizing would allow the amount of electricity available to sell and use to be determined. The amount of dry feedstock/year that is entered into WROSE is then converted to wet feedstock/day. SGC (2012) provides biogas data for various substrates including food waste, which delivers 204m^3 of biogas/ton of wet waste. This allows the amount of biogas per day to be calculated.

Moller et al. (2009) stated that biogas has a calorific value of 23MJ/m^3. Using the conversion of 1kWh = 3.6MJ and the fact that gas to electricity generators have an efficiency of 40% (Moller et al., 2009), it resulted in 2.56kWh of electricity per m^3 of biogas being produced.

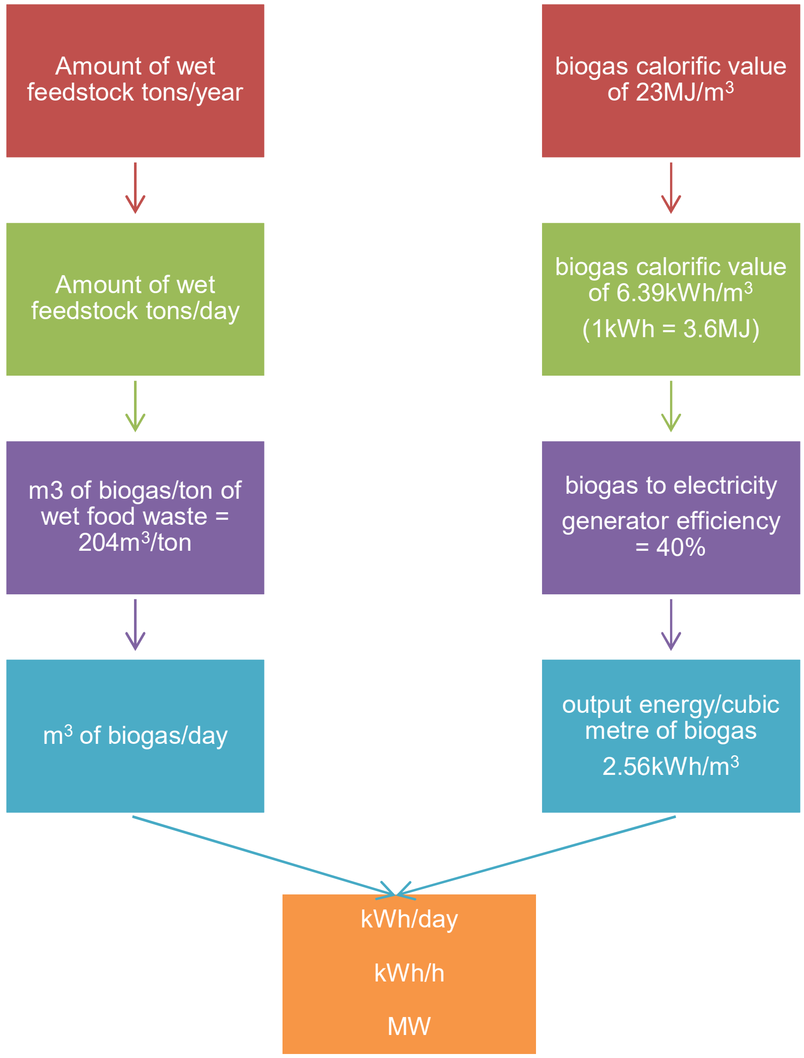


Figure 8.11 – AD calculations

A compost degradation factor of 0.6 was used to determine the amount of digestate that would be produced from the AD process and hence would be available to sell and generate an income. The price of digestate can range from R200 to R100 per ton. Based on the renewable energy feed in tariff (REFIT) stipulated by the National Electricity Regulator of South Africa (NERSA), the sale price of electricity amounts to R0.96/kWh for biogas projects.

Once again the above methodology was used to create a completely integrated system that could be implemented into WROSE where the initial input of waste mass is all that is need to calculate the capital and operating costs and income generated from the sale of electricity and digestate.

8.10.1.4. Aerobic composting

Moodley (2007) extensively studied the capital and operating costs of dome aeration technology (DAT) composting facilities in South Africa. Capital costs amounted to ± R2 million for a shredder able to process 180 tons/day. Operating costs accounted for miscellaneous materials, labour, a front end loader, water and packaging, which amounted to approximately R152.05/ton. The National Organic Waste Composting Strategy developed by the Department of Environmental Affairs (2013) also provides a comprehensive costing for a composting plant, with prices for labour and equipment very similar to Moodley (2007).

The sale of the compost would be required to generate an income and be sufficient to offset the capital and operating costs. The City of Cape Town IWMP (2004) provided a sale price of R250/ton of compost, whilst Lorenco (2007) provided a price of R280/ton. Reliance Composting (2015) provided sale prices for compost in South Africa with compost that has a particle size not exceeding 50mm costing approximately R308/ton and 30mm compost costing R391/ton.

A compost degradation factor of 75% was used to determine to amount of compost available to sell from the original organic waste quantity (Douglas, 2007).

8.10.2. Financial sustainability

Previously WROSE calculated the capital and operating costs, and the income of waste management strategies without taking into consideration the time value of money, the long term economic sustainability and financial autonomy. A discounted cash flow analysis was introduced into WROSE to evaluate potential projects using the concept of time value of money over a varied period.

The internal rate of return (IRR) is defined as the interest rate at which the benefits are equivalent to the costs. Three scenarios develop from the discounted cash flow analysis using the IRR. Scenario 1 is where the sale price of electricity, digestate, compost and recyclables is set at the sale prices acquired, and the IRR is determined to either be negative (not feasible) or positive (feasible). Scenario 2 occurs where the income variables are varied in order to determine the break even point of the analysis, i.e. where IRR = 0. Scenario 3 occurs where the income variables are varied in order to meet the weighted average cost of capital (WACC) calculation.

The weighted average cost of capital (WACC) is the rate the company is expected to pay to satisfy its creditors, owners and other providers of capital. It takes into account the cost of debt and the cost of equity in the same ratio as the debt to equity ratio. This calculation can be seen in Appendix D.

As discounted cash flows are always estimates, the results needs to be checked for a sensitivity to variables. The most important sensitivity analysis is the break even case which returns an IRR = 0. Using the break even case, a “spider diagram” is produced where various variables are altered to establish their sensitivity to the IRR. The spider diagram highlights the critical variables that affect the IRR the most.

8.11. WROSE Microsoft Excel Interface Development

The final step of the methodology was to apply all previous stages to develop WROSE into a single coherent Microsoft Excel interface. The formula function of Excel was extensively used to store the often complex emission calculations and formulas. Excel was also used due to its ability to create graphs from inputted data.

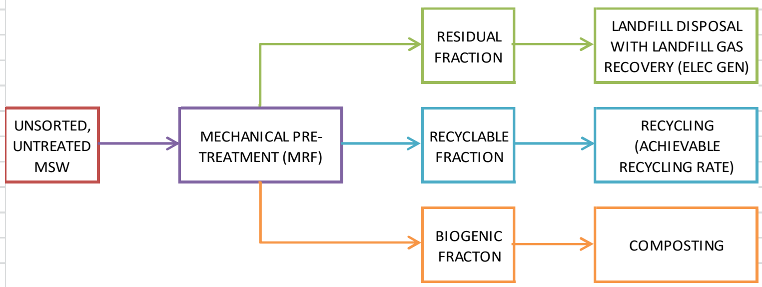
WROSE makes use of the tabs available on Excel to successfully split the tool into simplified outputs that still remain connected between tabs. The input tab makes use of locked cells that only allow data to be entered where required, this tab is shown in Table 8.9.

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL				
W.R.O.S.E				
WASTE MATERIAL OR	TONS	QUANTITY OF WASTE DISPOSED IN BASELINE SENARIO		
WASTE FRACTION	LANDFILL			
newspaper	9915.6448			
general mixed paper (CWM)	7287.4016			
scrap boxes and cardboard (K4)	4823.4236			
low density polyethylene (LDPE)	1941.316			
high density polyethelene (HDPE)	1687.4516			
Polyethelene terephthalate (PET)	3001.5732			
polypropylene (PP)	2553.5772			
polyvinyl chloride (PVC)	2867.1744			
polystyrene (PS)	851.1924			
glass	10722.0376			
steel cans/tin	6227.1444			
aluminium cans	1254.3888			
biogenic food waste	50235.2848			
garden refuse green	1105.0568		PLEASE INPUT CURRENT RECYCLING RATE	
garden refuse wood	29.8664		CURRENT RR	ACHIEVABLE RR
other	44829.4664		10.00%	40.00%
TOTAL WASTE DISPOSED/DIVERTED	149332			

Table 8.9 – Sample WROSE Excel input tab.

Each waste management scenario is outputted on a separate tab, this provides clear and concise results that are easy to interpret. The waste management scenarios are also displayed in WROSE as a graphic and can be seen in table 8.10. An “over ride” feature is also available for WROSE that allows the user to enter a new scenario not developed in Section 8.3, this is necessary if a user wishes to create its own waste management scenarios independently of the WROSE scenarios developed above.

SCENARIO 5



WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR WASTE FRACTION	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			5949.38688	3966.25792		
general mixed paper (CWM)			4372.44096	2914.96064		
scrap boxes and cardboard (K4)			2894.05416	1929.36944		
low density polyethylene (LDPE)			1164.7896	776.5264		
high density polyethelene (HDPE)			1012.47096	674.98064		
Polyethelene terephthalate (PET)			1800.94392	1200.62928		
polypropylene (PP)			1532.14632	1021.43088		
polyvinyl chloride (PVC)			1720.30464	1146.86976		
polystyrene (PS)			510.71544	340.47696		
glass			6433.22256	4288.81504		
steel cans/tin			3736.28664	2490.85776		
aluminium cans			752.63328	501.75552		
biogenic food waste						50235.2848
garden refuse green						1105.0568
garden refuse wood						29.8664
other			44829.4664			
TOTAL WASTE DISPOSED/DIVERTED	0	0	76708.86176	21252.93024	0	51370.208
						149332

Table 8.10 – Sample WROSE Excel GHG output tab

Tables 8.11 and Table 8.12 show sample WROSE economic analysis and sensitivity analysis outputs. These make use of the Excel graphing function along with conditional formatting. The flexibility of Excel provided an excellent platform for the development of WROSE into an easy to use integrated system, whereby a single data input is required and carried through allowing WROSE to provide waste management decision makers with sufficient evidence to draw conclusions from basic input data.

LFG PLANT

ECONOMIC FEASIBILITY OF WACC CASE

ASSUMPTIONS:		
1	Project life	10
2	Payback period	10
3	Debt Interest rate	9.0%
4	Debt percentage	50.0%

ESTIMATED REVENUE:	
Production Cost/KWH	R 0.36
Raw Materials/KWH	R 0.00
GM/KWH	R 0.36
KWH/H	909.2
KWH/m	654606.0274
KWH/y	7855272.329
REVENUE/YEAR =	R 2,827,898

YEAR	RAMP UP	REVENUE	CAPITAL THROUGH DEBT	CAPITAL RECOVERY	INTEREST	OPERATING COSTS	GROSS PROFIT BEFORE TAX	DEPRE-CIATION
0			-R 5,000,463				-R 5,000,463	
1	80%	R 2,262,318.43		-R 329,131	-R 450,042	-R 800,074	R 683,072	R 2,000,185
2	85%	R 2,403,713.33		-R 358,753	-R 420,420	-R 850,079	R 774,462	R 2,000,185
3	90%	R 2,545,108.23		-R 391,040	-R 388,132	-R 900,083	R 865,852	R 2,000,185
4	95%	R 2,686,503.14		-R 426,234	-R 352,938	-R 950,088	R 957,243	R 2,000,185
5	100%	R 2,827,898.04		-R 464,595	-R 314,577	-R 1,000,093	R 1,048,633	R 2,000,185
6	100%	R 2,827,898.04		-R 506,409	-R 272,764	-R 1,000,093	R 1,048,633	R 0
7	100%	R 2,827,898.04		-R 551,985	-R 227,187	-R 1,000,093	R 1,048,633	R 0
8	100%	R 2,827,898.04		-R 601,664	-R 177,508	-R 1,000,093	R 1,048,633	R 0
9	100%	R 2,827,898.04		-R 655,814	-R 123,359	-R 1,000,093	R 1,048,633	R 0
10	100%	R 2,827,898.04		-R 714,837	-R 64,335	-R 1,000,093	R 1,048,633	R 0
				-R 5,000,463	-R 2,726,927	IRR =	12.86%	

ESTIMATED CAPITAL COST:	R	10,000,925.42
ESTIMATED OPERATING COST:	R	1,000,092.54

TONS/DAY	409.1288
REQUIRED MW	0.909

Table 8.11 – Sample WROSE Excel economic analysis

Weighted Average Cost Of Capital	
DEBT:EQUITY RATIO	50%
COST OF DEBT	9%
WEIGHTED COST OF	4.5%
BASIC RISK FREE RA	8%
BUSINESS RISK	7%
SECTOR RISK	1.0
WEIGHTED COST OF	8%
WACC	**12.0%**

SENSITIVITY	
capex	0%
debt interest rate	0%
price deviation	0%
operating costs	0%

SENSITIVITY ANALYSIS		
DESCRIPTION	VARIATION	
Capex	-20%	9.7%
	-10%	4.8%
	0%	0.2%
	10%	-3.8%
	20%	-7.9%
Interest rate	-20%	2.3%
	-10%	1.3%
	0%	0.2%
	10%	-0.7%
	20%	-1.8%
Income	-20%	-22.9%
	-10%	-8.3%
	0%	0.0%
	10%	7.1%
	20%	12.9%
Operating costs	-20%	6.1%
	-10%	3.3%
	0%	0.2%
	10%	-3.0%
	20%	-6.8%

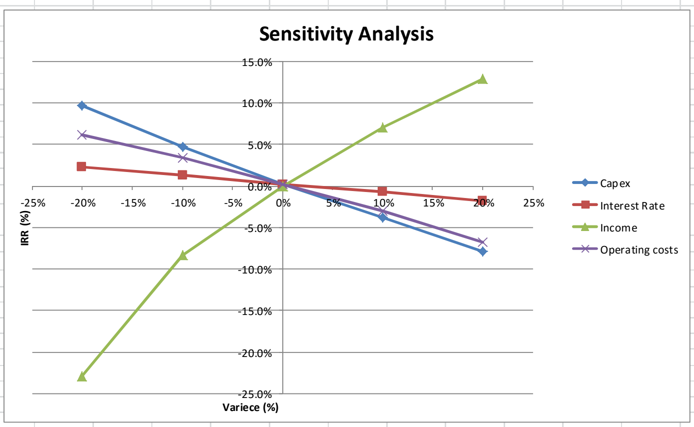


Table 8.12 – Sample WROSE Excel sensitivity analysis

8.12. WROSE Validation and Assumptions

WROSE is inherently validated as the emission, landfill and economic factors it is based on are themselves individually validated during their development and compared to real life data. The factors used by WROSE are intrinsically correct as they are based of multiple sets of real life data, allowing WROSE itself to be validated at a grass roots level. Validation also takes place with the comparison of results produced by different factors for the same indicator. US EPA emission factors are compared to South African greenhouse gas emissions factors. Greenhouse gas emissions are validated on two levels, namely through the use of real life data using large data set and multiple case studies. The second level of validation is in the method in which these factors are applied, each waste strategies has an individual waste emission factor with specific method of application. Furthermore, waste emission factors are constantly changing due to the ever evolving world we live in, this results in the need to constanly update emission factors in WROSE as a method of validation.

Two factors are used for the landfill space savings indicator allowing validation through comparison. Landfill space saving factors are again validated in the development and are dependent on the number of case studies the factors are based off and the availability of data. Each parameter used needs validation separately. The economic analysis is developed through the use of real world data from multiple sources, in order to validate itself, with validation coming from the constant update of economic data.

That being said, WROSE has factors implemented based of various assumptions, these are:

- Material recovery facility capital and operating costs are assumed to be applicable to South African conditions as they are derived from international factors
- Anaerobic digestion capital and operating costs are also assumed to be applicable to South Africa, as they were derived from international factors

- Economies of scale are assumed to be insignificant for landfilling and composting as no data is available with this regard.

These assumptions lead directly to the accuracy of WROSE, the assumptions mentioned above form an integral part of the economic analysis of the various strategies and are critical in the comparison of those strategies with each other. To counter act the inaccuracy developed through the use of these assumptions, a sensitivity analysis was further developed for WROSE. The sensitivity analysis as discussed in section 8.7.2, allows for a 20% change in variables such as the capital and operating costs of the MRF and AD and determines the expected outcome of the strategy with this change.

8.13. Chapter Summary

The methodology comprises mostly of quantitative analysis with regard to greenhouse gas emissions, landfill space savings and the economic analysis. South African methodological approaches from literature were used to an extent where possible and when this was not available, data from the US EPA were used. The qualitative approach consisted of semi-structured interviews with waste management engineers concerning the indicator assessment. A summary of the results produced by the WROSE excel model are shown in the next chapter together with discussion.

Chapter 9 – Case Study Descriptions

9.1. Introduction

The following chapter describes the case studies used in this research. Case studies excel at allowing us to understand a complex issue. The use of case studies can add new and innovative knowledge or further confirm something that is already known through previous research. Case studies also help to highlight contextual relationships between the data being analysed.

EThekwini, Msunduzi and Newcastle municipalities were reviewed, with their waste disposal strategies comprehensively evaluated. Particular emphasis was placed on waste services, waste systems, infrastructure and landfills in the municipalities

9.2. EThekwini

9.2.1. Introduction

EThekwini was chosen to be a case study due to the three active landfill gas projects currently being run in the municipality. This provided an alternative status quo compared to the standard landfilling occurring in majority of landfills in South Africa. EThekwini is also the only and largest metropolitan municipality in Kwa Zulu natal.

EThekwini Metropolitan Municipality is found in the province of KwaZulu-Natal on the east coast of South Africa as shown in Figure 9.1. The municipality experiences a predominantly sub-tropical climate in the coastal areas. EThekwini also manages the city of Durban, which is home to millions of people who form a diverse society, which faces a number of social, economic and environmental challenges.

The eThekwini Municipality spans an area of 2297 km^2 with an approximate population of 3.5 million people. EThekwini's health care services include 16 provincial hospitals and 8 community health centres. Services offered by the health department include a communicable disease centre, a social developmental programme, environmental health services, as well as clinical support services.

According to Statistics South Africa in 2011 there was a total population of 3 442 361 people, of these people 84.8% live in urban housholds,14.7% in tribal/traditional households and 0.5% live on farms. There are 956 713 households and 105 567 agricultural households. 70% of the eThekwini population has access to flush toilets whereas only 2% of the population has no access to toilet facilities at all.

9.2.2 Location

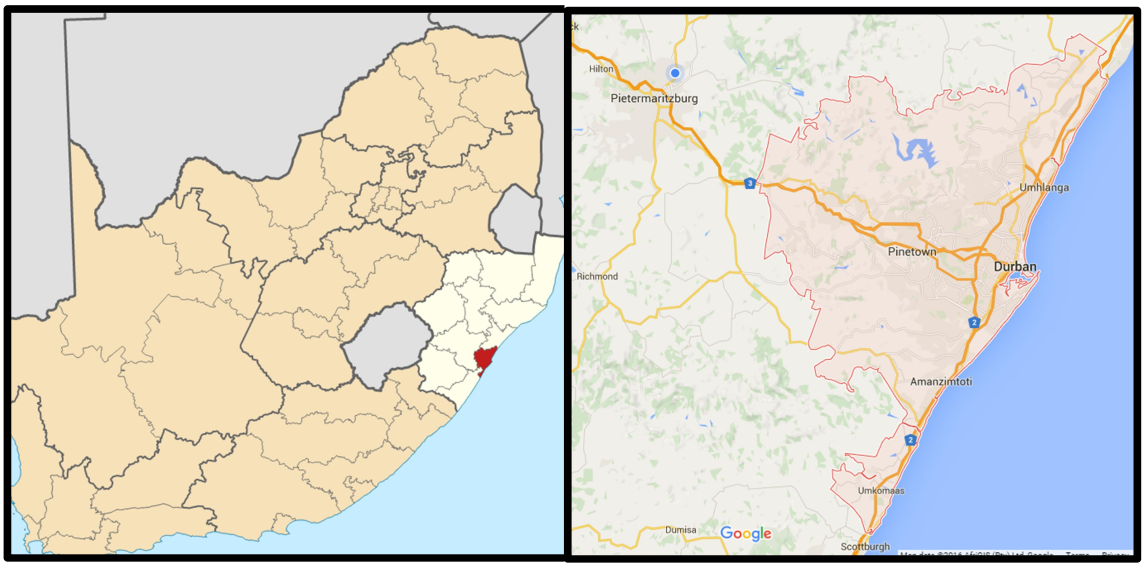


Figure 9.1 – EThekwini Metropolitan Municipality (Google Maps, 2016)

9.2.3. Waste Services and landfills

The cleansing and solid waste unit of eThekwini municipality has three active landfill sites, three landfill gas projects, 23 recycling plants, six transfer stations, and two leachate plants. 86.1% of the population has access to weekly refuse removal (as shown in Figure 9.2) with urban waste generation rates ranging between 0.4 and 0.8kg per capita per a day, and 0.18kg per capita per a day for the rural population.

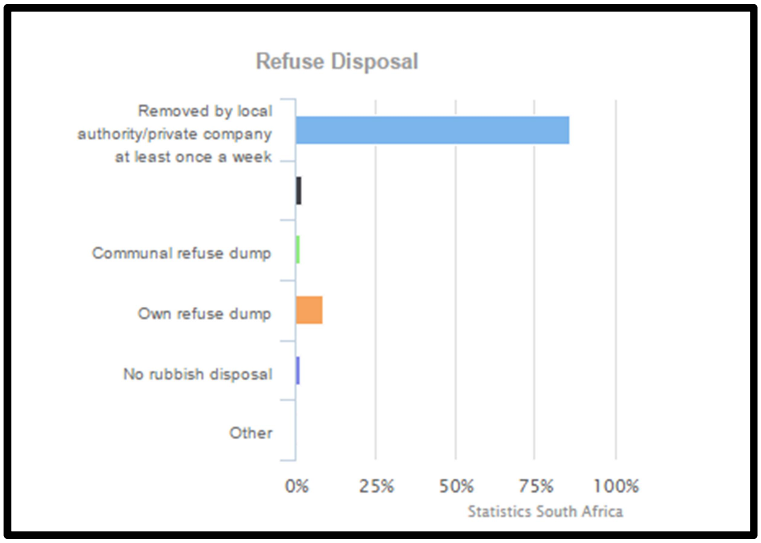


Figure 9.2 – Refuse disposal in eThekwini (Statistics SA, 2016)

Durban Solid Waste (DSW) provides waste services in eThekwini such as collection, transportation, storage and final treatment and disposal of waste. Waste is collected in black refuse bags for general waste, green bags for garden refuse and orange bags for paper recycling in residential areas. Green wheeled refuse bins are also used and are highly popular in multi-dwelling areas such as flats and apartments, due to the reduced space requirement.

The municipality was the first in Africa to launch a “Gas to Electricity” project. This project involved the three council-owned landfill sites i.e. Mariannhill, La Mercy and Bisasar. The project was registered with the Clean Development Mechanism (CDM) and generates income from the sale of certified emission reductions (CER’s) and electricity, which is then used in the overall running of the eThekwini Municipality.

Electricity generation capacity of 0.5MW, 1MW and 6.5MW was installed at La Mercy, Mariannhill and Bisasar respectively. La Mercy was later abandoned because the gas generated was not adequate despite initial pumping trial indications. Bisasar, the busiest landfill in Africa, exceeded all expectations. Currently 50 000 MWh is generated per year, enough to power 3 750 small houses, and CO_2 emissions are reduced by 20 000 tonnes per month (Strachan et al., 2004)

9.2.4. Bisasar Road Landfill

The Bisasar Road landfill is situated in the Springfield area near the Durban Solid Waste head office and is surrounded by formal and informal settlements. An aerial view of the site can be seen in Figure 9.3. It began operation in 1980 and was closed during the year 2015. The Bisasar Road site accepted up to 3 300 tonnes of waste per day. This waste comprises of domestic MSW, garden refuse, commercial and industrial waste with 40% of the waste stream being inert. The landfill covers an area of approximately 44 hectares, with a total capacity of 21 million m^3 (Couth et al., 2010).

The site has spark ignition engine generators to generate electricity and enclosed landfill gas flaring equipment to combust gas which is surplus to the capacity of the operational engines. At present 6.5MW of engine capacity have been installed, and is operational. There is the potential to expand this capacity to 8MW. The site incorporates a typical landfill gas collection and treatment infrastructure including 77 vertical and 77 horizontal wells, pipework, engines for generation of electricity, flares for combustion and a range of monitoring equipment to record the necessary data. The landfill has been combusting methane in landfill gas and generating electricity since March 2008. Leachate is collected and discharged for treatment at the northern waste water treatment works (Moodley, 2010).

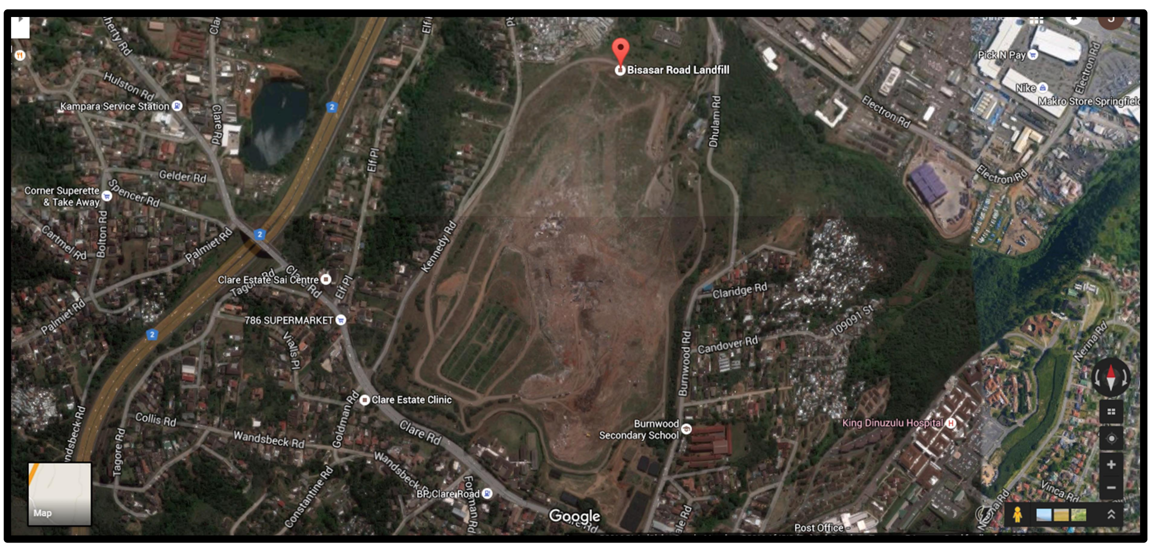


Figure 9.3 – Bisasar Road landfill (Google Maps, 2016)

9.2.5. Mariannhill Landfill

The Mariannhill site is located on the south west edge of Pinetown in Durban and can be seen in Figure 9.4. The landfill currently receives garden refuse, medical waste as well as construction waste. The landfill covers an area of approximately 33 hectares and has a capacity of 5 million m^3 (Couth et al., 2010). Operations began in October 1997 and it currently receives between 450 and 700 tonnes per day.

The site has purpose-built spark-ignition engines with a capacity of 1000 kW. An average of 420 000 kWh of electricity is generated at the Marriannhill site per month, which has saved Durban approximately R60 000 per month in electricity costs. Seasonal climatic variations have also had a significant effect on landfill gas (LFG) extraction. In the winter season, drier and cooler conditions have resulted in a decrease in overall gas recovery from the landfill. Currently, the total extraction rate following the installation of the four new gas wells is of the order of 450 Nm^3/h with a gas quality of approximately 45% methane and less than 2% oxygen, with the quality being sensitive to even slight variations in extraction pressure. Power output measured at the generator is of the order of 800 to 850 kW. This is expected to increase to around a generation capacity of 1 MW during the wetter, warmer months in the summer.

The landfill also has a leachate treatment plant, MRF and a nursery that is used for the growth of indigenous plant species in order to preserve the biodiversity of the site. The original soil and vegetation is temporarily stored in a nursery, and once a cell is closed, it is then used to rehabilitate the area. This rehab process has made landfilling more environmentally, socially and economically sustainable than a single rehab phase once a landfill is closed.

The 50m^3/day leachate treatment plant was constructed on the site in 2004 after extensive testing in a pilot phase. The plant consists of a sequenced batch reactor, equalisation tank and reed bed that is used for a final polishing treatment (Strachan et al., 2004). Leachate was previously disposed of as waste water to the sewer system before being replaced by the treatment plant. The treated leachate is used for irrigation purposes or as a dust suppressant. An MRF was constructed in 2007, but has since been upgraded to include mechanical sorting equipment. A recovery rate of 9 - 13% of recyclables has been achieved at the MRF. The site combines environmentally sustainable engineering and design and has been registered as a national conservancy site.

Figure 9.4 – Mariannhill landfill site (Google Maps, 2016)

9.2.6. La Mercy Landfill

The La Mercy site is situated in the northern region of KwaZulu-Natal surrounded by sugar cane fields, and within 1km of the King Shaka airport. At La Mercy, the site was divided between the northern section and southern section, with the two separated by an old access road, this can be seen in Figure 9.5. The landfill began operation in 1993 and was closed in 2006. The site initially accepted around 60 tons of waste but this increased to 250 tons of waste per a day. The site covers an area of 6.2 hectares.

Six vertical wells were installed in the southern section and eleven in the northern section for the CDM project. High oxygen levels and leachate levels have had an adverse effect on the wells and have had caused major problems with the extraction of gas.

The Berea red sand used as cover material further silted up the gas wells and further reduced the gas yield. A 1000Nm^3 flare and 0.5MW was commissioned in November

2006 and December 2006 respectively, but due to the lack of gas, the engine did not complete final commissioning as it could not be run at maximum output. The gas flow has reduced to around 90Nm^3/hr and at this stage all the gas is flared.

Figure 9.5 – La Mercy landfill site (Google Maps, 2016)

9.2.7. Buffelsdraai Landfill

Buffelsdraai landfill is relatively new compared to the Mariannhill or the Bisasar landfill. It is located 8kms west of Verulam and has an estimated lifespan of over 50 years. The site was commissioned in June 2006 and receives approximately 450 tonnes of general municipal waste per day.

This site has a capacity to receive approximately 2000 tons per day and will be ideally suited when the Bisasar Road landfill closes (Payne, 2005). The landfill covers an area of 100 hectares with an estimated airspace of 45 million m^3. This landfill currently has no gas recovery system nor does it have an engine to generate electricity (eThekweni Municipality: Cleansing and Solid Waste Unit, 2015). Figure 9.6 shows the Buffelsdraai landfill.

Figure 9.6 – Buffelsdraai landfill site (Google Maps, 2016)

9.3. Msunduzi Local Municipality

9.3.1. Introduction

The Msunduzi municipality was chosen as part of the case study due to its size in comparison with EThekwini, with it being roughly 3 times smaller. Msunduzi is also experiencing significant waste management problems with its landfill rapidly filling up and running out of space. Socio economic problems plague the landfill with illegal waste pickers working unprotected on the landfill, these complications result in Msunduzi being a unique case study.

Msunduzi is located 45 minutes by road from Durban and one hour by air from Johannesburg. The Msunduzi Local Municipality encompasses the Pietermaritzburg area which is the capital city of KwaZulu-Natal and one of 6 local municipalities that fall within the uMgungundlovu District Municipality (UMDM) as shown in Figures 9.7 and 9.8.

The UMDM has the fastest growing economy in KZN with a population of 1 017 763. The Msunduzi Municipality spans 634 km^2 and according to Statistics South Africa in 2011 the city had a population of 618 536 people, 163 993 households and 35 527 agricultural households. Msunduzi Municipality has only one landfill site situated on New England Road. It has three provincial hospitals and a large number of public schools. 51.6% of the population have flush toilets connected to sewerage. The city is home to many international events such as the Midmar Mile, Comrades Marathon and the Duzi Canoe Marathon.

9.3.2. Location

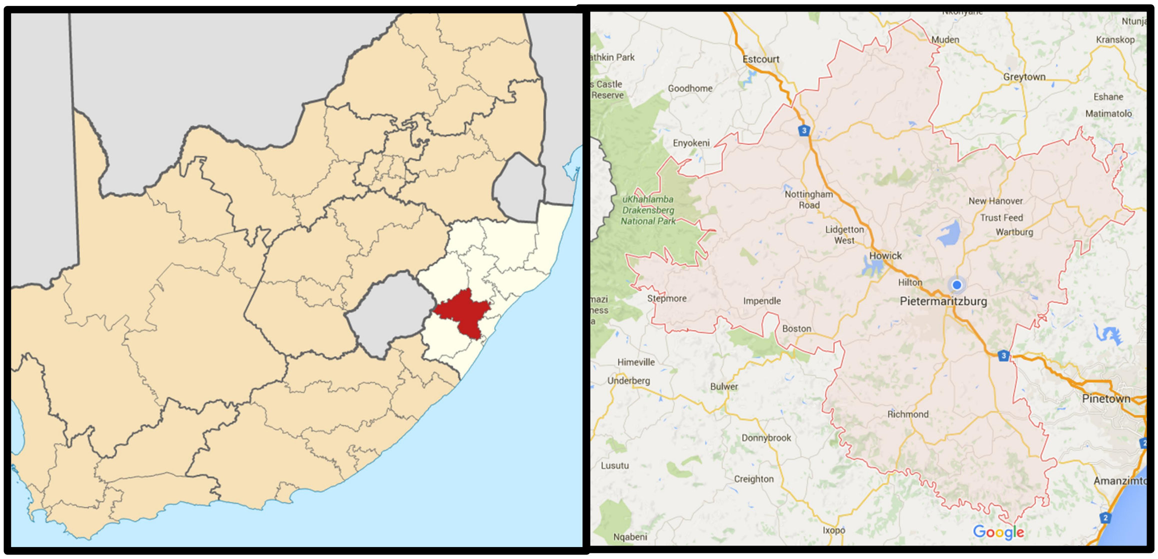


Figure 9.7 – UMgungundlovu District Municipality (Google Maps, 2016)

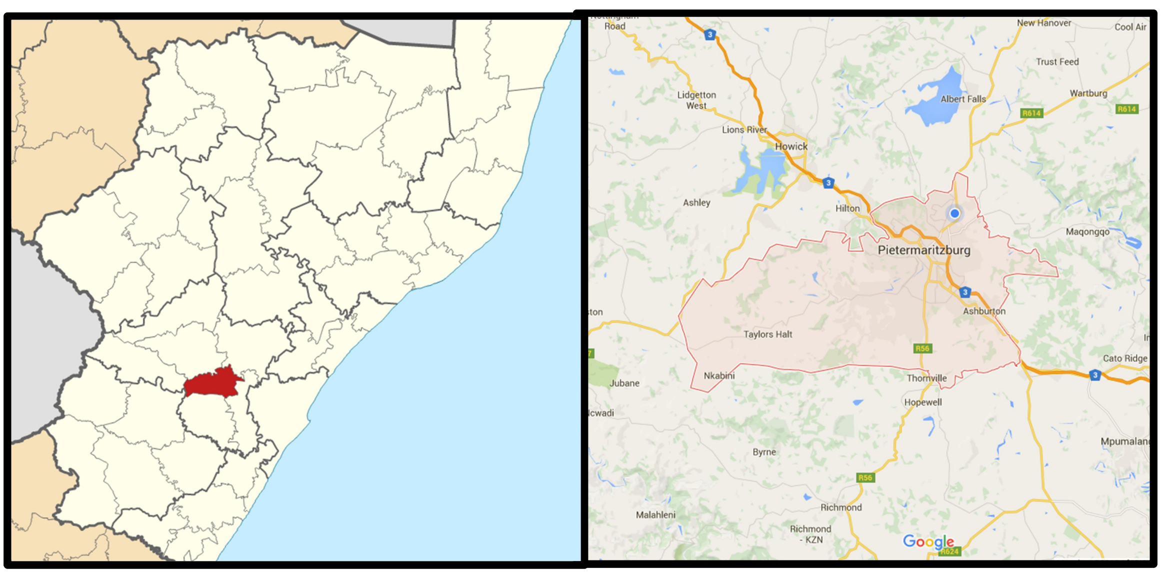


Figure 9.8 – Msunduzi Local Municipality (Google Maps, 2016)

9.3.3. Waste services and landfills

The Msunduzi Local Municipality provides the following public services: street sweeping, waste collection, removal of illegal dumping of waste and management of eight garden refuse sites and transfer stations. The UMgungundlovu District Municipality currently maintains five landfill sites with the New England Road Landfill situated in Msunduzi being the largest in operation which is. The CBD is swept and the refuse bagged, transported and disposed of every night of the year, with the exception of Christmas Day. Suburbs receive street cleaning when necessary. There is a door to door collection to every household in the municipality with 84 600 (52% as shown in Figure 9.9) houses receiving this service once a week. Residents are charged a tariff of R15.87 per a month for refuse collection. No households are serviced by private service providers (Msunduzi IWMP, 2014).

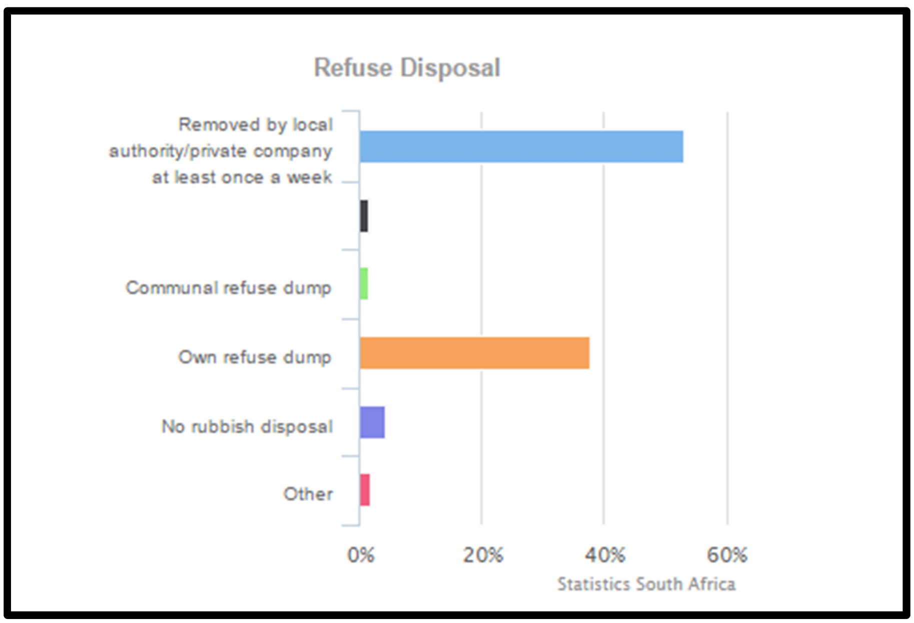


Figure 9.9 – Refuse removal in Msunduzi Local Municipality (Statistics SA, 2016)

9.3.4. New England Road Landfill

The New England Road landfill is located 1km east of the Pietermaritzburg CBD. The landfill began operation in 1950, has an area of 440 000m^2 and receives 700 tons of waste per day. The landfill has a lifespan of 70 years, which means landfill airspace will expire within four years and the search for a new landfill site is currently underway (Msunduzi Local Municipality, 2014). There are no waste treatment facilities in operation, but an organic waste composting facility is being developed in close proximity to the landfill to convert organic waste to compost (IEA Bioenegy, 2013).

The Msunduzi Local Municipality has created a formal recycling committee with instructions to construct a material recovery facility that will also be located on the site to manage all the municipality waste management activities and to resolve the on-going conflict between the informal waste pickers and the municipality. Leachate, methane and CO_2 emissions are all monitored on site. An aerial view of the landfill site is shown in Figure 9.10.

Figure 9.10 – New England Road Landfill site (Google Maps, 2016)

9.4. Newcastle

9.4.1. Introduction

Newcastle was chosen as a case study as it has won the Greenest and Cleanest Town award for three consecutive years. This is the result of the "Newcastle Goes Green" project, which is a partnership of different municipal departments (Moodley, 2012). The municipality provides contrast between the Msunduzi and EThekwini Municipalities, in terms of size, demographics and waste management as discussed below.

The Newcastle Local Municipality (NLM) falls within the Amajuba District Municipality as seen in Figures 9.11 and 9.12. It is found on the North West corner of KwaZulu-Natal and borders the Free State and Mpumalanga. The Newcastle Local Municipality spans an area of approximately 1 855km^2 and has a total population of 363 236 people. There are 84 272 urban households and 25 867 agricultural households. The vision of the Newcastle Local Municipality with regards to waste management is to provide efficient and effective waste services to all areas in Newcastle. This municipality places a large amount of importance on the need for recycling. Newcastle has also held the title of the greenest city in the province for the last seven years.

9.4.2. Location

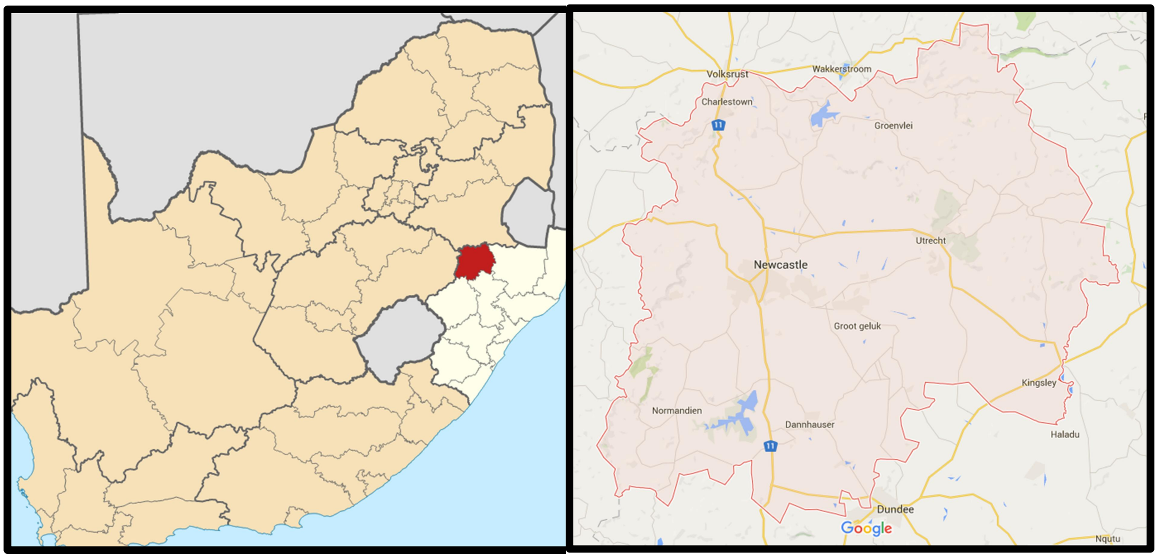


Figure 9.11 – Amajuba District Municipality (Google Maps, 2016)

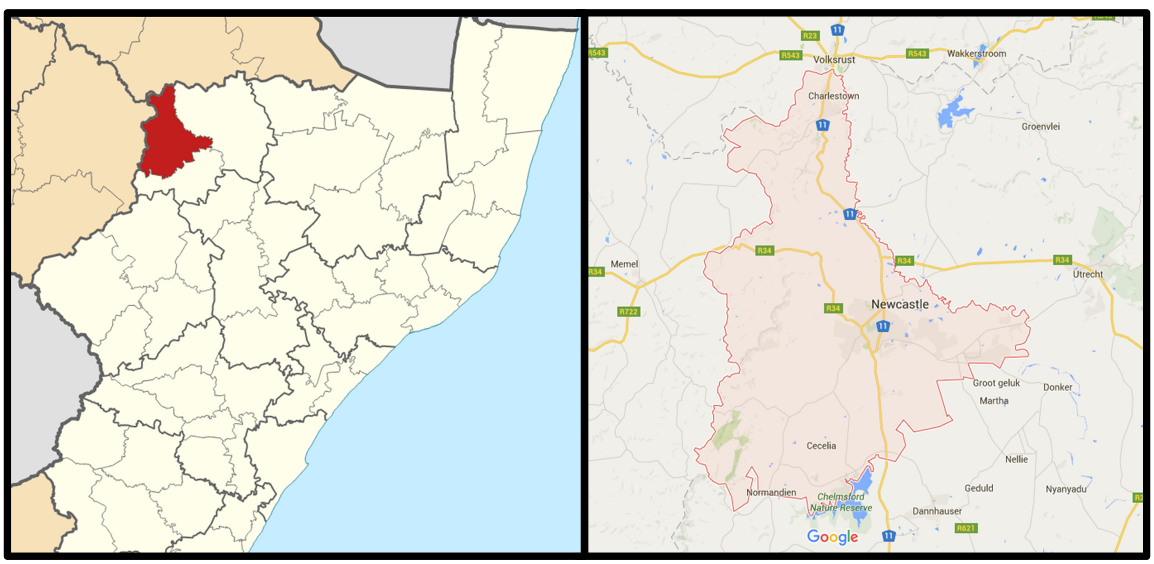


Figure 9.12 – Newcastle Local Municipality (Google Maps, 2016)

9.4.3. Waste services and landfills

71% of the population has weekly refuse removal, as shown in Figure 9.13. The urban population produces 0.35 to 0.61 kg per capita per day and the rural population produces only 0.03 to 0.35 kg per capita per day. Last year Newcastle was selected as one of the top five clean and green towns in SA. Newcastle has a completely integrated waste management programme including litter clean up and waste collection. It is a labour-intensive procedure with the manual labour creating employment. Refuse bins are supplied in both the informal settlements and in residential developed areas. Newcastle has been awarded the cleanest city in KwaZulu-Natal award on three occasions.

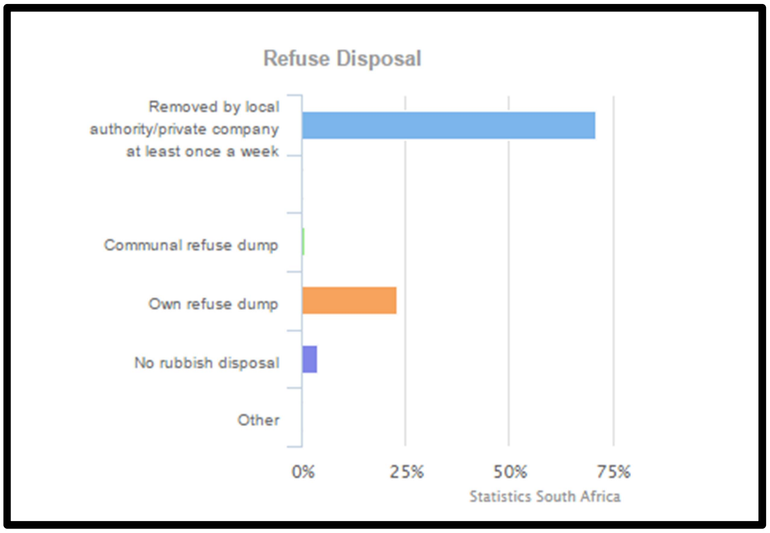


Figure 9.13 – Refuse removal in Newcastle Local Municipality (Statistics SA, 2016)

9.4.4. Newcastle landfill

The Newcastle landfill site is located on Madadeni Road on the outskirts of Newcastle as shown in Figure 9.14. The site is fully fenced, has a fully operational weighbridge and has boreholes which are used to monitor pollution levels. The site also deals with a large percentage of its biogenic waste through a waste diversion strategy. Most of the dry waste is also diverted from this site through an informal picking process. The landfill began operation in 1971 and is expected to close by 2017 (Kelly, 2014).

The NLM has incorporated source separation into the management strategy by adopting a 2 bag system where recyclable materials such as plastic, paper and metals are isolated from wet organic materials (NLM, 2014). The source separated MSW is then collected and transported to the Benwell transfer station and thereafter to the Newcastle Resource Centre (MBT plant). The Benwell transfer station receives approximately 35 000 tons of general waste per annum. The MBT plant separates the organic fraction to undergo in-vessel composting (IVC) at the Newcastle landfill, which has an operating capacity of 150 000 tons per annum (Newcastle City Council, 2011).

NLM has collaborated with a private company, Polyethylene Terephthalate Recycling, in order to convert plastic bottles into woven fibre by using various technologies. The fibre is then used as a fill for household material such as lounge suites (Maharaj, 2014). Newcastle city council (2011) expects there to be no additional need for waste collection and transfers facilities up until the year 2024.

Figure 9.14 – Newcastle landfill (Google Maps, 2016)

9.5. Chapter Summary

This chapter outlined the case study areas of eThekwini Metropolitan Municipality, Msunduzi Local Municipality and Newcastle Local Municipality. It was established that the three municipalities vary in terms of waste services. The eThekwini Municipality has gas to electricity systems in place together with an MRF and leachate treatment systems, whilst the Newcastle landfill has a MRF and composting scenario. The Msunduzi Municipality has a simple landfill but is in the process of developing further waste treatment strategies.

This chapter discussed certain pertinent aspects in detail in order to contextualise the study. The use of case studies allows us the apply the methodological approach and evaluate waste management strategies and derive real world results that can be used in decision making

The complete methodological approach to the study is discussed in the following chapter.

Chapter 10 - Results and Discussion

10.1. Introduction

Results from the indicator assessment are shown in this chapter in order to determine the indicators that will be used to assess the waste management scenarios. Following the selection of indicators, data is then presented for each of the three case studies according to the indicators chosen. Results shown in this chapter are as follows:

1. Indicator assessment
2. Waste stream analysis and tonnage reports
3. Current greenhouse gases quantification
4. Methodological comparison of greenhouse gas quantification
5. Historical greenhouse gas quantification
6. Scenario analysis
7. Landfill space savings data
8. Landfill diversion rate data
9. Economic analysis

The results aim to provide a comprehensive quantification of the scenarios and strategies of the case studies in order to make qualified decisions about waste management. The discussion aims to note any trends, inconsistencies and correlations found in the results.

10.2. Indicator Assessment

As explained in the Methodology Chapter, the indicator assessment was used to determine new indicators that could be used to update the WROSE model whilst also determining indicators that could be used in the future. A collated indicator matrix of the various evaluations are shown below in Table 10.1

Table 10.1 – Collated indicator evaluation

Environmental indicators	relevent	meaningful	comprehensive	transferable/Scalable/consistant	practicle/actionable	intergenerational/durable	SUM
Global warming potential (MTCO2eq)	2.5	2	3	2.5	2	3	15
Landfill space saving	3	3	3	3	2.5	3	17.5
Terrestrial Acidification Potential (SO2)	2	2	2	2	2	2	12
Eutrophication Potential (Nox)	2.5	2.5	2	2	2	2.5	13.5
Ozone Depletion Potential (CFC)	2.5	1.5	2	2	2	2	12
Waste diversion rate	2.5	2.5	2.5	2.5	2.5	3	15.5
Water consumed	2	1.5	1.5	1.5	2.5	2.5	11.5
Energy consumed	2	1.5	2	1.5	2.5	2.5	12
Economic indicators							
Capital costs	3	3	3	3	3	3	18
Operating cost	3	3	3	3	3	2.5	17.5
Income/Savings	3	3	2.5	3	2.5	2.5	16.5
Financial sustainablity	3	3	1.5	2.5	2.5	1.5	14
Sensitivity to variables	2	3	1.5	2.5	1.5	2	12.5
Social indicators							
Jobs creation	3	3	3	2	1.5	3	15.5
Noise generation	1.5	1.5	1.5	2.5	2.5	2.5	12
Public acceptance/Social perception	3	2.5	3	1.5	1.5	1.5	13
Cleanliness/Smell	3	3	1.5	2.5	3	2.5	15.5
Social participation	2	1.5	1.5	1	1	1	8

In the environmental indicator section, landfill space savings had the highest rating. Landfill diversion rate followed with the second highest, with the greenhouse gas emission having the third highest. Hence it was decided to update the GHG indicator and to add landfill diversion rate as an indicator to WROSE principally because it would be simple to incorporate into the model. The eutrophication, acidification and ozone depletion potential were the next highest but were not considered for adding into WROSE, but could potentially be added in the future. Similarly, energy and water consumption scored lowly in the matrix and were only considered for future evaluations.

The capital costs indicator recorded a perfect score in the economic evaluation, followed closely by the operating costs and income and savings. These indicators were originally in WROSE and were further updated and used, as explained in the methodology chapter. The financial sustainability and financial sensitivity indicators scored relatively low on the evaluation, however it was added to the WROSE model as an indicator in order to provide a comprehensive economic assessment of the scenarios. The financial sustainability was assessed through the internal rate of return (IRR) calculated through the use of a discounted cash flow analysis. The social evaluation was done with the view that the indicators assessed would be added into the model in the future. Job creation and cleanliness of strategies scored equally on the assessment with social participation required for each strategy scoring the lowest. As a result, methodologies to assess job creation and cleanliness of waste management strategies should be added in the future.

10.3. Waste stream and waste tonnages

The composition of the waste streams is applied to the tonnage reports for the municipalities to obtain annual quantities of each waste fraction. This data is used as inputs for the greenhouse quantification, landfill space savings, landfill diversion rate and economic analysis. Annual waste quantity data can be found in Appendix A. Waste tonnage reports which comprise of the tonnes of waste disposed through landfilling and tonnes of waste recycled for each municipality were obtained from the South African Waste Information Centre (SAWIC) which is run by the South African Department of Environmental Affairs.

10.3.1. EThekwini

A detailed waste stream analysis of eThekwini was completed only once in 1998 by SKC Engineers/Haultec, however this is out-dated. Douglas (2007) updated these results by averaging the 1998 study with more recent studies such as Mgingqizane (2004) and Marchetti (2007). This waste stream analysis was used by Friedrich and Trois (2013) and is shown in Figure 10.1.

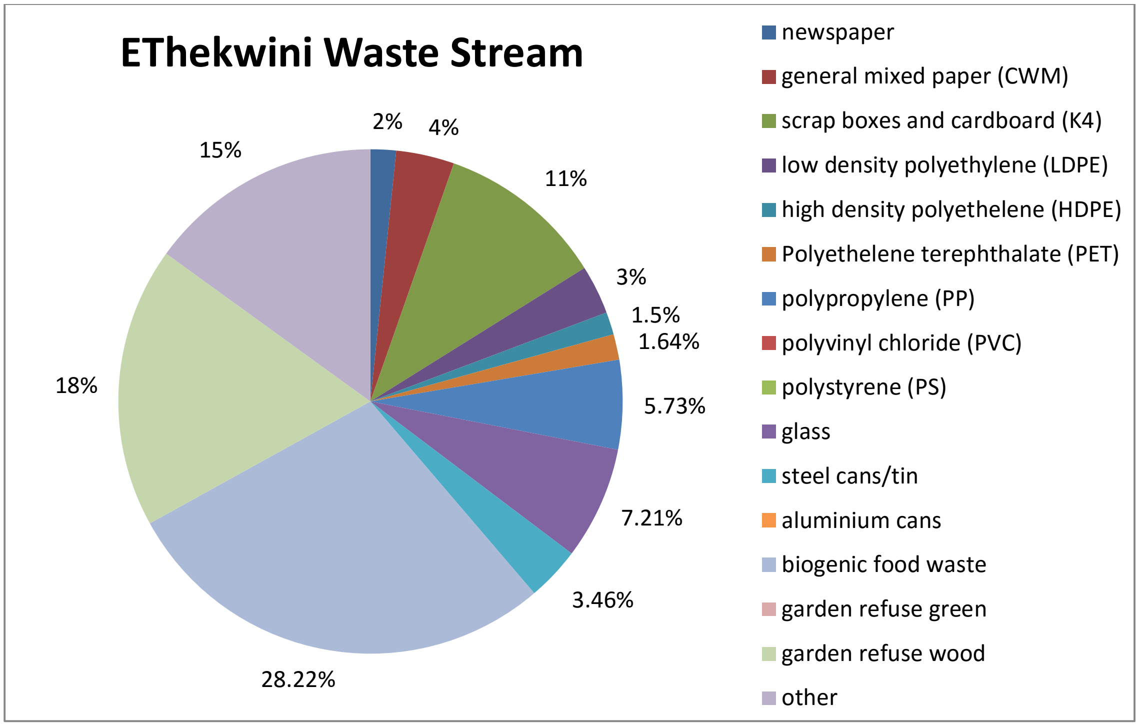
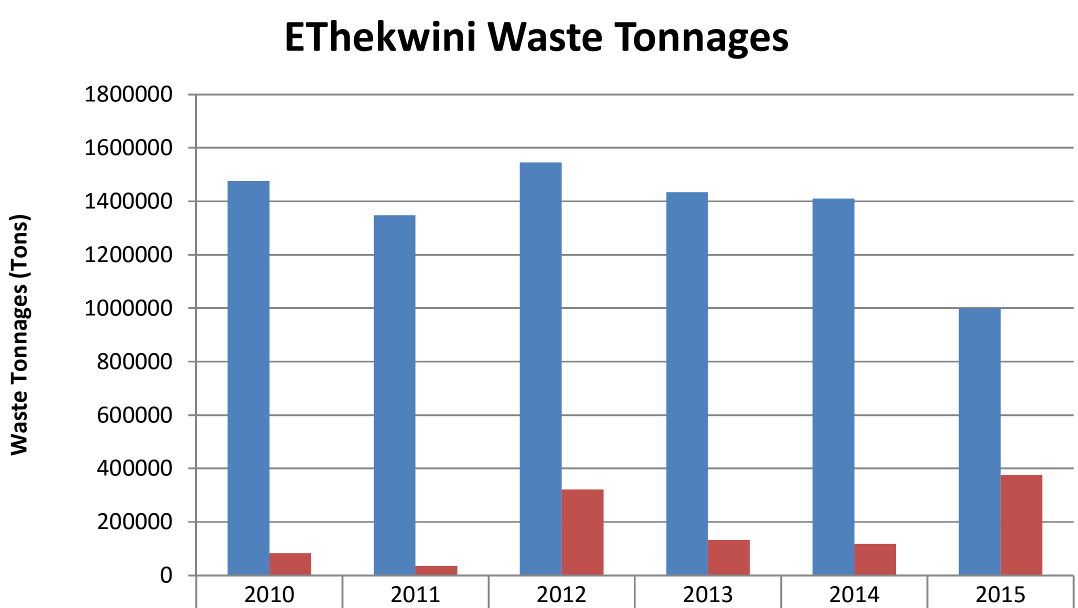


Figure 10.1 – eThekwini waste stream

The eThekwini waste stream analysis shows a large proportion of biogenic food waste, with garden refuse also contributing a large percentage to the overall composition. Recyclables (Papers, plastics, glass and cans) contribute 40% of the eThekwini waste stream, with scrap boxes (K4) being the largest contributor at 11%.

Tonnage reports were obtained from the SAWIC and show the amount of waste disposed of and waste recycled or recovered for the years 2010 – 2015 for eThekwini Metropolitan Municipality. This is shown in Figure 10.2.



	2010	2011	2012	2013	2014	2015
Disposed Tons	1476145.8	1348105.6	1545450.9	1433317.5	1410217.5	998987.6
Recycled Tons	82696.4	35430.0	321262.8	132478.2	117557.47	376055.0

Figure 10.2 – eThekwini waste tonnages

EThekwini waste disposal rates were constant throughout the years 2010 – 2014, however, during 2015 an increase in waste recycled and recovered was experienced resulting in a decreased amount of waste disposed of. This dramatic shift also impacts the recycling rate of eThekwini. The annual waste quantity of each waste fraction can be seen in Appendix A.

10.3.2. Msunduzi

Jagath (2010) completed a site specific waste stream analysis of the New England Road landfill located in Msunduzi Municipality. Physical sampling, sorting and characterising of the waste was completed. The main categories under which waste was classified were paper, cardboard, plastic, glass, metals and biogenic waste. Random sampling of the waste was conducted. The waste stream analysis can be seen in Figure 10.3.

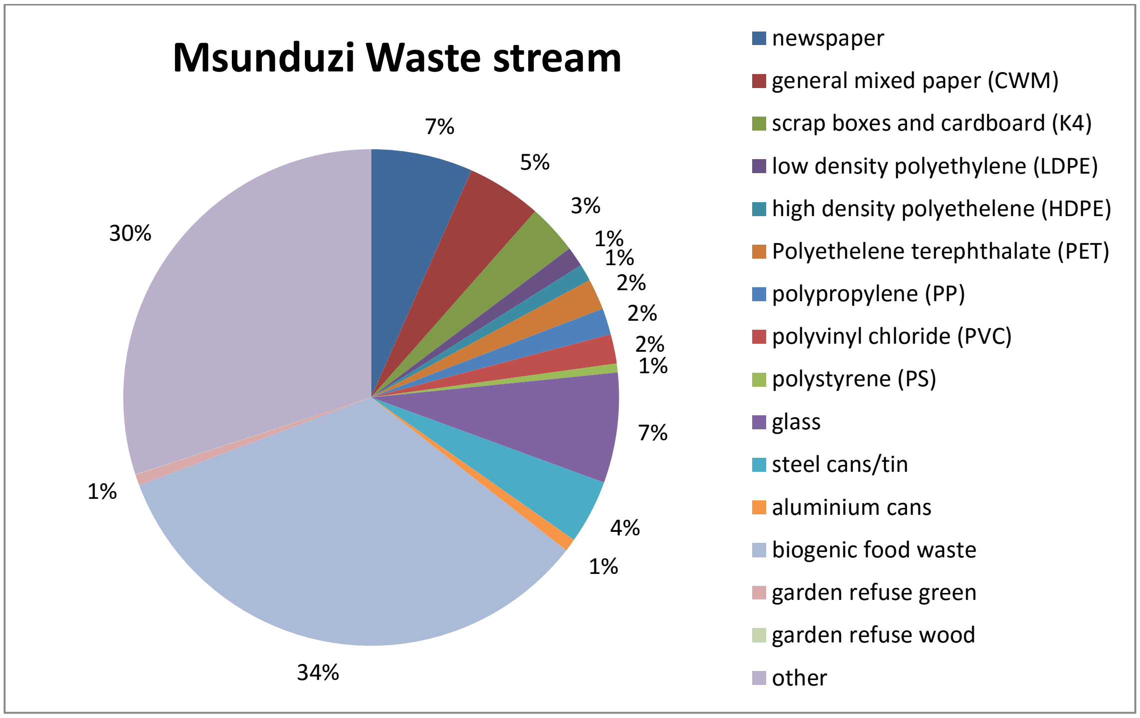


Figure 10.3 – Msunduzi Waste stream analysis

Biogenic food waste contributed 34% to the total waste stream, with a large percentage (30%) of waste falling into the category of “other” which consists of soil, sand, ash and textiles. Recyclables contributed 36%, with glass and newspaper both contributing the most at 7%. Garden refuse contributes only 1% in Msunduzi, compared to the high percentage in eThekwini.

Msunduzi waste tonnage data were again sourced from the SAWIC, however data were only available for the years 2013 – 2015. It shows an increase in waste disposed of from the year 2014 onwards, however the amount of waste recycled and recovered remains constant. This will result in a reduced recycling rate for the years 2014 and 2015. This can be seen in Figure 10.4. The waste fraction quantities for Msunduzi can be found in Appendix A.

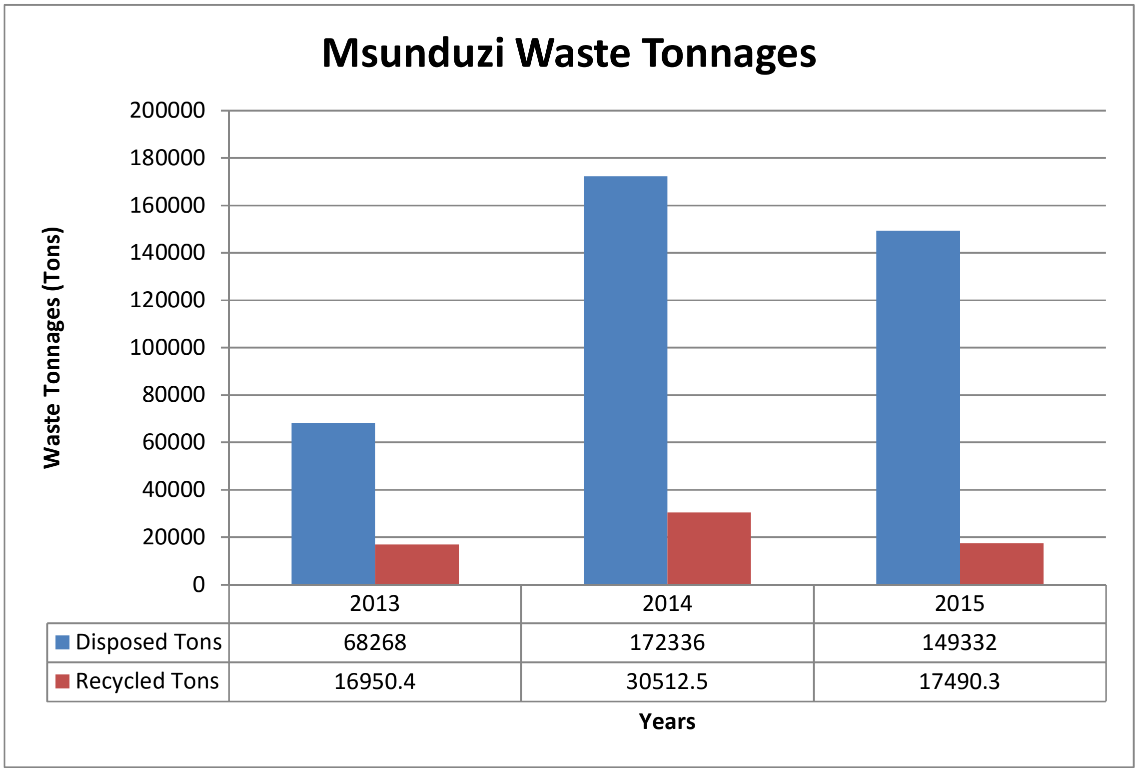


Figure 10.4 – Msunduzi waste tonnages

10.3.3. Newcastle

The Newcastle municipality conducted a waste stream analysis for the integrated waste management plan for 2013, which can be seen in Figure 10.5. Biogenic food waste contributed 11% to the total waste. Garden refuse contributed a total of 8%. Recyclables contributed 60% of the total, with large portions being from glass (12%), polystyrene (10%) and general mixed paper (16%). "Other" again contributed a large percentage, 21%, similar to Msunduzi.

The waste tonnage report for Newcastle provided interesting statistics, showing a large consistent decrease in waste disposed of since 2013. The waste recycled and recovered remains relatively constant throughout these years. This would result in an increase in recycling rate over the shown time period. The tonnage reports can be seen in Figure 10.6, and the total waste fraction quantities can be seen in Appendix A.

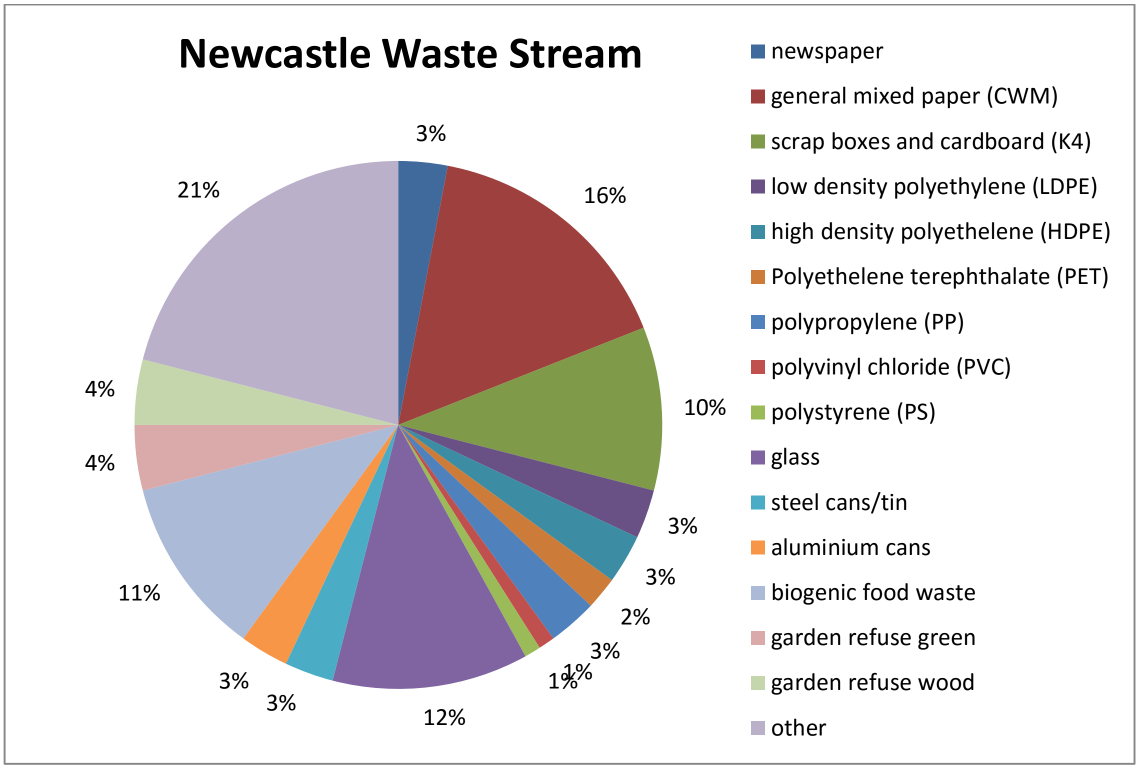
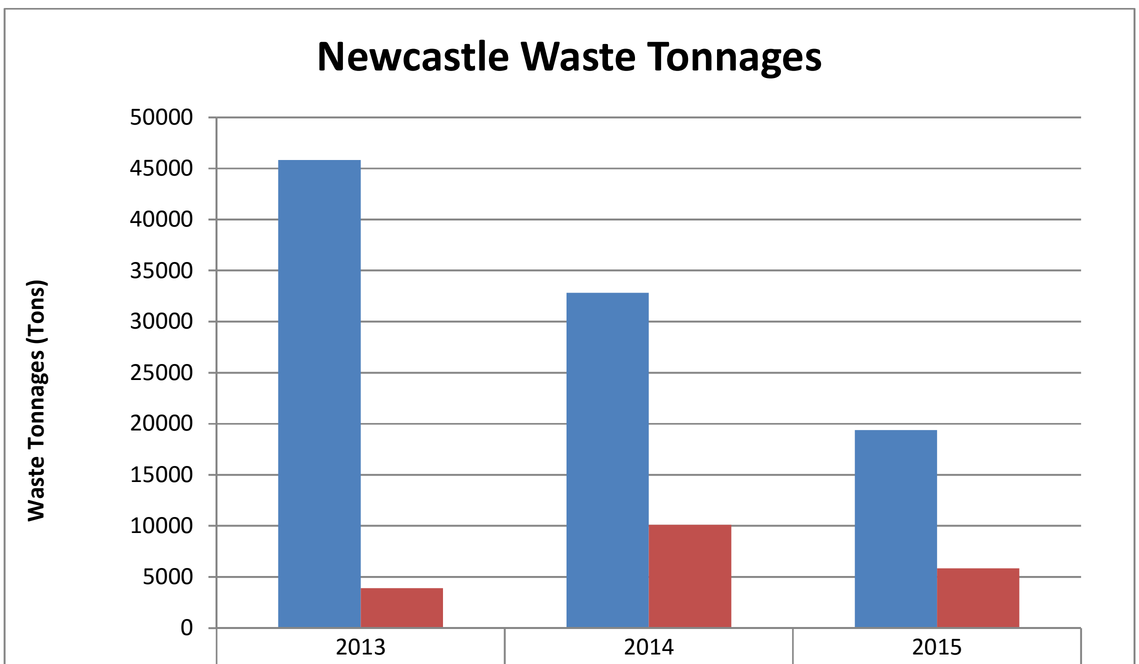


Figure 10.5 – Newcastle waste stream analysis



	2013	2014	2015
Disposed Tons	45817	32841	19366
Recycled Tons	3900	10100	5869

Figure 10.6 – Newcastle tonnage reports

10.4. Current GHG Quantification

Four sets of results were produced with regard to the greenhouse gas quantification assessment. These were a current greenhouse gases quantification, a methodological comparison, a historical comparison and finally a scenario analysis. These results either produced a net emission of greenhouse gases or a net reduction in emissions. A negative result indicates a net reduction and a positive result indicates a net increase in emissions of $MTCO_2$ equivalents.

The carbon emissions and reductions assessment of scenarios 3 – 5 are dependent on the recycling rate and the achievable recyclable rate. Table 10.2 shows the current recycling rates for eThekwini, Msunduzi and Newcastle. The achievable recovery rate is in accordance with the targets of the Polokwane Declaration which targets an increase of 30% in the recycling rate by the year 2012 (Austin and Gets, 2009). However this was not achieved in many municipalities and will be used as the target recycling rate for this study.

Table 10.2 – Current Recycling rate for eThekwini, Msunduzi and Newcastle

Recycling Rate	2010	2011	2012	2013	2014	2015
EThekwini	5%	3%	17%	8%	8%	27%
Msunduzi	-	-	-	20%	15%	10%
Newcastle	-	-	-	8%	24%	23%

10.4.1. EThekwini

A summary of the results obtained from the greenhouse quantification assessment for eThekwini Municipality using the WROSE model is presented in Figure 10.7. All input and output data can be found in Appendix B.

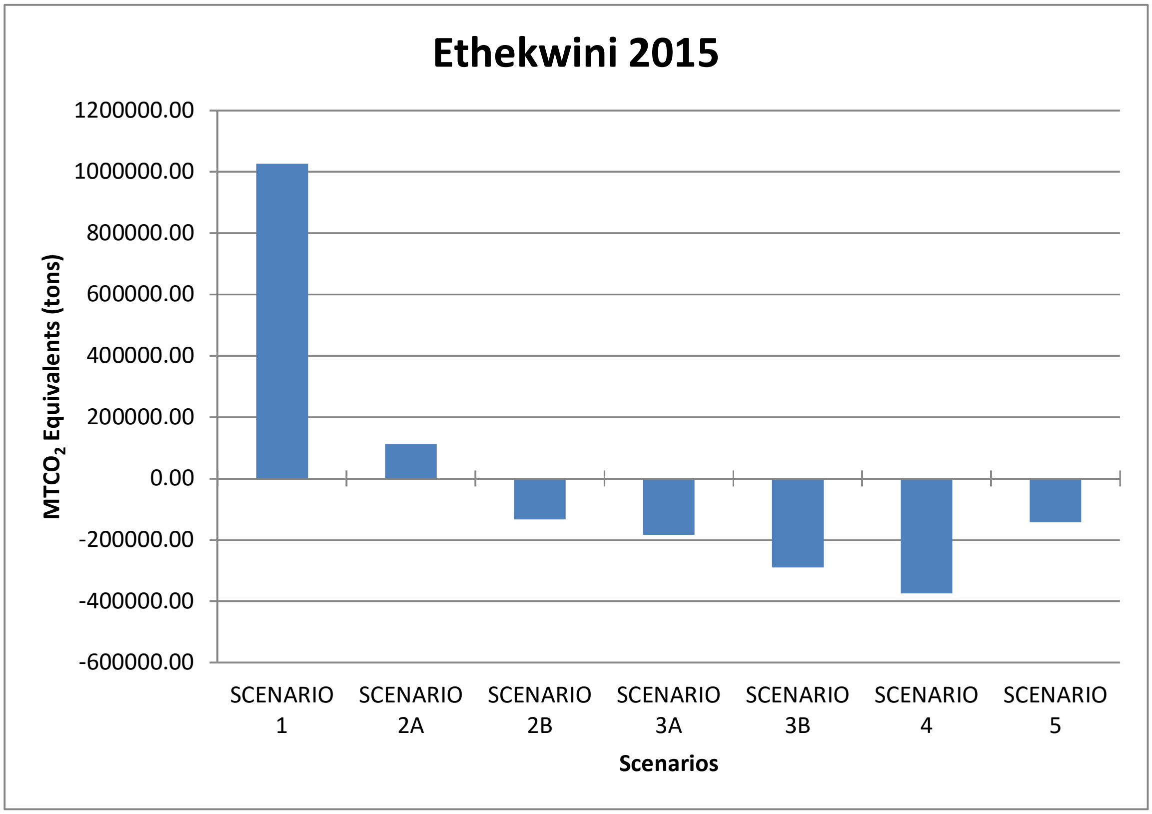


Figure 10.7 – Carbon emission reduction assessment for eThekwini

Landfill disposal in eThekwini results in 1 026 600 $MTCO_2$ equivalents/annum. The additional scenarios all produced substantially lower emissions with the majority of the scenarios producing a net reduction of emissions. Flaring (2A) of methane produced through the landfilling process drastically reduces the carbon emissions to 112 426 $MTCO_2$ equivalents. Scenarios 2B (Landfill gas with electricity generation) and 3A (Landfill gas with electricity generation with current recycling rate) provide negative emissions meaning a net reduction in carbon emissions. Scenario 4 which incorporates landfilling with gas generation, recycling of recyclables at an achievable recovery rate of 57% (27% + 30%) and anaerobic digestion of biogenic waste, produces the greatest environmental benefit resulting in a reduction of -374 436 $MTCO_2$ equivalents. Scenario 3B (Landfill gas with electricity generation and an achievable recycling rate) also produced a significant reduction in carbon emissions with -289 359 $MTCO_2$ reduced. Scenario 5 which integrates composting of biogenic waste along with landfill gas generation and recycling produced reductions of -142 454 $MTCO_2$ equivalents.

10.4.2. Msunduzi 2015

The results from the carbon emission/reduction assessment for Msunduzi are presented in Figure 10.8. Input and output data can be found in Appendix B.

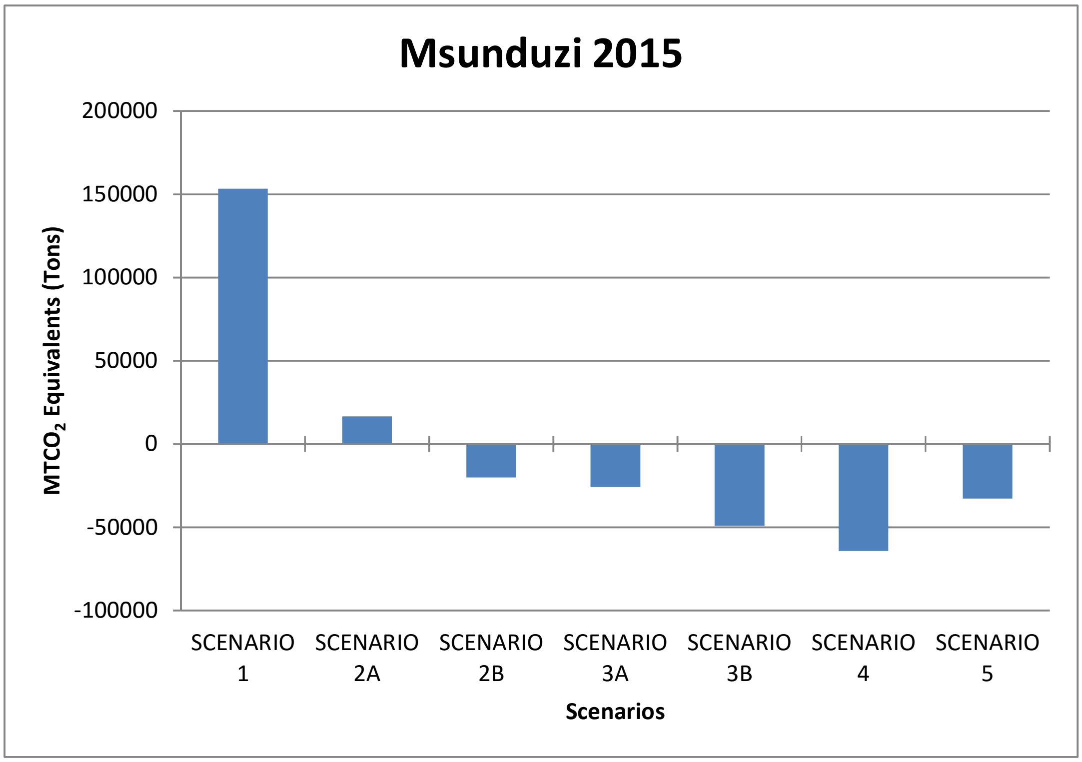


Figure 10.8 – Msunduzi carbon emissions/reduction assessment

The Msunduzi Municipality produced similar results to the eThekwini Municipality in terms of the scenarios producing either a net emission or reduction. The magnitude and quantity of the emissions differ due to the varied waste quantities in the municipalities. The status quo of the Msunduzi Municipality (scenario 1) results in emissions of 153 298 $MTCO_2$ equivalents. Implementation of a landfill gas recovery system could theoretically reduce emissions to 16 645 $MTCO_2eq$ with flaring (Scenario 2A) and a net reduction of -20 046 $MTCO_2eq$ with an electricity generation system (Scenario 2B). The current recycling rate of 10% in scenario 3A results in a net reduction of - 25 927 $MTCO_2eq$, however if the recycling rate were to be increased to 40% as in scenario 3B, the net reduction of emissions would increase to -49 130 $MTCO_2eq$. Once again scenario 4 results in the greatest reduction of CO_2 emissions with - 64 236 $MTCO_2eq$.

10.4.3. Newcastle 2015

The results from the carbon emission/reduction for Newcastle Municipality are presented in Figure 10.9. Input and output data can be found in Appendix B.

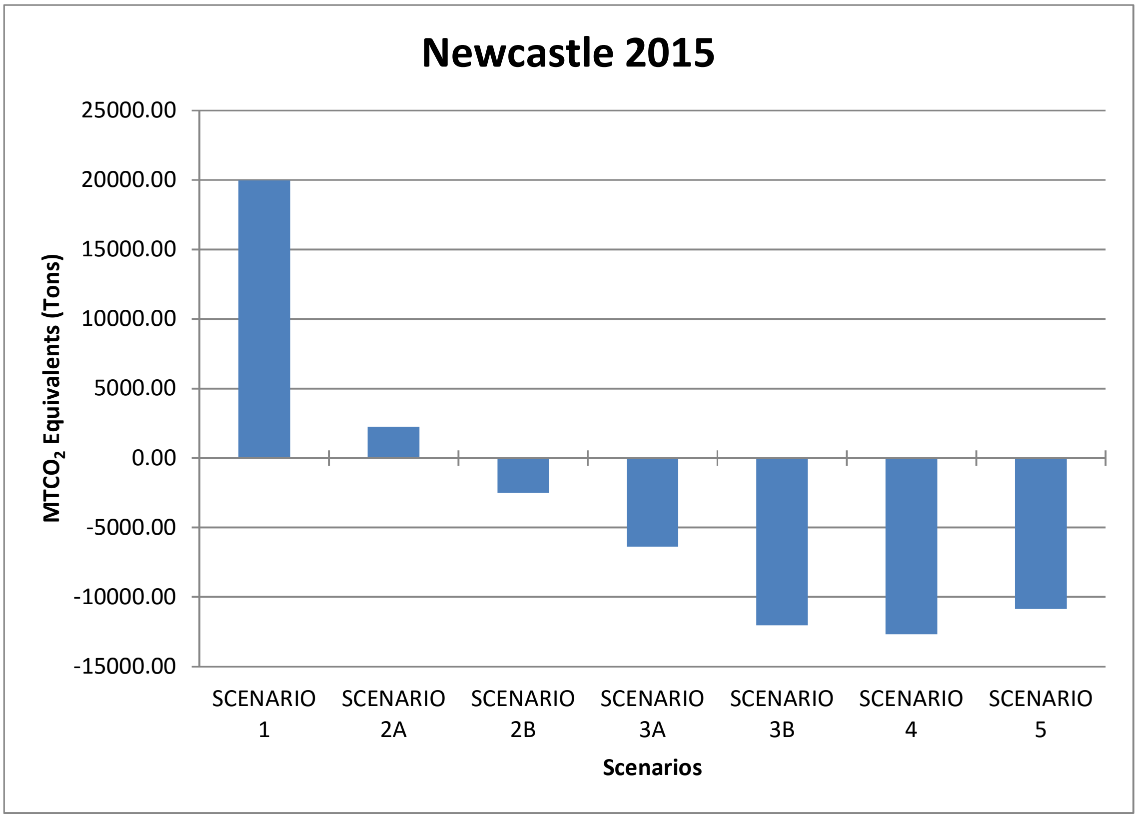


Figure 10.9 – Newcastle carbon emission/reduction assessment

Once again, the results produced were similar to the eThekwini and Msunduzi Municipalities, with scenario 1 and 2A producing a net positive increase of emissions with 19 964 $MTCO_2eq$ and 2 243 $MTCO_2eq$ respectively. Scenario 4 which consists of anaerobic digestion again produced the greatest reduction of greenhouse gases with -12 671 $MTCO_2eq$.

The current recycling rate of 23% together with a landfill gas recovery system would produce a reduction of 20 046 $MTCO_2eq$, however if this recycling rate were to be increased to 53% with the use of a material recovery facility (MRF), scenario 3B would produce a significant reduction of -12 021 $MTCO_2eq$.

10.5. Methodological comparison

10.5.1. EThekwini

The results from the methodological comparison between South African and USA emission factors for the EThekwini municipality are presented in Figure 10.10.

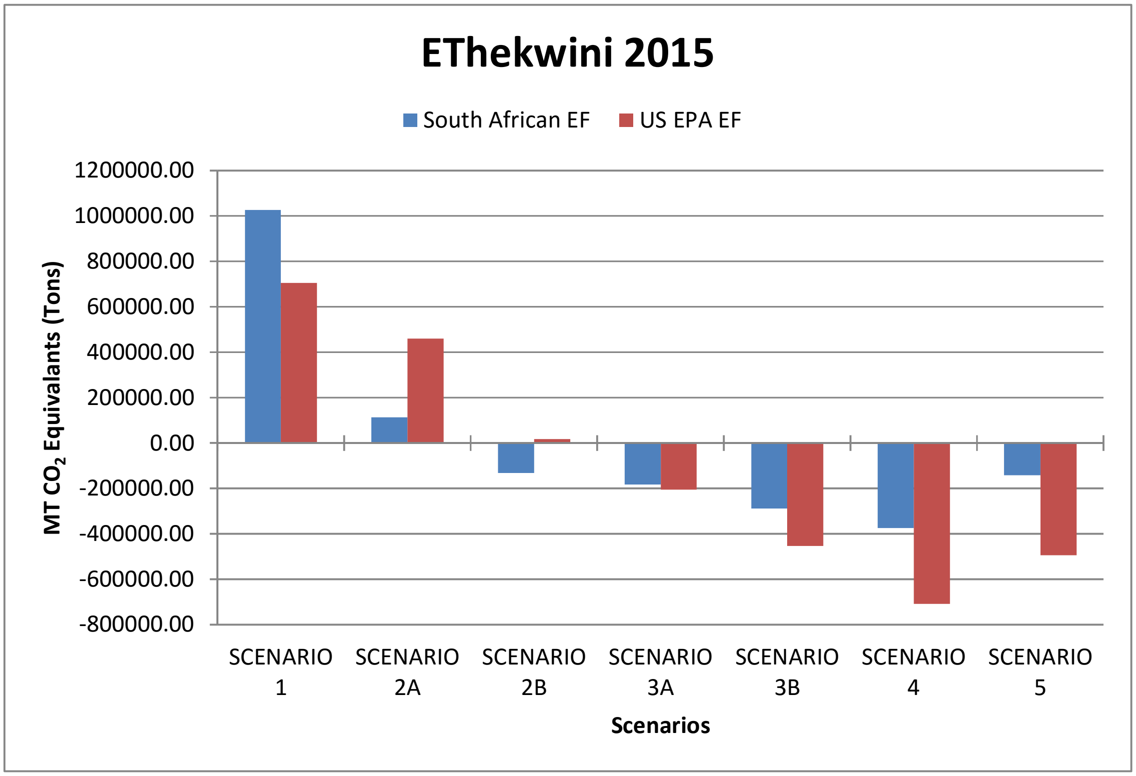


Figure 10.10 – eThekwini methodological comparison

From the methodological comparison it can be seen that the US EPA emission factor over estimates the effect biogenic waste has on the carbon emissions compared to the South African emission factors. This cannot only be seen in scenario 2 but also 3 to 5 where the reduction of net emissions through anaerobic digestion and composting of biogenic waste is higher than the estimate of the South African emission factors. This difference can be attributed to the biogenic fraction as it is the largest fraction of the waste stream, along with having the greatest emission factor for landfilling. Scenario 4 produces the greatest reduction of emissions for both methodologies, with scenario 1 producing the greatest emissions.

10.5.2. Msunduzi

The results from the methodological comparison between South African and USA emission factors for Msunduzi municipality are presented in Figure 10.11.

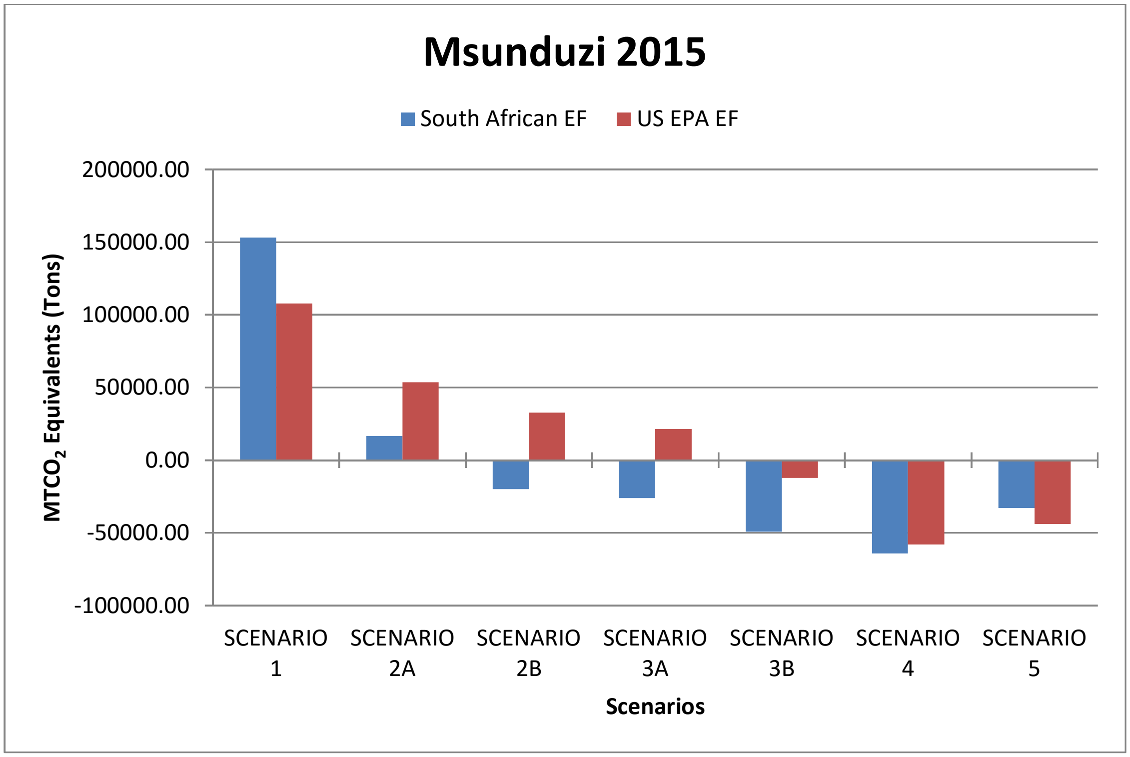


Figure 10.11 – Msunduzi methodological comparison

The high biogenic content in the Msunduzi waste stream resulted in scenarios 2B, 3A and 3B differing from the eThekwini comparative scenario. For scenarios 2B. 3A and 3B, the US EPA biogenic waste landfilling emission factor is 0.43 $MTCO_2eq/ton$ whilst the South African factor is -0.1445 $MTCO_2eq/ton$, hence the higher the biogenic waste fraction is, as is in the case of Msunduzi, the US EPA methodology can be expected to produce a higher emission estimate. Both methodologies result in scenario 4 producing the greatest reduction in emissions.

10.5.3. Newcastle

The results from the methodological comparison between South African and USA emission factors for Newcastle municipality are presented in Figure 10.12.

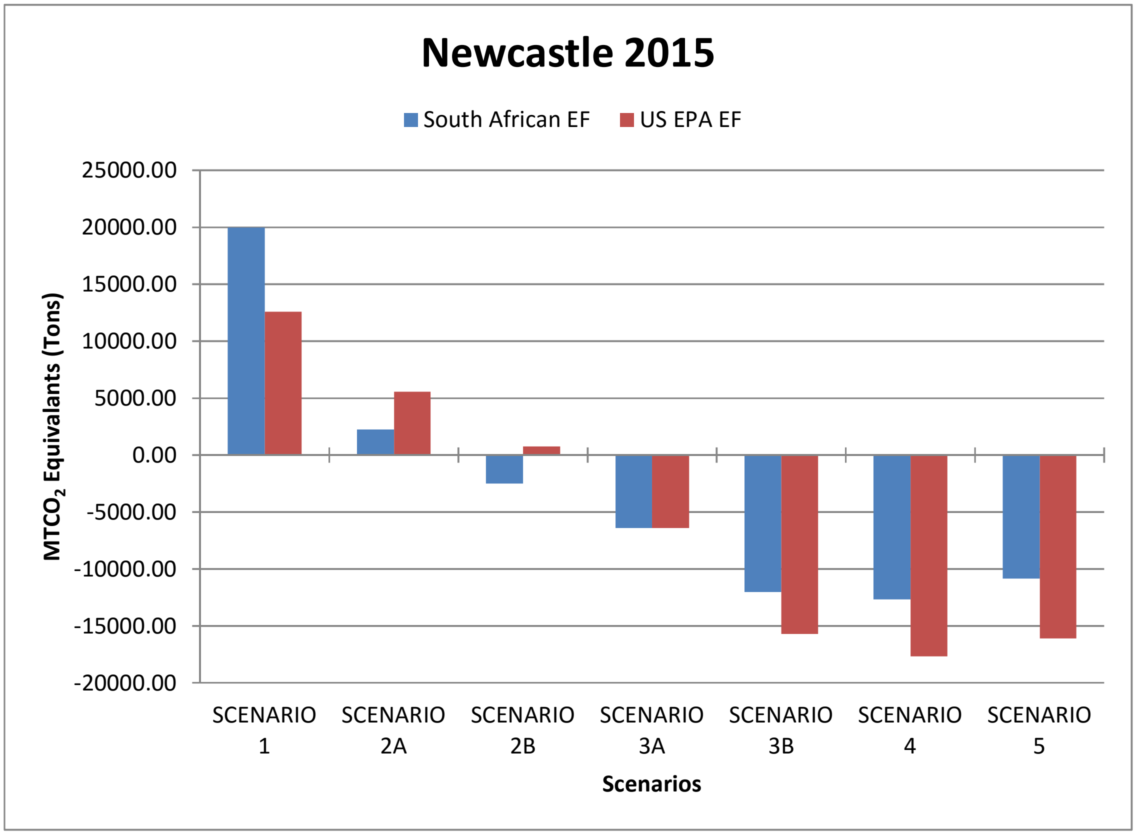


Figure 10.12 – Newcastle methodological comparison

Newcastle municipality produced similar results to that of eThekwini in terms of net emissions and net reductions of carbon dioxide discharge. The magnitude of these emissions were however different due to the varied inputs of waste quantities between the municipalities. The US EPA factors again have higher emission and reduction values of carbon dioxide equivalents compared to the SA emission factors. Scenario 3A however produced almost identical estimates with -6380 $MTCO_2$ equivalents for both methodologies. Both methodologies also indicate that scenario 4 would produce the greatest reduction of emissions, however scenarios 3B and 5 also estimate a significant reduction in carbon dioxide equivalents.

10.6. Historical data

10.6.1. EThekwini

Historical GHG emission estimates for eThekwini between the years of 2010 and 2015 are shown in Figure 10.13.

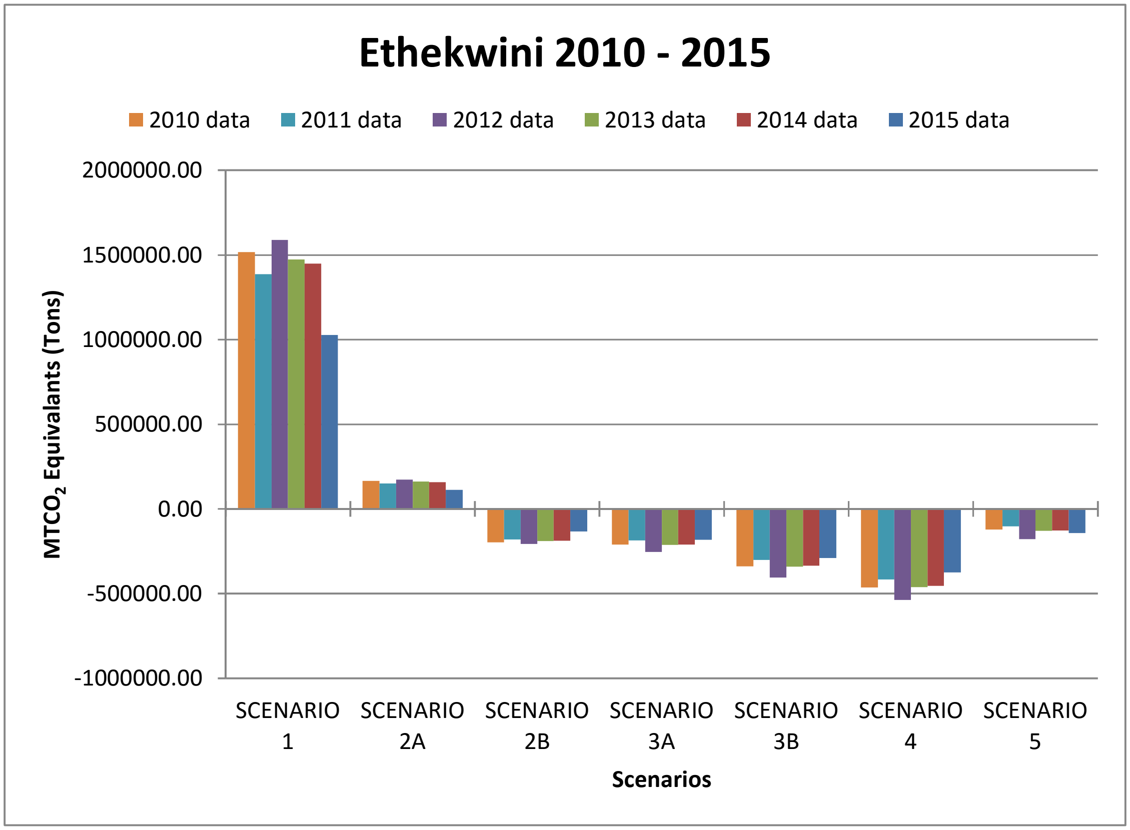


Figure 10.13 – Historical emissions estimates for eThekwini

The historical estimates shows the effect the recycling rate has on the $MTCO_2eq$ because the recycling rate varies each year resulting in the total tonnage of waste disposed of not being directly proportional to the $MTCO_2eq$. Scenario 1 produces the greatest variation of the estimate, with 2015 producing the least carbon emissions and 2012 the greatest, this can be attributed directly to the quantity of waste disposed of in these years being the lowest and highest. Scenario 2A through to scenario 5 produce very little variation, with all estimates being similar.

10.6.2. Msunduzi

Historical GHG emission estimates for Msunduzi between the years of 2013 and 2015 is shown in Figure 10.14.

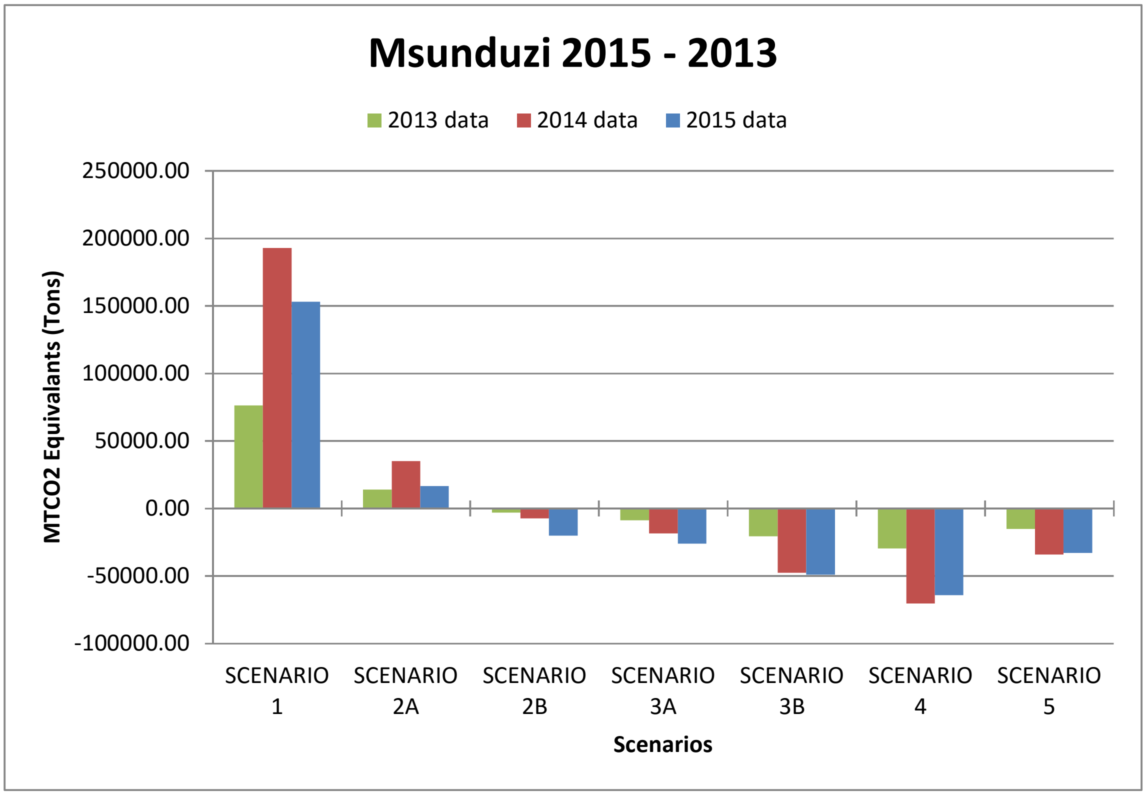


Figure 10.14 – Historical emissions estimates for Msunduzi

Similar to eThekwini's historical emissions estimate, scenario 1 and 2A produces a net increase of emission of carbon dioxide equivalents, whilst 2B through to 5 produces a net reduction in emissions for all the years modelled. The varied recycling rate through the years does not greatly impact the emissions estimate as 2014 produces the highest and 2015 the lowest emissions/reductions, which mimics the tonnage reports.

10.6.3. Newcastle

Historical GHG emission estimates for Newcastle between the years of 2013 and 2015 is shown in figure 10.15.

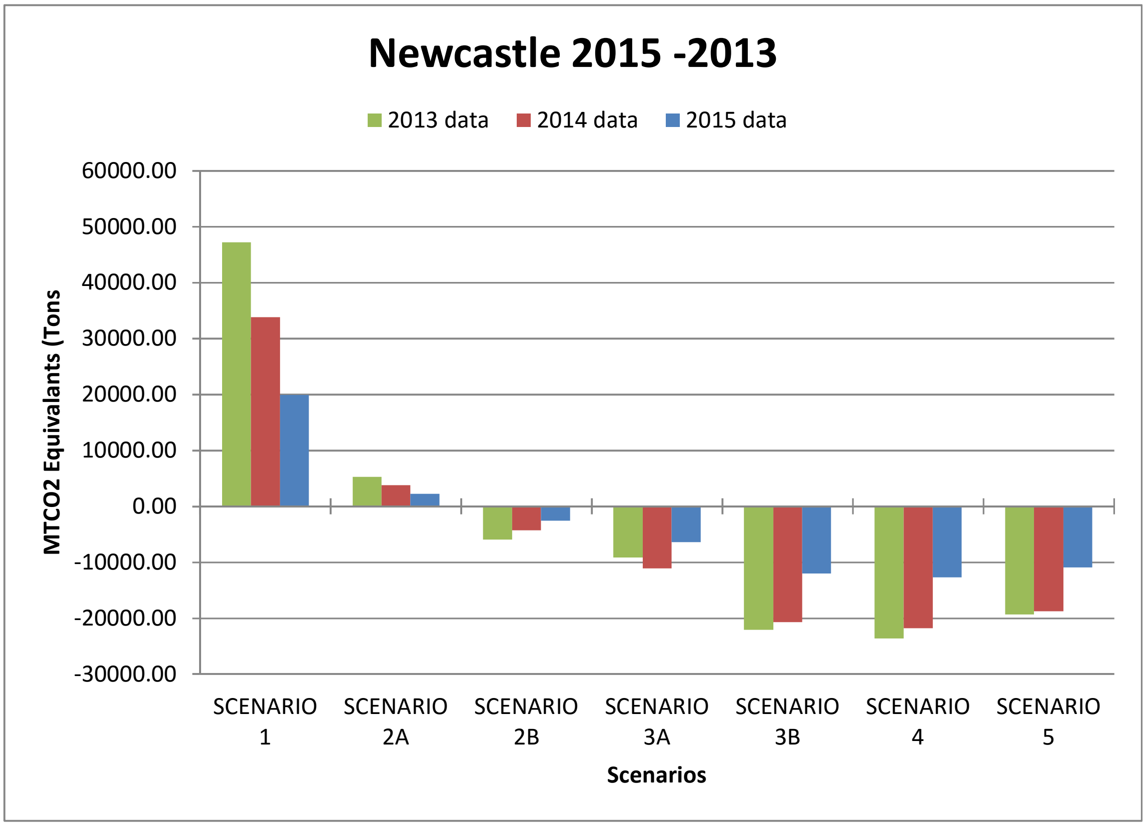


Figure 10.15 – Historical emissions estimates for Newcastle

As explained above, the historic emissions for scenarios 1 to 2 are directly proportional to the quantity of waste disposed of in that year, however in scenarios 3 to 5, various recycling rates are introduced into the model for the years estimated. This is evident in scenario 3A where 2014 data produces the greatest reduction in $MTCO_2eq$ emissions regardless of 2013 having the greatest quantity of waste landfilled. This is further confirmed by the 2014 recycling rate being 24% compared to 2013's 8%.

Scenario 1 and 2A again produce a net positive increase in emissions, whilst the additional scenarios produce a net reduction in emissions for the three years modelled.

10.7. Scenario Analysis

10.7.1. Scenario 1

Table 10.3 shows the average percentage contribution of the individual waste fractions from scenario 1.

Table 10.3 – Individual waste fractions for scenario 1

	Ethekwini		Msunduzi		Newcastle	
Waste Fraction	Emission (MTCO2EQ)	% Emission contribution	Emission (MTCO2EQ)	% Emission contribution	Emission (MTCO2EQ)	% Emission contribution
newspaper	16447	1.6	10077	6.6	590	3.0
general mixed paper (CWM)	38073	3.7	7406	4.8	3149	15.8
scrap boxes and cardboard (K4)	109243	10.6	4902	3.2	1968	9.9
low density polyethylene (LDPE)	31778	3.1	1973	1.3	590	3.0
high density polyethelene (HDPE)	14721	1.4	1715	1.1	590	3.0
Polyethelene terephthalate (PET)	16650	1.6	3050	2.0	394	2.0
polypropylene (PP)	58175	5.7	2595	1.7	590	3.0
polyvinyl chloride (PVC)	0	0.0	2914	1.9	197	1.0
polystyrene (PS)	0	0.0	865	0.6	197	1.0
glass	73201	7.1	10897	7.1	2362	11.8
steel cans/tin	35128	3.4	6329	4.1	590	3.0
aluminium cans	0	0.0	1275	0.8	590	3.0
biogenic food waste	286510	27.9	51054	33.3	2165	10.8
garden refuse green	0	0.0	1123	0.7	787	3.9
garden refuse wood	182749	17.8	30	0.0	787	3.9
other	152595	14.9	45560	29.7	4133	20.7
Transport Emissions	11329	1.1	1532	1.0	283	1.4
TOTAL	1026600	100.0	153298	100.0	19964	100.0

This scenario produces the greatest amount of emissions for the municipalities through the degradation of biogenic food waste and garden refuse, with this waste fraction contributing 45.7%, 33.3% and 18% respectively of the total emissions for the three municipalities. The second greatest contributor of GHG emissions is the newspaper, CWM and K4 fractions accounting for between 14.6 and 28.7% of the total emissions. These materials degrade under aerobic conditions, however some of the carbon does not degrade and is stored causing a carbon sink. Transportation emissions contribute approximately 1% of the total GHGs.

10.7.2. Scenario 2

Tables 10.4 and 10.5 shows the average percentage contribution of the individual waste fractions from scenario 2

Table 10.4 – Individual waste fractions for scenario 2A

	Ethekwini		Msunduzi		Newcastle	
Waste Fraction	Emission (MTCO2EQ)	% Emission contribution	Emission (MTCO2EQ)	% Emission contribution	Emission (MTCO2EQ)	% Emission contribution
newspaper	1638	1.5	1003	6.0	59	2.6
general mixed paper (CWM)	3791	3.4	737	4.4	314	14.0
scrap boxes and cardboard (K4)	10878	9.7	488	2.9	196	8.7
low density polyethylene (LDPE)	3164	2.8	196	1.2	59	2.6
high density polyethelene (HDPE)	1466	1.3	171	1.0	59	2.6
Polyethelene terephthalate (PET)	1658	1.5	304	1.8	39	1.7
polypropylene (PP)	5793	5.2	258	1.6	59	2.6
polyvinyl chloride (PVC)	0	0.0	290	1.7	20	0.9
polystyrene (PS)	0	0.0	86	0.5	20	0.9
glass	7289	6.5	1085	6.5	235	10.5
steel cans/tin	3498	3.1	630	3.8	59	2.6
aluminium cans	0	0.0	127	0.8	59	2.6
biogenic food waste	28530	25.4	5084	30.5	216	9.6
garden refuse green	0	0.0	112	0.7	78	3.5
garden refuse wood	18198	16.2	3	0.0	78	3.5
other	15195	13.5	4537	27.3	412	18.4
Transport Emissions	11329	10.1	1532	9.2	283	12.6
TOTAL	112426.0645	100.0	16645	100.0	2243	100.0

Scenarios 2A and 2B which incorporate landfill gas recovery systems, reduce emissions significantly. A reduction of 914 174 $MTCO_2$ equivalents is experienced if 2A is implemented in eThekwini, and nearly 1 159 625 $MTCO_2$ equivalents are saved if 2B is implemented. Once again biogenic food waste and garden refuse contribute the greatest amount to the emissions of GHG for 2A in all the municipalities. It should be noted that emissions for 2A is positive whilst 2B is negative, indicating a net reduction of $MTCO_2$ equivalents.

In scenario 2B biogenic waste and the newspaper, CWM, and K4 fraction contribute to the greatest reduction in emissions. All others fractions contribute to the reduction of emissions but the transport fraction contributes to an increase in emissions which accounts for 7.6 – 11.2% of the total.

Table 10.5 – Individual waste fractions for scenario 2B

	Ethekwini		Msunduzi		Newcastle	
Waste Fraction	Emission (MTCO2EQ)	% Emission contribution	Emission (MTCO2EQ)	% Emission contribution	Emission (MTCO2EQ)	% Emission contribution
newspaper	-2339	1.8	-1433	7.1	-84	3.3
general mixed paper (CWM)	-5413	4.1	-1053	5.3	-448	17.8
scrap boxes and cardboard (K4)	-15532	11.7	-697	3.5	-280	11.1
low density polyethylene (LDPE)	-4518	3.4	-281	1.4	-84	3.3
high density polyethelene (HDPE)	-2093	1.6	-244	1.2	-84	3.3
Polyethelene terephthalate (PET)	-2367	1.8	-434	2.2	-56	2.2
polypropylene (PP)	-8271	6.2	-369	1.8	-84	3.3
polyvinyl chloride (PVC)	0	0.0	-414	2.1	-28	1.1
polystyrene (PS)	0	0.0	-123	0.6	-28	1.1
glass	-10408	7.8	-1549	7.7	-336	13.3
steel cans/tin	-4995	3.8	-900	4.5	-84	3.3
aluminium cans	0	0.0	-181	0.9	-84	3.3
biogenic food waste	-40737	30.6	-7259	36.2	-308	12.2
garden refuse green	0	0.0	-160	0.8	-112	4.4
garden refuse wood	-25984	19.5	-4	0.0	-112	4.4
other	-21696	16.3	-6478	32.3	-588	23.4
Transport Emissions	11329	-8.5	1532	-7.6	283	-11.2
TOTAL	-133025	100.0	-20046	100.0	-2516	100.0

10.7.3. Scenario 3

Tables 10.6 and 10.7 show the average percentage contribution of the individual waste fractions from scenario 3

	Ethekwini		Msunduzi		Newcastle	
Waste Fraction	Emission (MTCO2EQ)	% Emission contribution	Emission (MTCO2EQ)	% Emission contribution	Emission (MTCO2EQ)	% Emission contribution
newspaper	-8743	4.8	-2886	11.1	-280	4.4
general mixed paper (CWM)	-9702	5.3	-1362	5.3	-750	11.7
scrap boxes and cardboard (K4)	-26364	14.4	-877	3.4	-446	7.0
low density polyethylene (LDPE)	-10554	5.8	-419	1.6	-179	2.8
high density polyethelene (HDPE)	-4342	2.4	-341	1.3	-161	2.5
Polyethelene terephthalate (PET)	-9834	5.4	-940	3.6	-206	3.2
polypropylene (PP)	-18239	10.0	-534	2.1	-170	2.7
polyvinyl chloride (PVC)	0	0.0	-654	2.5	-65	1.0
polystyrene (PS)	0	0.0	-194	0.7	-65	1.0
glass	-13239	7.2	-1705	6.6	-414	6.5
steel cans/tin	-27788	15.2	-2421	9.3	-410	6.4
aluminium cans	0	0.0	-2560	9.9	-2618	41.0
biogenic food waste	-29738	16.2	-6533	25.2	-237	3.7
garden refuse green	0	0.0	-144	0.6	-86	1.4
garden refuse wood	-18968	10.4	-4	0.0	-86	1.4
other	-15838	8.6	-5830	22.5	-452	7.1
Transport Emissions	10143	-5.5	1478	-5.7	244	-3.8
TOTAL	-183206	100.0	-25927	100.0	-6383	100.0

Table 10.6 – Individual waste fractions for scenario 3A

As explained above, the current recycling rate was used for scenario 3A and an achievable rate used for scenario 3B. Biogenic food waste was again still the highest contributor of emission reductions in the eThekwini and Msunduzi municipalities. However, recycling of aluminium and steel cans contributed 47.6% and 56% in the reduction of emissions for Newcastle with regard to scenario 3A and 3B. Aluminium and steel cans have emission factors of -19.11 $MTCO_2$ and -2.58 $MTCO_2$ per ton respectively, these are significantly larger than other emission factors and can result in large reductions in emissions.

Newspaper, CWM and K4 yet again contributed a large percentage to the reduction of total emissions in both scenarios for the three municipalities. Only transportation emission contributed to an increase of GHG emissions with all other fractions causing a net reduction.

Table 10.7 – Individual waste fractions for scenario 3B

	Ethekwini		Msunduzi		Newcastle	
Waste Fraction	Emission (MTCO2EQ)	% Emission contribution	Emission (MTCO2EQ)	% Emission contribution	Emission (MTCO2EQ)	% Emission contribution
newspaper	-15860	5.5	-7247	14.7	-535	4.5
general mixed paper (CWM)	-14467	5.0	-2289	4.7	-1144	9.5
scrap boxes and cardboard (K4)	-38398	13.3	-1417	2.9	-663	5.5
low density polyethylene (LDPE)	-17260	6.0	-836	1.7	-304	2.5
high density polyethelene (HDPE)	-6840	2.4	-632	1.3	-261	2.2
Polyethelene terephthalate (PET)	-18130	6.3	-2460	5.0	-402	3.3
polypropylene (PP)	-29313	10.1	-1028	2.1	-283	2.4
polyvinyl chloride (PVC)	0	0.0	-1373	2.8	-114	0.9
polystyrene (PS)	0	0.0	-407	0.8	-114	0.9
glass	-16386	5.7	-2174	4.4	-515	4.3
steel cans/tin	-53115	18.4	-6983	14.2	-836	7.0
aluminium cans	0	0.0	-9698	19.7	-5924	49.3
biogenic food waste	-40737	14.1	-7259	14.8	-308	2.6
garden refuse green	0	0.0	-160	0.3	-112	0.9
garden refuse wood	-25984	9.0	-4	0.0	-112	0.9
other	-21696	7.5	-6478	13.2	-588	4.9
Transport Emissions	8826	-3.1	1314	-2.7	193	-1.6
TOTAL	-289359	100.0	-49130	100.0	-12021	100.0

10.7.4. Scenario 4

Table 10.8 shows the average percentage contribution of the individual waste fractions from scenario 4.

Table 10.8 – Individual waste fractions for scenario 4

	Ethekwini		Msunduzi		Newcastle	
Waste Fraction	Emission (MTCO2EQ)	% Emission contribution	Emission (MTCO2EQ)	% Emission contribution	Emission (MTCO2EQ)	% Emission contribution
newspaper	-15860	4.2	-7247	11.3	-535	4.2
general mixed paper (CWM)	-14467	3.9	-2289	3.6	-1144	9.0
scrap boxes and cardboard (K4)	-38398	10.3	-1417	2.2	-663	5.2
low density polyethylene (LDPE)	-17260	4.6	-836	1.3	-304	2.4
high density polyethelene (HDPE)	-6840	1.8	-632	1.0	-261	2.1
Polyethelene terephthalate (PET)	-18130	4.8	-2460	3.8	-402	3.2
polypropylene (PP)	-29313	7.8	-1028	1.6	-283	2.2
polyvinyl chloride (PVC)	0	0.0	-1373	2.1	-114	0.9
polystyrene (PS)	0	0.0	-407	0.6	-114	0.9
glass	-16386	4.4	-2174	3.4	-515	4.1
steel cans/tin	-53115	14.2	-6983	10.9	-836	6.6
aluminium cans	0	0.0	-9698	15.1	-5924	46.8
biogenic food waste	-122617	32.7	-21850	34.0	-927	7.3
garden refuse green	0	0.0	-160	0.2	-112	0.9
garden refuse wood	-25984	6.9	-4	0.0	-112	0.9
other	-21696	5.8	-6478	10.1	-588	4.6
Transport Emissions	5629	-1.5	799	-1.2	162	-1.3
TOTAL	-374436	100.0	-64236	100.0	-12671	100.0

Biogenic food waste contributes the greatest percentage emissions reductions for eThekwini and Msunduzi, however in Newcastle recyclable aluminium and steel cans produces the greatest reduction in emissions. Newspaper, CWM and K4 produce a significant contribution to the reduction of GHG emissions in all three municipalities. The recyclable plastic fraction produces a small but significant contribution to the reduction in emissions, accounting for 18% of total emissions for eThekwini and 10.4% for Msunduzi and 11.7% in Newcastle.

Transport emissions are the only fraction to contribute to an increase in emissions with approximately 1% of the total emission originating from transportation.

10.7.5. Scenario 5

Table 10.9 shows the average percentage contribution of the individual waste fractions from scenario 5

Table 10.9 – Individual waste fraction for scenario 5

	Ethekwini		Msunduzi		Newcastle	
Waste Fraction	Emission (MTCO2EQ)	% Emission contribution	Emission (MTCO2EQ)	% Emission contribution	Emission (MTCO2EQ)	% Emission contribution
newspaper	-15860	11.1	-7247	22.1	-535	4.9
general mixed paper (CWM)	-14467	10.2	-2289	7.0	-1144	10.5
scrap boxes and cardboard (K4)	-38398	27.0	-1417	4.3	-663	6.1
low density polyethylene (LDPE)	-17260	12.1	-836	2.6	-304	2.8
high density polyethelene (HDPE)	-6840	4.8	-632	1.9	-261	2.4
Polyethelene terephthalate (PET)	-18130	12.7	-2460	7.5	-402	3.7
polypropylene (PP)	-29313	20.6	-1028	3.1	-283	2.6
polyvinyl chloride (PVC)	0	0.0	-1373	4.2	-114	1.0
polystyrene (PS)	0	0.0	-407	1.2	-114	1.0
glass	-16386	11.5	-2174	6.6	-515	4.7
steel cans/tin	-53115	37.3	-6983	21.3	-836	7.7
aluminium cans	0	0.0	-9698	29.6	-5924	54.5
biogenic food waste	52154	-36.6	9294	-28.4	394	-3.6
garden refuse green	0	0.0	204	-0.6	143	-1.3
garden refuse wood	33266	-23.4	6	0.0	143	-1.3
other	-21696	15.2	-6478	19.8	-588	5.4
Transport Emissions	3590	-2.5	787	-2.4	139	-1.3
TOTAL	-142454	100.0	-32730	100.0	-10863	100.0

Steel and aluminium can recycling results in the greatest reduction of GHG emissions for all three municipalities. All recyclable fractions produce a significant reduction in emissions, as their emission factors are substantially larger than if they were to be landfilled.

Unlike the other scenarios, biogenic waste, garden refuse and transport emission all contribute to an increase in $MTCO_2$. This is due to the composting emission factor being 0.185 $MTCO_2$/ton resulting in an increase in emissions.

10.8. Landfill Space savings

10.8.1. EThekwini

The results from the landfill space savings assessment for the eThekwini municipality waste streams are presented in Table 10.10 and Figure 10.16.

Table 10.10 – Landfill space savings for eThekwini

Methodology	Landfill space savings			
	Scenario 3A	Scenario 3B	Scenario 4	Scenario 5
Waste diverted from landfills (tons)	104 519	220 651	671 714	682 383
Mixed MSW density (m^3)	87 099	183 876	559 761	568 652
US EPA MSW Landfill density (m^3)	265 782	561 095	941 418	1 000 953

The quantity of waste diverted from landfills increased steadily through the scenarios, with 3A producing the lowest quantity of waste diverted and scenario 5 producing the greatest amount of waste diverted. However a large difference can be seen between scenarios 3B and 4. This is due to biogenic waste being diverted to anaerobic digestion and composting rather than being landfilled in scenarios 4 and 5. This biogenic waste again plays an important role in landfill space savings as it did in the GHG quantification assessment.

The mixed MSW density methodology produced the most conservative estimate, while the US EPA methodology producing the greatest space savings. Both methodologies estimated that scenario 5 would produce the greatest amount of savings with 568 652m^3 being saved using the mixed MSW methodology and 1 000 953m^3 saved using the US EPA estimate. Figure 10.16 below shows a scenario by scenario comparison of the methodologies. All landfill space savings calculations can be seen in Appendix C.

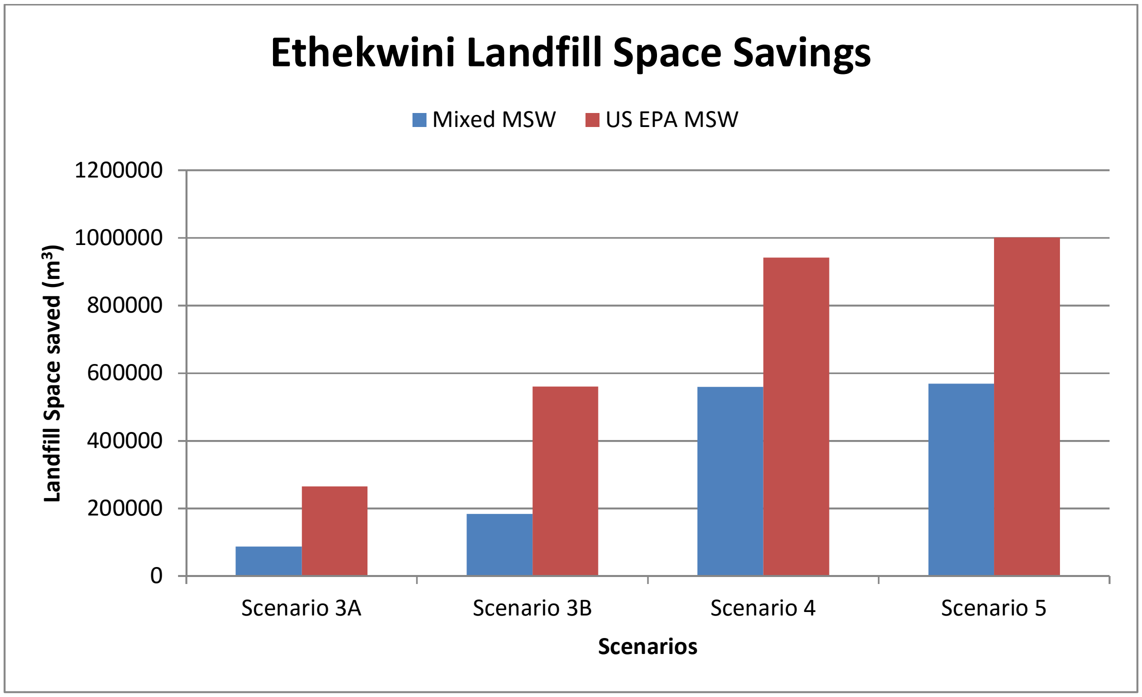


Figure 10.16 – eThekwini landfill space saving comparison

From Figure 10.16, it can be seen that the US EPA methodology produces roughly double the estimate of landfill space savings than the mixed MSW method. A systematic increase in savings can also be seen between the scenarios. The mixed MSW methodology estimates a small difference in savings between scenarios 4 and 5, but the US EPA methodology predicts a much larger difference between the scenarios. As discussed in the methodology chapter, a range of landfill space savings methodologies was used because site conditions and landfill operations, such as degree of compaction, would differ from one landfill to another.

10.8.2. Msunduzi 2015

The results from the landfill space savings assessment for the Msunduzi Municipality waste streams are presented in Table 10.11 and Figure 10.17.

Table 10.11 – Landfill space savings for Msunduzi

Methodology	Landfill space savings			
	Scenario 3A	**Scenario 3B**	**Scenario 4**	**Scenario 5**
Waste diverted from landfills (tons)	5 313	21 252	101 629	72 623
Mixed MSW density (m^3)	4 427	17 710	84 691	60 519
US EPA MSW Landfill density (m^3)	14 694	58 776	126 547	102 409

A significantly lower quantity of waste is diverted in the Msunduzi Municipality compared to the eThekwini Municipality; however, this is due to the low amount of refuse entering the waste stream in Msunduzi. Scenario 3A produced the lowest quantity of waste diverted along with the lowest quantity of landfill space savings using both methodologies. Unlike eThekwini, scenario 4 produced the greatest quantity of waste diverted and the greatest landfill space savings.

Similar to eThekwini, the mixed MSW methodology produced conservative results, with the US EPA producing the largest estimated savings for Msunduzi. Scenario 3A diverted only 5 313 tons of waste and this resulted in an estimated 4 427m^3 space saved using the mixed MSW method and 14 694m^3 using the US EPA method. This is a significant difference and can be attributed to the majority of US EPA density factors being below 0.8 tons/m^3, whilst the mixed MSW factor is a constant 1.2 ton/m^3.

Figure 10.17 shows the comparison between the two methodologies. The US EPA estimate is significantly higher than the mixed MSW methodology for scenarios 3A and 3B; however, the two methodologies are comparable for scenarios 4 and 5. The large biogenic fraction that is diverted in scenarios 4 and 5 results in the two methodology estimates being comparable, as the US EPA space saving factor for biogenic waste is 1.186 tons/m^3 which is very similar to the mixed MSW value of 1.2 tons/m^3.

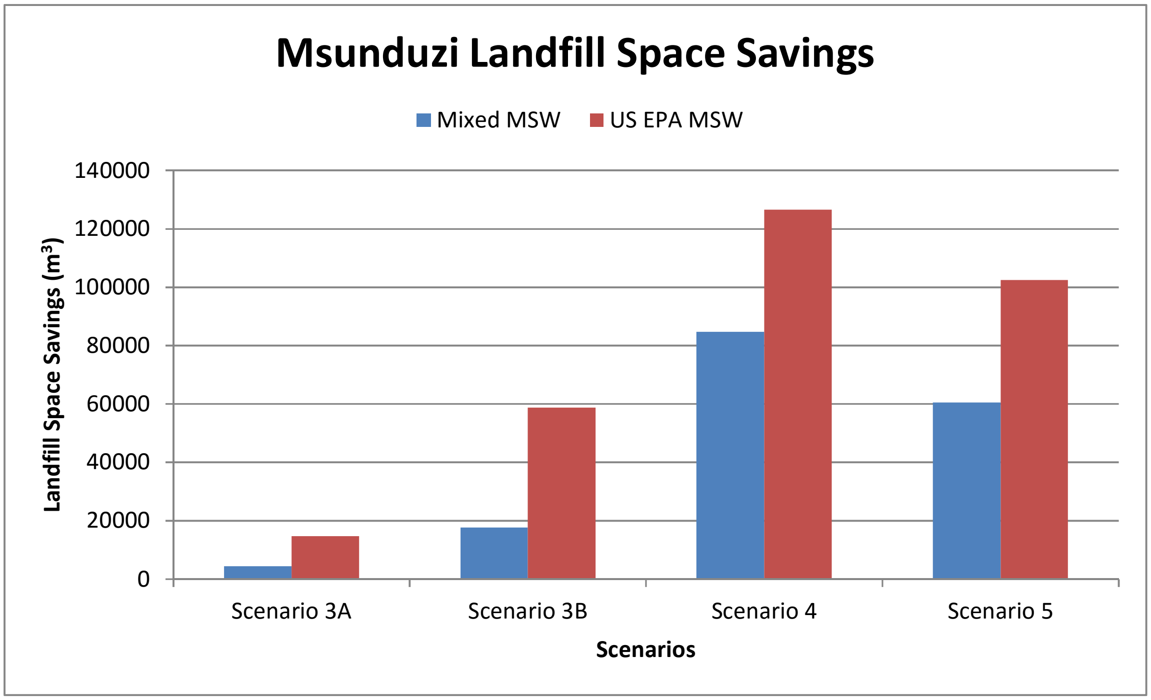


Figure 10.17 – Msunduzi landfill space saving comparison

10.8.3. Newcastle

The results from the landfill space savings assessment for the Newcastle municipality waste streams are presented in Table 10.12 and Figure 10.18.

Table 10.12 – Landfill space savings for Newcastle

Methodology	Landfill space savings			
	Scenario 3A	Scenario 3B	Scenario 4	Scenario 5
Waste diverted from landfills (tons)	2 672	6 158	9 566	9 837
Mixed MSW density (m^3)	2 227	5 132	7 972	8 198
US EPA MSW Landfill density (m^3)	6 857	15 802	18 675	19 340

The Newcastle Municipality results estimated a low waste diversion quantity similar to Msunduzi, yet again this can be attributed to the low quantity of refuse entering the waste stream. A systematic increase can be seen in Figure 10.18 that shows a steady increase in the space saved throughout the different scenarios. Scenario 3A produced the lowest landfill space savings and scenario 5 provided the greatest savings, similar to eThekwini Municipality.

As with the previous case studies the mixed MSW methodology provides the conservative estimate. Scenario 3A produced the lowest estimate of 2 227m^3 with the mixed MSW method and 6 857m^3 with the US EPA methodology. Scenario 3A consists of a large recyclable fraction being diverted, which together with lower US EPA space saving factors results in a significantly higher estimate. This effect is reduced in scenarios 4 and 5 where the biogenic fraction is diverted. As explained above the biogenic fraction has similar space saving factors for both methodologies.

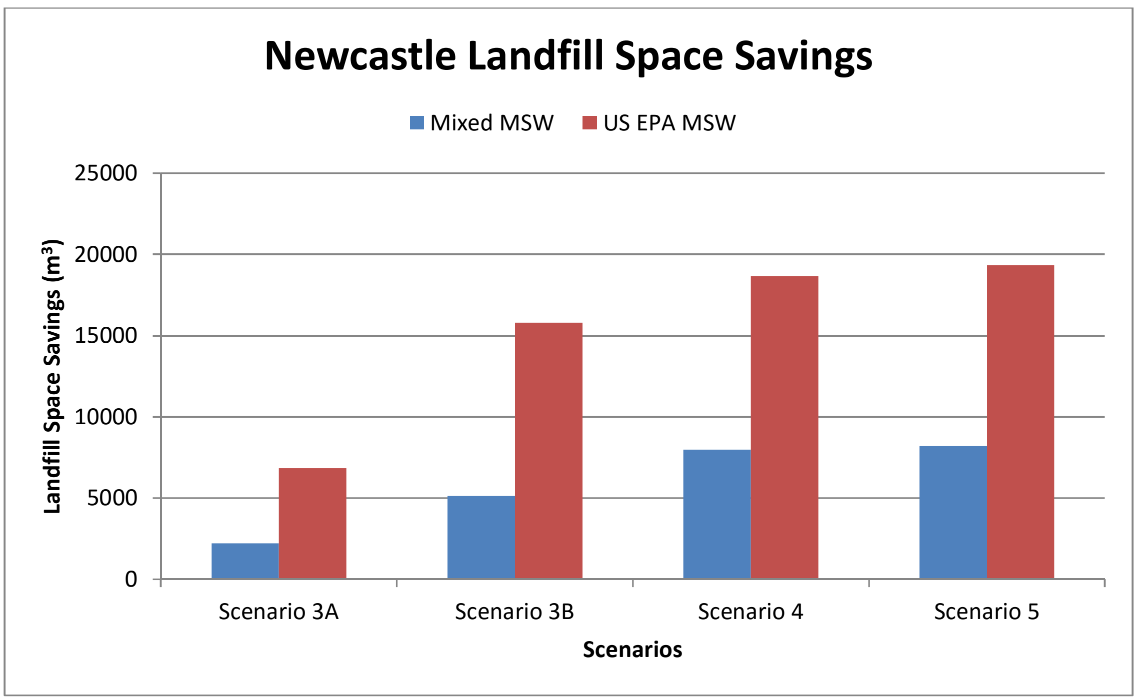


Figure 10.18 – Newcastle landfill space savings comparison

10.9. Landfill Diversion Rate

For the landfill space savings analysis, which used the total quantity of waste diverted, it was possible to see that Msunduzi and Newcastle diverted a significantly lower amount of waste compared to eThekwini, Comparison of the municipalities would not be possible due to this variation in waste quantities. The landfill diversion rate was used to universally compare different case studies. The diversion rates are shown in Table 10.13.

Table 10.13 –Landfill diversion rates

Methodology	Landfill Diversion Rate (%)			
	Scenario 3A	**Scenario 3B**	**Scenario 4**	**Scenario 5**
EThekwini Metro Municipality	10	22	58	68
Msunduzi Local Municipality	4	14	57	49
Newcastle Local Municipality	14	32	46	51

Scenarios 3A and 3B diverted all recyclables whilst scenario 4 and 5 diverted recyclables and biogenic waste, this is clearly evident in the diversion rates of the scenarios. Msunduzi has the lowest diversion rate for scenarios 3A and 3B; this can be attributed to the low recycling rate of 10% experienced in 2015. EThekwini will have the highest diversion rate if scenarios 4 or 5 were to be implemented, this is due to the large fraction of biogenic waste in the waste stream that would be diverted for scenarios 4 and 5. Newcastle municipality has the highest diversion rate in scenarios 3A and 3B although it does not have the highest recycling rate.

The landfill diversion rate provided an easy method to compare the municipalities with one other, which was not possible with the other indicator due to the varied quantity of waste entering the waste stream.

10.10. Economic analysis

10.10.1. EThekwini Economic

Landfill gas recovery systems, material recovery facilities, anaerobic digestion and aerobic composting were assessed for their economic feasibility. Capital costs, operating costs income generated and the internal rate of return of the projects were determined. Different economic scenarios were modelled using a discounted cash flow analysis in order to determine the robustness of the projects. A sample discounted cash flow analysis for the best case scenario for landfill gas recovery system for eThekwini can be seen in Table 10.14. All other discounted cash flow analyses can be seen in Appendix D. Three discounted cash flows (best case scenario, break even scenario and WACC scenario) were done for each of the four strategies; this was replicated for each of the three case studies.

Discounted cash flow analysis selected variables include

- Project life of 10 years
- Payback period of 10 years
- Debt interest rate of 9%
- Debt percentage of 50%
- Rand to dollar exchange rate of R13.63 = 1 USD (20th October 2015)
- Weighted average cost of capital = 12% (See appendix D for WACC calculation)

These values of the variables were selected in order to be conservative, however, it would be possible to simply vary the values and the model would update in order to accommodate the new inputs.

The sensitivity analysis was used to determine the flexibility of the model, capital costs, operating costs, income and debt interest rate were varied between -20% and 20% and the effect on the internal rate of return was plotted. Table 10.15 shows the summary of the economic analysis of eThekwini Municipality and Figures 10.19 to 10.22 shows the sensitivity analysis of the models.

Table 10.14 – Discounted cash flow analysis of the best case scenario for a landfill gas recovery system of EThekwini

LFG PLANT

ECONOMIC FEASIBILITY OF BEST CASE

ASSUMPTIONS:

1	Project life	10
2	Payback period	10
3	Debt Interest rate	9.0%
4	Debt percentage	50.0%

ESTIMATED REVENUE:

Production Cost/KWH	R 0.90
Raw Materials/KWH	R 0.00
GM/KWH	R 0.90
KWH/H	6082.1
KWH/m	4379123.726
KWH/y	52549484.71
REVENUE/YEAR =	**R 47 294 536**

YEAR	RAMP UP	REVENUE	CAPITAL THROUGH DEBT	CAPITAL RECOVERY	INTEREST	OPERATING COSTS	GROSS PROFIT BEFORE TAX	DEPRE-CIATION
0			**-R 33 451 640**				-R 33 451 640	
1	80%	R 37 835 628.99		-R 2 201 790	-R 3 010 648	-R 5 352 262	R 27 270 929	R 13 380 656
2	85%	R 40 200 355.80		-R 2 399 951	-R 2 812 486	-R 5 686 779	R 29 301 140	R 13 380 656
3	90%	R 42 565 082.62		-R 2 615 947	-R 2 596 491	-R 6 021 295	R 31 331 350	R 13 380 656
4	95%	R 44 929 809.43		-R 2 851 382	-R 2 361 056	-R 6 355 812	R 33 361 560	R 13 380 656
5	100%	R 47 294 536.24		-R 3 108 006	-R 2 104 431	-R 6 690 328	R 35 391 771	R 13 380 656
6	100%	R 47 294 536.24		-R 3 387 727	-R 1 824 711	-R 6 690 328	R 35 391 771	R 0
7	100%	R 47 294 536.24		-R 3 692 622	-R 1 519 815	-R 6 690 328	R 35 391 771	R 0
8	100%	R 47 294 536.24		-R 4 024 958	-R 1 187 479	-R 6 690 328	R 35 391 771	R 0
9	100%	R 47 294 536.24		-R 4 387 204	-R 825 233	-R 6 690 328	R 35 391 771	R 0
10	100%	R 47 294 536.24		-R 4 782 053	-R 430 385	-R 6 690 328	R 35 391 771	R 0
				-R 33 451 640	**-R 18 242 351**	**IRR =**	**87.69%**	

ESTIMATED CAPITAL COST:	R 66 903 279.15
ESTIMATED OPERATING COST:	R 6 690 327.91

TONS/DAY	2736.9523
REQUIRED MW	6.082

	Tons/ year	Required MW	Capital Cost (Rands)	Interest accrued	Operating cost (Rands/year)	Scenarios	Income Rate	Income (Rands/year)	IRR %
Landfilling	998 987	6.08	R66 903 279	R18 242 351	R6 690 327	Best Case	R0.90/kWh	R47 294 536	87
						Breakeven	R0.30/kWh	R15 764 845	0
						WACC	R0.36kWh	R18 917 814	12
MRF	220 651	-	R89 540 655	R24 414 824	R24 307 585	Best Case	Various	R265 167 732	421
						Breakeven	-86%	37 123 482	0
						WACC	-85%	40 570 663	12
AD	451 062	26	706 733 639	192 703 302	27 932 717	Best Case	R0.96kWh R250/ton	289 388 104	48
						Breakeven	R0.42kWh R100/ton	124 104 823	0
						WACC	R0.5kWh R150/ton	156 00 967	12
AC	461 732	-	14 055 770	3 832 552	70 206 361	Best Case	210	72 722 801	12
						Breakeven	208	72 099 463	0
						WACC	210	72 722 801	12

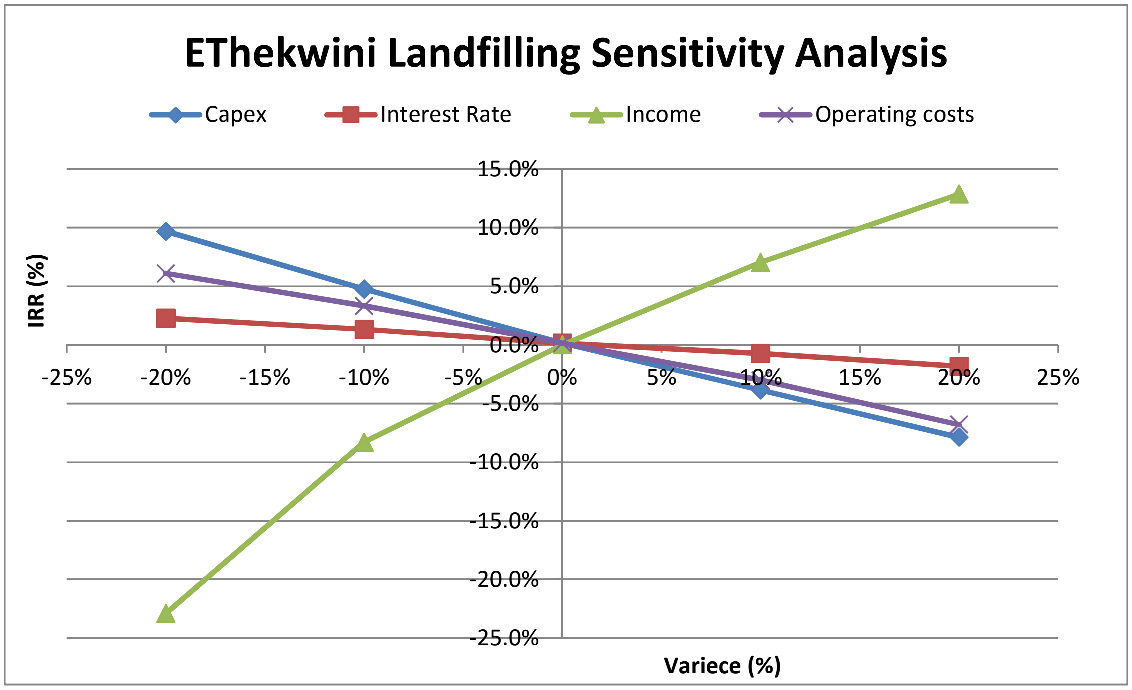


Figure 10.19 – eThekwini landfilling sensitivity analysis

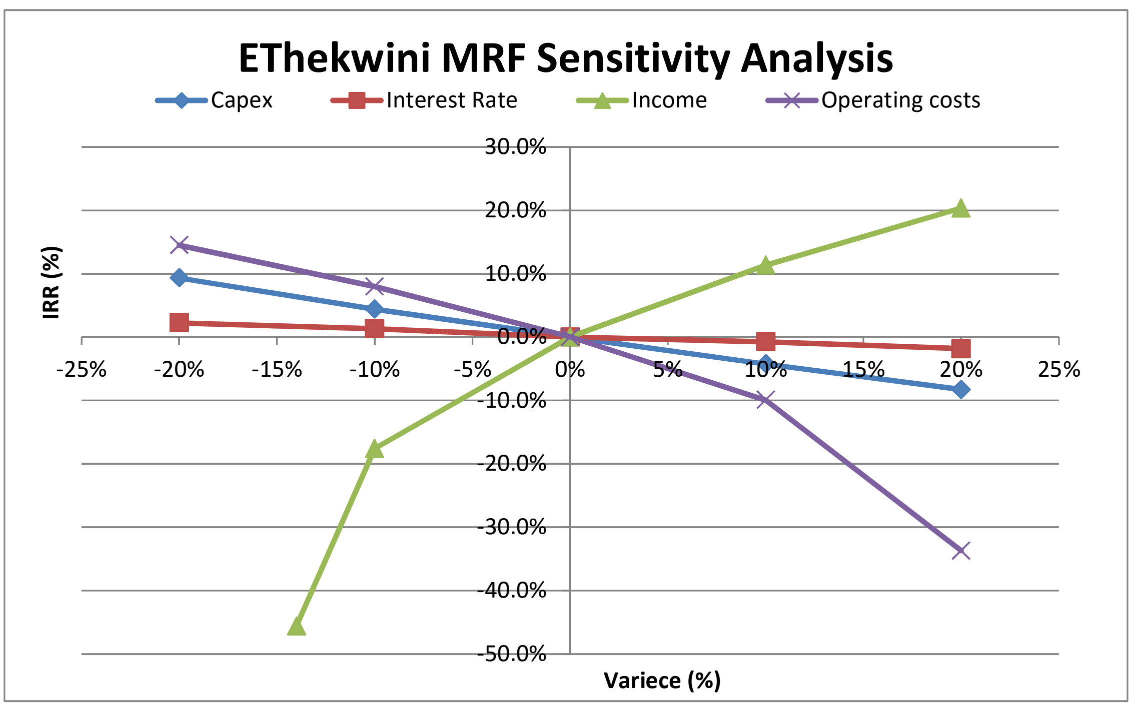


Figure 10.20 – eThekwini MRF sensitivity analysis

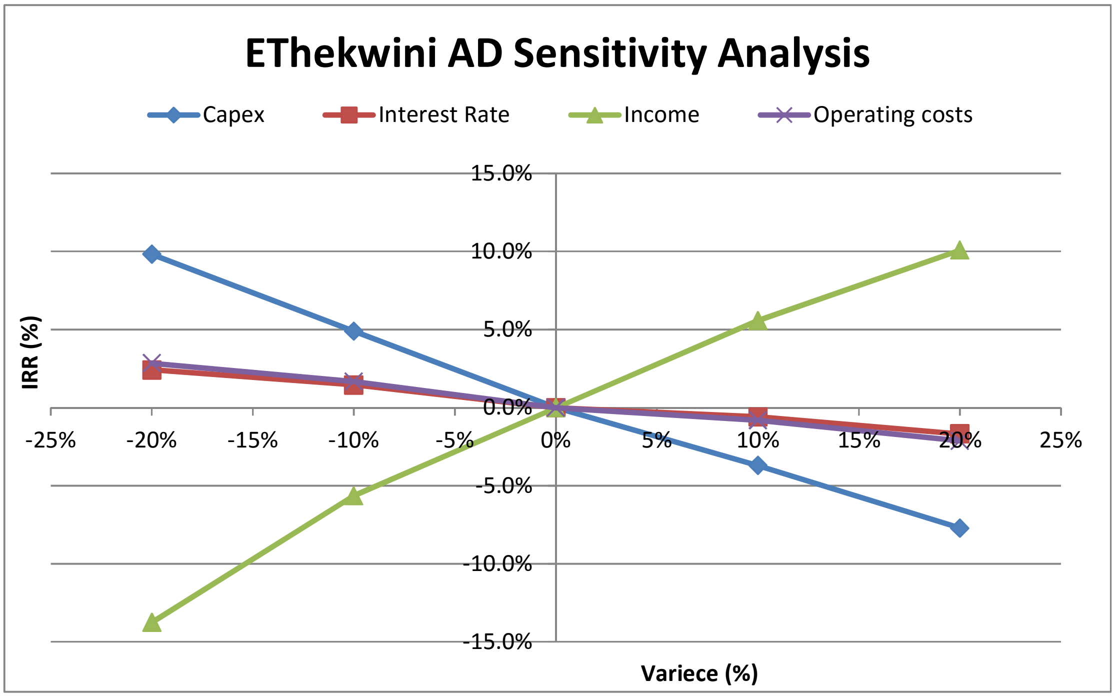


Figure 10.21 – eThekwini anaerobic digestion sensitivity analysis

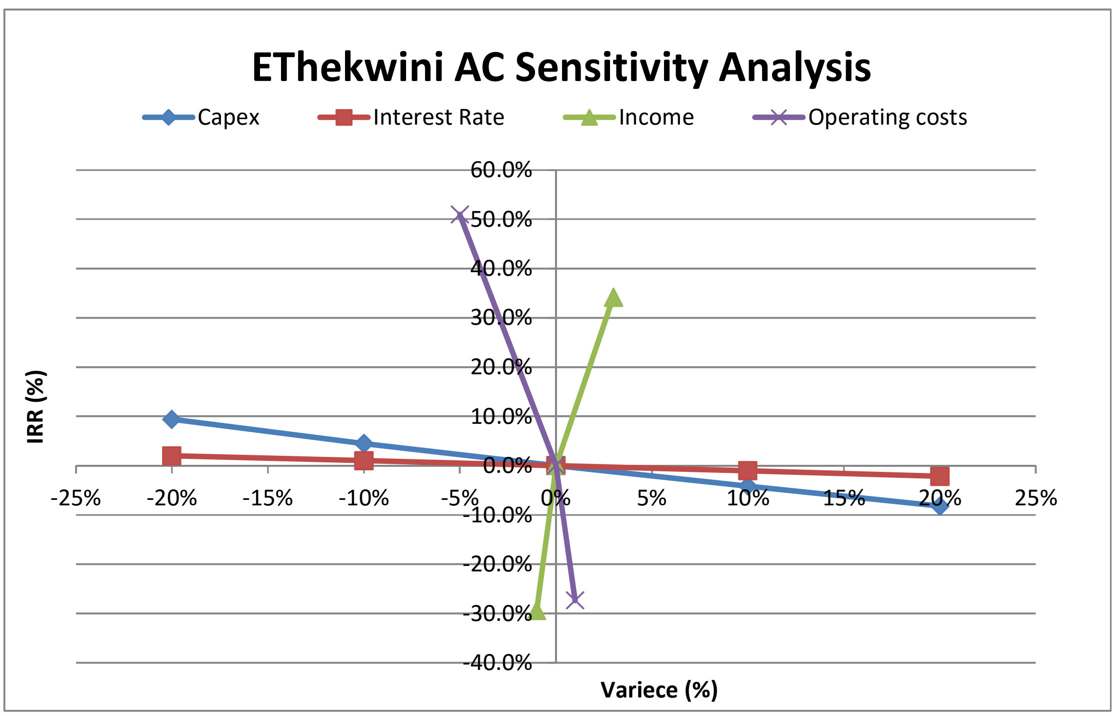


Figure 10.22 – eThekwini aerobic composting sensitivity analysis

The best case scenario for the landfill gas recovery system was found to have a high internal rate of return of 87%. This can be attributed to the income of R47 million which can be generated through REFIT tariffs of a 6MW generation capacity. Likewise a material recovery facility would also generate an extremely high IRR of 421%. This is due to the high income which can be generated from the 220 000 tons of recyclable material in eThekwini. The material recovery facility has the highest feasibility of the different strategies. Anaerobic digestion analysis provided high capital costs of R706 million and operating costs of R192 million, due to the large biogenic fraction of waste, together with the high rand dollar exchange rate used. Nevertheless, the project resulted in a 48% IRR. The composting strategy resulted in an IRR equal to the WACC, however this was the lowest of all the strategies at 12%. A high income of R72 million can be expected but this is offset by the high operating costs of R70 million/year.

The modelled landfill gas recovery system was found to be highly sensitive to the income generated from the sale of electricity. Capital costs were found to have a feasible sensitivity with a 20% increase in capital costs resulting in a -8% IRR. Interest rates and operating costs were found to have a low sensitivity to change. Similarly to landfilling, MRF income and capital costs were found to be the most sensitive variable in the model, with -20% decrease in income resulting in a -14% IRR. Again debt interest rate and operating costs were found to have very little effect on the IRR when varied. Anaerobic digestion was also found to be highly variable to the income with a decrease of -20% in income resulting in a -13.8% IRR. Aerobic composting was found to be extremely sensitive to income and operating costs. A 1% increase in operating costs results in a 27% decrease in the internal rate of return, and a 1% decrease in income resulting in a 29% decrease in IRR. This sensitivity analyses shows that the composting model is extremely sensitive to a change in variables.

10.10.2. Msunduzi Economic

Table 10.16 shows the summary of the economic analysis of Msunduzi municipality and Figures 10.23 to 10.24 show the sensitivity analysis of the models. Discounted cashflow analysis for the best case scenarios can be seen in Appendix D.

	Tons/ year	Required MW	Capital Cost (Rands)	Interest accrued	Operating cost (Rands/year)	Scenarios	Income Rate	Income (Rands/year)	IRR %
Landfilling	149 332	0.91	10 000 925	2 726 927	1 000 092	Best Case	R0.9/kWh	7 069 745	87
						Breakeven	R0.3/kWh	2 356 582	0
						WACC	R0.36/kWh	2 827 898	12
MRF	21 252		34 854 330	9 503 643	12 990 364	Best Case	Various	20 206 053	18
						Breakeven	-12%	17 781 327	0
						WACC	-5%	19 195 751	12
AD	80 376	4.78	269 884 818	73 588 822	14 427 953	Best Case	R0.96/kWh R250/ton	51 567 068	1
						Breakeven	R0.93/kWh R250/ton	50 327 200	0
						WACC	R1.25/kWh R250/ton	63 552 452	12
AC	51 370		1 563 781	426 392	7 810 840	Best Case	210	8 090 808	12
						Breakeven	208.2	8 021 458	0
						WACC	210	8 090 808	12

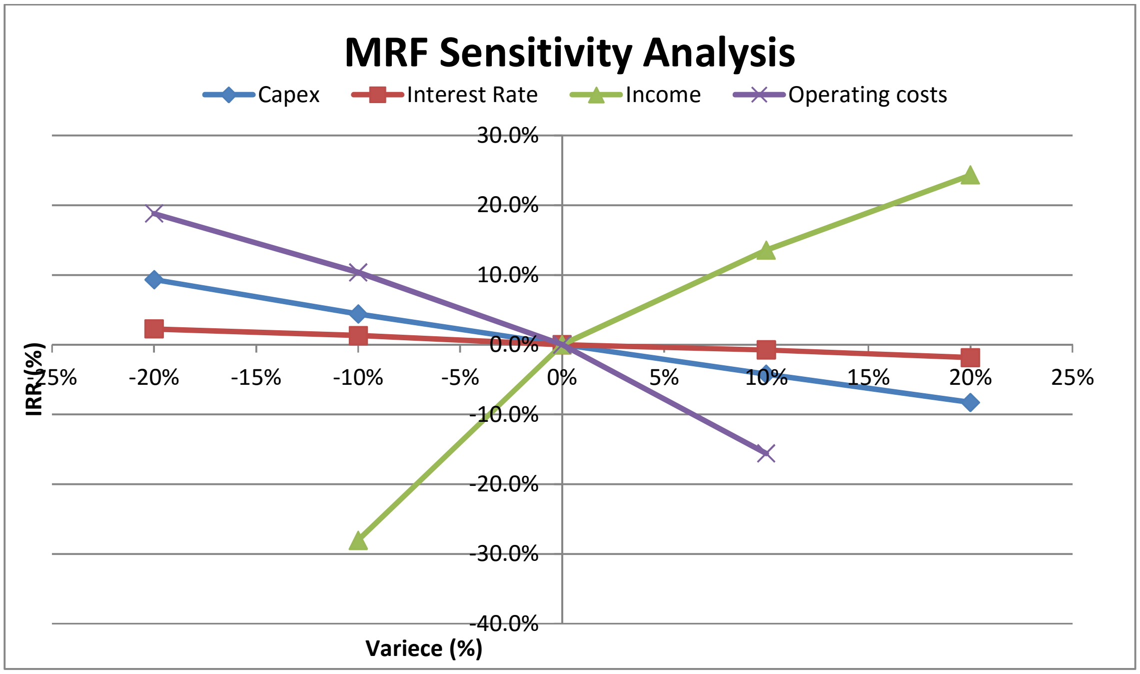


Figure 10.23 – Msunduzi MRF sensitivity analysis

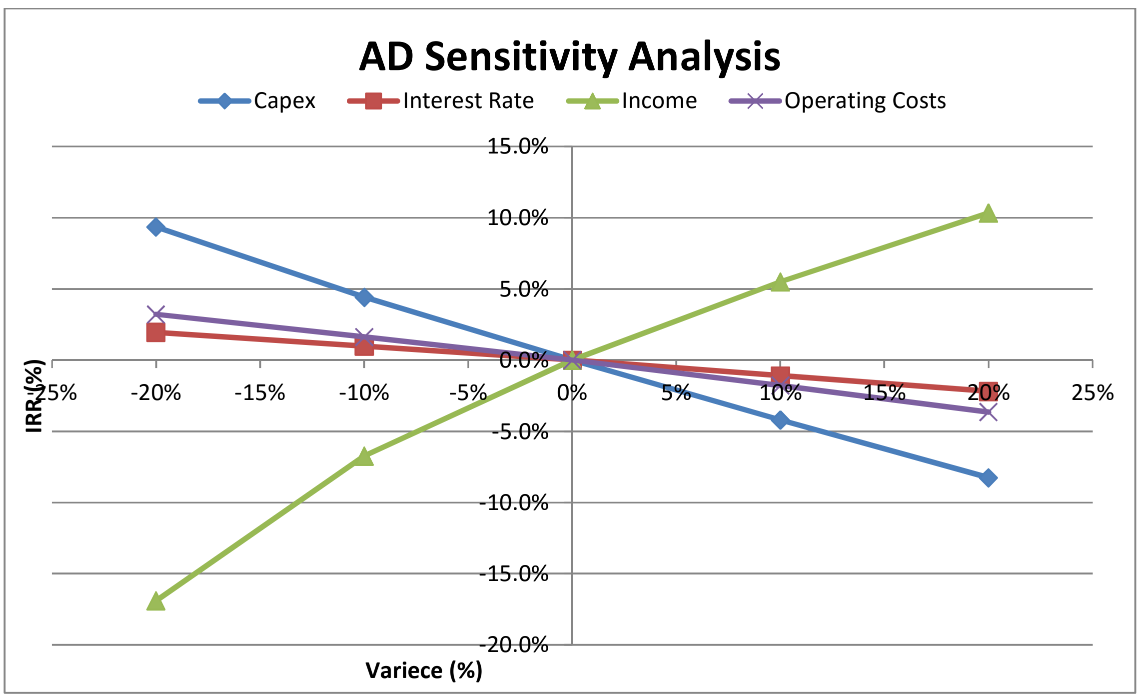


Figure 10.24 – Msunduzi AD sensitivity analysis

The following conclusions can be drawn from the economic analysis and the sensitivity analysis.

The landfilling and composting models resulted in the internal rate of return being exactly the same as the eThekwini models. This is due to the linear relationships used to determine the capital costs and the income from the total tonnages processed for the year. For this reason, the sensitivity analysis of landfilling and composting provided the same results as eThekwini.

The landfilling gas recovery strategy capital costs amounted to R10 million rand for a 0.9MW system. The best case scenario would result in R7 million being produced as income through REFIT tariffs. The MRF strategy was also estimated to be feasible with an IRR of 18%. The anaerobic digestion strategy resulted in being marginally higher than the break even case with an IRR of 1%. Taking into account the sensitivity analysis and the high capital costs of R269 million, it would be impracticable to implement an AD plant in Msunduzi. The composting strategy proves to be feasible once again and requires low capital costs of R1.5 million, however the operating costs were estimated to be R7.8 million.

The MRF sensitivity analysis indicated that the IRR was highly sensitive to the income generated and to the operating costs. A 10% decrease in income yielded a -28% IRR whilst a 10% increase in operating costs yielded a -16% IRR. Both these scenarios would result in an extremely unfeasible situation. Income was again the most sensitive variable for the AD strategy. In both cases the interest rate did not affect the IRR greatly.

10.10.3. Newcastle Economic

Table 10.17 shows the summary of the economic analysis of Newcastle municipality and Figures 10.25 to 10.26 show the sensitivity analysis of the models. The discounted cash flow analysis for the best case scenarios can be seen in Appendix D.

	Tons/ year	Required MW	Capital Cost (Rands)	Interest accrued	Operating cost (Rands/year)	Scenarios	Income Rate	Income (Rands/year)	IRR %
Landfilling	19 366	0.12	1 296 961	353 639	129 696	Best Case	R0.9/kWh	916 834	87
						Breakeven	R0.3/kWh	305 611	0
						WACC	R0.36/kWh	366 734	12
MRF	6 158		30 714 553	8 374 861	12 133 646	Best Case	Various	6 041 379	N/A
						Breakeven	170%	16 311 722	0
						WACC	192%	17 640 825	12
AD	3 408	0.2	46 253 398	12 611 799	4 300 391	Best Case	R0.96/kWh R250/ton	2 186 735	N/A
						Breakeven	R5.25/kWh R600/ton	10 411 263	0
						WACC	R6.50/kWh R600/ton	12 601 988	12
AC	3 679		112 010	30 542	559 474	Best Case	210	579 528	12
						Breakeven	208.2	574 560	0
						WACC	210	579 528	12

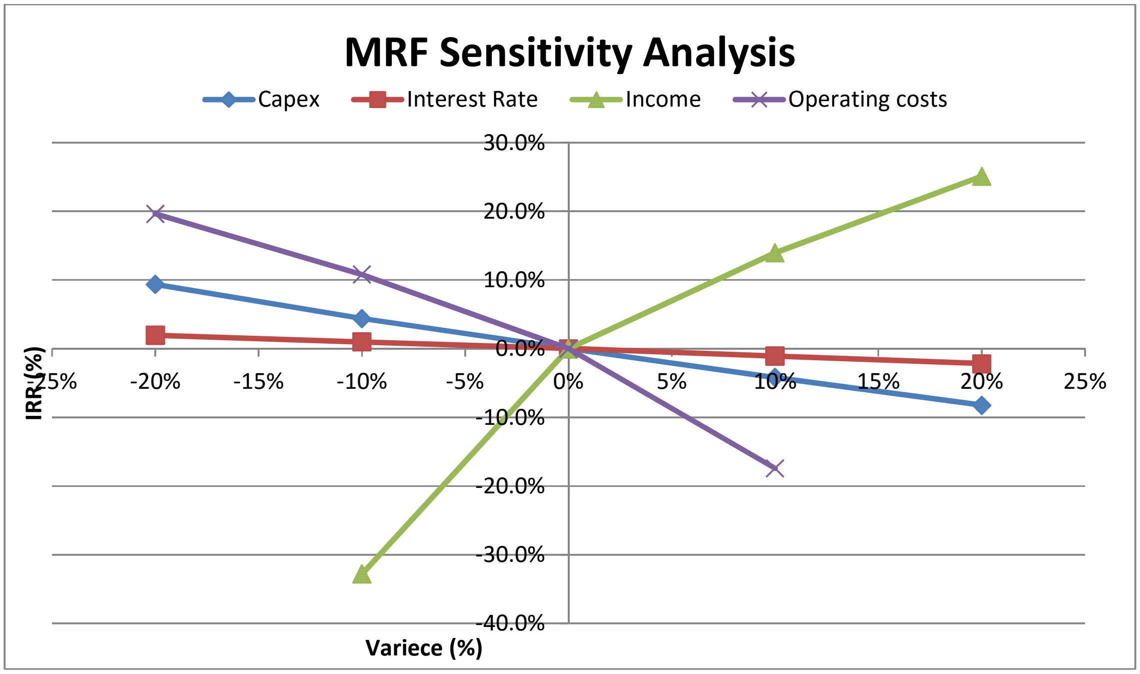


Figure 10.25 – Newcastle MRF sensitivity analysis

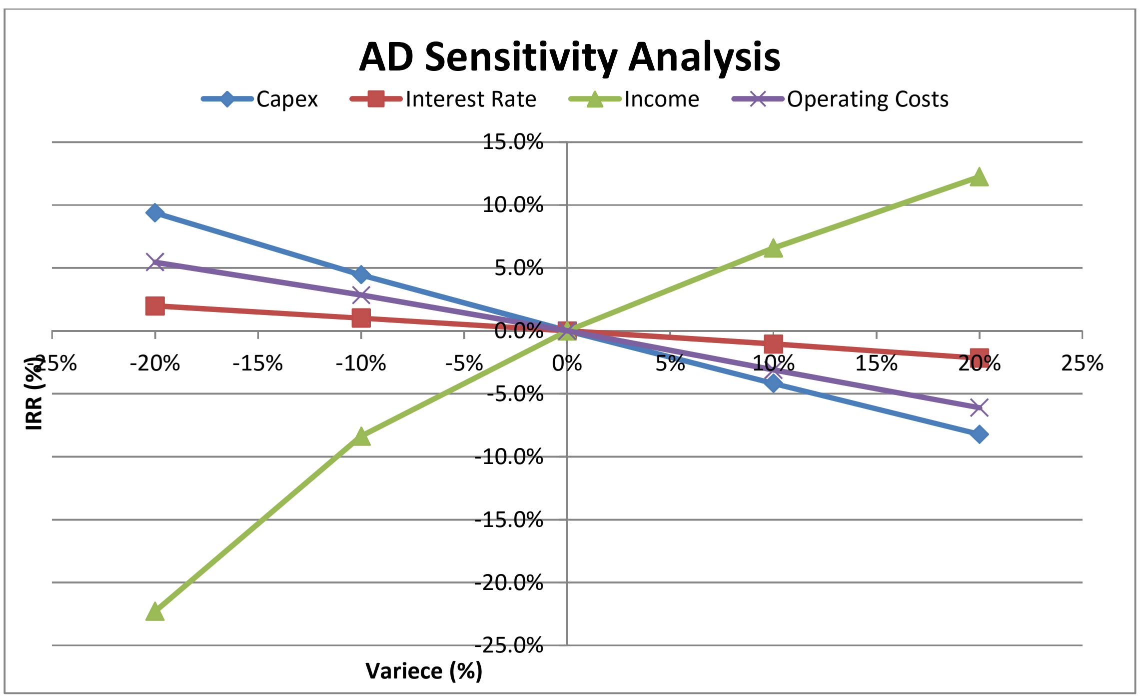


Figure 10.26 – Newcastle AD sensitivity analysis

The following conclusions can be drawn from the economic analysis and the sensitivity analysis.

The landfilling and AC strategy provided the same IRR as the eThekwini and Msunduzi case studies, which confirms that the strategy is economically viable regardless of the input quantity of waste. The low quantity of waste in the Newcastle municipality resulted in a 0.12MW generation capacity needed for the landfill gas recovery strategy and 0.2MW for the AD strategy.

The MRF and AD strategies were rendered unfeasible by the IRR being extremely low which could not be calculated through the iterative process. This could again be due to the quantity of waste resulting in the requirement of small MRFs and ADs, which would not be feasible due to economies of scale. Cost advantages are experienced as a project increases in size, output and scale of the operation, as fixed costs are spread over a greater number of units of output.

The IRR was highly sensitive to the income generated for both the MRF and AD strategies. Operating and capital costs were also found to be sensitive variables. The debt interest rate once again did not affect the IRR greatly.

A LFG recovery system proved to be the most economically feasible strategy that could be implemented in the Newcastle Municipality. Composting also proved to be feasible. For an MRF or AD project to be feasible in the Newcastle Municipality, the waste quantity would need to increase or the income generated from the project would need to be drastically increased.

10.11. Chapter Summary

The eThekwini, Msunduzi and Newcastle municipalities were evaluated according to greenhouse gas emission, landfill space savings, landfill diversion rate and economic viability.

The greenhouse gas evaluation provided data estimates regarding the different scenarios set out in the methodology chapter. Table 10.18 shows the greenhouse gas emissions summary.

Table 10.18 – GHG emissions summary

$MTCO_2$ EQ	**Scenario 1**	**Scenario 2A**	**Scenario 2B**	**Scenario 3A**	**Scenario 3B**	**Scenario 4**	**Scenario 5**
EThekwini	1 026 600	112 426	-133 025	-183 206	-289 359	-374 436	-142 454
Msunduzi	153 298	16 645	-20 046	-25 927	-49 130	-64 236	-32 730
Newcastle	19 964	2 243	-2 516	-6 383	-12 021	-12 671	-10 863

Scenario 1 and 2A resulted in positive emissions whilst the other scenarios resulted in a net reduction in GHG emissions. Scenario 1 also resulted in the greatest increase in emissions and scenario 4 resulted in the greatest reduction in emissions for all three case studies. The biogenic and recyclable fraction was found to play an important role in GHG emissions increase and reductions. The difference between scenarios 3B and 4 in the Newcastle municipality was found to be marginal compared to the other municipalities this could be due to the nature of the waste having a low biogenic content, that is diverted in scenario 4. US EPA methodology was found to produce higher emission increases and reductions than the South African emission factors.

The landfill space savings and diversion rate assessment both found scenario 4 and 5 to be the most environmentally friendly, with the greatest landfill airspace being saved in scenarios 4 and 5 for the three municipalities. The diversion rate was found to be the best method of comparing the case studies, which was not possible with GHG emissions and landfill airspace savings

The MRF strategy was found to be the most economically feasible strategy to implement in the EThekwini Municipality but landfill gas recovery systems were found to be the most economically feasible for both Newcastle and Msunduzi.

It should be noted that the capital and operating costs, and income estimates are based on available data. However, there is a general lack of local data especially with regard to MRF and AD plant costs as these strategies are not used extensively throughout South Africa.

The dependence on European and North American data may affect cost estimations as converting from Dollars to Rands does not constitute an accurate estimate. Costs for labour, water, electricity and other utilities vary within the different economies (Rapport et al., 2008). Economy of scale is also not taken into account for the landfilling gas recovery and composting capital and operating costs.

Chapter 11 - Conclusion

11.1. Introduction

This study comprised of the following components in assessing the potential zero waste scenarios and strategies for the eThekwini, Msunduzi and Newcastle municipalities.

- Further development of various zero waste scenarios
- Further development of the WROSE model
- GHG emission/reduction evaluation of each scenario
- Landfill airspace assessment of each scenario
- Waste diversion rate assessment of each scenario
- Discounted cash flow analysis of the various strategies that evaluated the capital, and operating costs and potential income.

This chapter aims to summarise these results, comment on challenges and make recommendations based on the results of the study.

11.2. Summary of results

The waste stream of all three case studies showed a significant fraction of biogenic and recyclable waste. These fractions of waste showed the potential of alternative waste management strategies such as anaerobic digestion, composting and recycling. These waste groups also have the potential to decrease the GHG emissions as shown in the 'Results' chapter, where the scenarios that divert these waste groups produced the greatest reduction in GHG emissions, the greatest landfill space saving and the greatest diversion rates.

The alternative scenarios all produced a noticeable reduction in GHG emissions compared to the baseline scenario of landfilling. One million $MTCO_2eq$ are produced through landfilling in eThekwini whilst a reduction of -374 436 $MTCO_2eq$ is estimated for scenario 4. 153 298 $MTCO_2eq$ are estimated to be emitted in Msunduzi municipality through landfill disposal and a reduction of - 64 236 $MTCO_2eq$ can be expected if scenario 4 is implemented. Similarly in Newcastle scenario 1 produced the greatest emissions with 19 964 $MTCO_2eq$ and scenario 4 the greatest reduction with - 12 671 $MTCO_2eq$.

The landfill airspace and waste diversion rate assessment indicated that scenarios 4 and 5 would produce the greatest environmental benefit in all three case studies. In eThekwini, scenarios 4 and 5 diverted 671 714 tons and 682 383 tons respectively which resulted in between 559 761m^3 and 1 000 953m^3 landfill airspace saved. A significantly lower quantity of waste would be potentially diverted in Msunduzi for scenarios 4 and 5, this would result in an estimate landfill airspace saved of 60 519m^3 and 126 547m^3. Newcastle would save between 7 972m^3 and 19 340m^3 of landfill airspace if scenarios 4 or 5 were implemented. The diversion rate provided an inclusive method of comparing the different case studies, once again scenario 4 and 5 resulted in the greatest estimated diversion rates. Diversion rates of 46% to 68% were estimated for these scenarios across the three case studies.

EThekwini's economic analysis resulted in the material recovery facility having the greatest internal rate of return and thus being the most feasible strategy. It was concluded that this was largely due to the large quantity of waste and recyclable present in the waste stream. The high capital and operating costs were simply offset through the income generated from the sale of recyclables. Landfilling with gas generation was found to be the most feasible in Msunduzi, followed by a material recovery facility with an IRR of 18%. Whilst not extremely profitable, the material recovery facility does return an IRR greater than the weighted average cost of capital. The Newcastle economic analysis was problematic due to the low quantity of waste entering the waste stream resulting in anaerobic digestion and material recovery facility not being feasible and returning an extremely low (negative) IRR. Therefore landfilling and composting were the only feasible options in Newcastle.

11.3. Challenges

The high capital and operating costs of landfill gas recovery systems, anaerobic digestion and material recovery facilities, remain the greatest challenge towards their implementation in South African municipalities. The relevance of these waste diversion strategies is questioned when large areas of South Africa have no formal rubbish removal at all. 5% of the population of Msunduzi has no formal refuse removal in addition to 4% of Newcastle and 2% of eThekwini. This results in 114 303 people within the three municipalities making use of informal refuse disposal methods. These basic requirements need to be met before waste divergent strategies can be implemented, however with limited and insufficient waste management budgets service, delivery in all areas in not possible.

The high capital costs can be offset by the development and economic growth that can be expected from large scale engineering projects that promote job creation and skills development. The costs can also be offset by the environmental and social benefits. The eThekwini landfill gas recovery system is a successful example where high capital and operating costs were overcome in the implementation of a waste diversion strategy

Incentives and subsidies are needed to established markets for products yielded from the waste diversion strategies. Electricity generated from the production of landfill gas and biogas from anaerobic digestion is sold at a much higher rate than standard coal produced electricity. This creates a higher income for the project and results in the project being more economically feasible whilst also encouraging investment in renewable energy. This is subsidised through the NERSA renewable energy feed-in tariff. Initiatives like this, together with commitment from government, are needed to make composting from MSW, anaerobic digestion digestate and recyclables more attractive to investors.

Social challenges, such as the negative social perception of waste management, high levels of social participation required for source separation, cleanliness and noise generation from machinery, will need to be overcome in order to successfully implement waste diversion strategies. Composting and anaerobic digestion can be implemented in enclosed facilities thus limiting the impact of odours. Public perception of waste management may be improved through education and providing information on waste diversion benefits to the public. There are significant challenges to the implementation of waste diversion strategies however there are benefits that are equally advantageous.

11.4. Recommendations

The following research gaps were realised through the study and the following recommendations are made.

Environmental

- The WROSE model can be greatly improved by the development of emission factors for sulphur dioxide, nitrous oxides and chlorofluorocarbons using South African data. These emissions are produced primarily through the use of machinery and transportation in the waste sector.
- Energy and water consumption of the waste management strategies should be implemented as an indicator into the WROSE model to evaluate the utilities cost and environmental impact of their consumption.
- A comprehensive waste stream analysis needs to be completed by the eThekwini and Msunduzi municipalities in order to improve the estimated GHG emissions.

Economic

- A detailed feasibility study of anaerobic digestion and material recovery facilities should be completed in order to accurately assess capital and operating costs in the South African context. Cost curves using South African data would have a greater applicability in the WROSE model compared to comprehensive cost estimate quotations that would be different for each case study and therefore unfeasible.
- Economies of scale needs to be incorporated into the capital and operating costing for landfill gas recovery systems and composting strategies, in order to improve the economic modelling of these strategies.

Social

- Social indicators such as job creation and the cleanliness of the strategies scored highly on the matrix evaluation. A methodology needs to be determined in order to evaluate the social indictors and include this in WROSE in the future.
- Indicators such as public perception and willingness of social participation can be evaluated through the use of a questionnaire to the residents of the case study municipality.

Additional environmental, economic and social indicators should be evaluated further to truly assess the various scenarios and strategies.

11.5. Conclusion

The primary conclusion that can be drawn from this research is that biological treatment together with mechanical treatment as in scenario 4 and 5 produces the greatest reduction in GHG emissions. Biological treatment of the waste occurs through the use of anaerobic digestion and the composting of biogenic waste. Mechanical treatment of the waste is in the form of sorting and separation of untreated municipal solid waste into recyclables and biogenic waste in a material recovery facility. The study concluded that extremely high capital and operating costs of strategies together with the low estimated income are the main barriers for implementation in South Africa.

This study evaluated the environmental and economic impacts of various waste management scenarios through the use of a model called WROSE. The study focused on three municipalities within KwaZulu-Natal as case studies, with the aim of making the model applicable to all municipalities in South Africa. The principle environmental impact evaluated was the carbon dioxide GHG emissions. These emissions were quantified by further developing the WROSE model to use South African emission factors which could then be compared to emission factors developed by the United States Environmental Protection Agency. The principal economic indicator was the internal rate of return, which was determined through a discounted cash flow analysis which made use of the capital and operating costs and income, in order to calculate the IRR. The zero waste scenarios were assessed and compared on the basis of these indicators. Using these results the research is intended to provide information and data for municipal waste engineers and managers in order to assess the alternatives to landfilling. The comparative principle the WROSE model is based on, allows the model to be applicable in assisting South African municipalities in evaluating different sustainable waste management strategies, other than landfill disposal, that provides an economically feasible solution, whilst also diverting waste and reducing GHG emissions.

Chapter 12 – References

Adhikari, B.K., Barrington, S., Martinez, j., King, S., 2008. Characterization of food waste and bulking agents for composting. Waste Management, volume 28, pp 795–804

Agama biogas, 2009. Sustainable Cities: Biogas energy from waste a feasibility study and guidelines for implementing biogas from waste projects in municipalities guidelines report.

Armijo, C., Puma, A., Ojeda, S., 2011. A set of indicators for waste management programs. 2nd international conference on environmental engineering and applications, volume 17. Singapore.

Austin, G., Gets, A., 2009. Biogas energy from waste: A feasibility study and guidelines for implementing biogas from waste projects in municipalities. Southern African Cities Network.

Bagghi, A., 2004. Design of landfills and integrated solid waste management. Third edition. John Wiley and Sons Inc. Hoboken. New Jersey.

Barlaz, M.A., Ham, R, K. & Schaefer, D.M., 1989. Mass balance analysis of decomposed refuse in laboratory scale lysimeters. Journal of environmental engineering, volume 115 (6), pp 1088 – 1102.

Barlaz, M.A., Ham, R.K., 1993. Leachate and gas generation: geotechnical practises for waste disposal. Chapmen and Hall. London.

Black, R. J., G. L. Miller., 1998. Benefits of using compost and mulch in Florida roadside planting. Environmental Horticulture Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

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.

Bove, R., Lunghi, P., 2006. Electric power generation from landfill gas using traditional and innovative technologies. Energy conversion and management, volume 47, pp 1391 – 1401.

Calreycle, 2008. Current anaerobic digestion technologies used for treatment of municipal organic solid waste. California integrated waste management board. California.

Chang, C.N., Chang, S.C., Lin, J.G., 1997. Enhancement of anaerobic digestion of waste activated sludge by alkaline solubilisation. Bioresource Technology, volume 62, pp 85 – 90.

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.

Cimpan, C., Maul, A., Jansen, M., Pretz, M., Wenzel, H., 2014. Central sorting and recovery of MSW recyclable materials: A review of technological state-of-the-art, cases, practice and implications for materials recycling. Journal of Environmental Management, volume 156, pp 181 – 199.

Clavreul, J., Guyonnet, D., Tonini, D., Christensen T., 2013. Stochastic and epistemic uncertainty propagation in LCA. International Journal of life cycle assessment, volume 18(7), pp 1383 – 1403.

Coelho, T.M., Castro, R., Gobbo Jr, J.A., 2011. PET containers in Brazil: Opportunities and challenges of a logistics model for post consumer waste recycling. Resource, Conservation and Recycling, volume 55(3), pp 291 – 299.

Coetzee, J.A., Haider, M.S., Hall, C.J., Keraan, S., 2007. Impacts on solid waste disposal resulting from the implementation of integrated waste management polices and plans: City of Cape Town, South Africa. Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, Santa Margherita di Pula, Cagliari, Sardinia, Italy, October 2007.

Cole, M.A., Liu, X., Zhang, L., 1994. Plant and Microbial Establishment in Pesticide contaminated Soils Amended With Compost. Bioremediation through Rhizosphere Technology, pp 210 – 222.

Conghos, M.M., Aguirre, M.E., Santamaria, R.M., 2003. Biodegradation of sunflower hulls with different nitrogen sources under mesophilic and thermophilic incubations. Biol. Fert. Soils, volume 38, pp 282–287.

Council Directive 75/442/EEC on Waste (1975). Official Journal of the European Communities, L 194/39, 15 July 1975, subsequently amended by Council Directive 91/156/EEC

Council for Scientific and Industrial Research (CSIR), 2011. Municipal waste management – good practises. CSIR. Pretoria.

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., 2012. Cost effective waste management through composting in Africa. Waste management.

Craighill, A.L., Powell, J.C., 1996. Lifecycle assessment and economic evaluation of recycling: a case study. Resource, Conservation and Recycling, volume 17, pp 75 – 95.

Das, D., 2012. Feasibility study of food waste to energy conversion through anaerobic digestion. Faculty of California State University.

Department of Environmental Affairs (DEA), 2013. The national organic waste composting strategy: draft guideline document for composting. Pretoria

Department of Environmental Affairs (DEA), 2014. South African greenhouse gas mitigation potential analysis. Pretoria.

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

Department of Environmental Affairs and Tourism, 2011. National Waste Management Strategy. Department of Environmental Affairs and Tourism, Pretoria.

Department of Water Affairs and Forestry (DWAF). 1998. Waste management series: The minimum requirements for waste disposal by landfill. Second edition. CTI Printers. Cape Town.

Department of Water Affairs and Forestry, 2005. Waste management series: Minimum requirements for the handling, classification and disposal of hazardous waste. draft 3rd edition. Pretoria.

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

EWAG, 2014. Anaerobic Digestion of Biowaste in Developing Countries Practical Information and Case Studies. Swiss federal institute of aquatic science and technology. Dubendorf, Switzerland.

E-waste association of South Africa (e-WASA), 2008. E waste assessment of South Africa. eWASA. South Africa.

Fiksel, J., 2009. Design for the Environment. A Guide to Sustainable Product Development. Second edition. McGraw-Hill., New York, NY, USA.

Finck, A. 1982. Fertilizers and fertilization: Introduction and practical guide to crop fertilization. Verlag Chemie. GimbH, Weinheim. Federal Republic of Germany.

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, R. Van Dorland, 2007. Changes in atmospheric constituents and in radiative forcing. Climate change 2007: The physical science basis. contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change Cambridge University Press. United Kingdom.

Friedrich E., Trois, C., 2013. Current and future greenhouse gas emissions from the management of municipal solid waste in the eThekwini municipality south Africa. Journal of cleaner production, volume 2015, pp 1 – 13.

Friedrich E., Trois, C., 2013. GHG emission factors developed for the collection, transport and landfilling of municipal waste in South African municipalities. Waste Management, volume 33, pp 1013 – 1026.

Friedrich E., Trois, C., 2013. GHG emission factors developed for the recycling and composting of municipal waste in South African municipalities. Waste Management, volume 33, pp 2520 – 2531.

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

Glavic, P., Lukman, R., 2007. Review of sustainability terms and their definitions. Journal of Cleaner Production, volume 15, pp 1875 – 1885
GreenEng, 2010. UMDM waste characterisation study – inception report.

Harper, S.R., Pohland, F.G., 1988. Landfill lessening environmental impacts. Civil Engineering, volume 58(11), pp 66 – 69

Haug, R.T., 1993. Compost Engineering. The Practical Handbook. Lewis Publishers. USA

Hoitink, H. A. J., Fahy, P.C., 1986. Basis for the control of plant pathogens with compost. Annual Review of Phytopathology, volume 24, pp 93 – 114.

Hoornweg, H., Thomas, L., Otten, L., 2000. Composting and Its Applicability in Developing Countries. Urban waste management. The World Bank.

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.

IPCC, 2014. Summary for Policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jagath, R., 2010. An assessment of carbon emissions reduction potential through zero waste activities in South African municipalities. Masters of Science in Engineering. UKZN.

Kelly, T., 2014. Integrated waste management plan. Newcastle local municipality.

Kjeldsen, P., Barlaz, M.A., Rooker, A.P., Baun, A., Lendin, A., Christensen, H., 1992. Present and long term composition of MSW landfill leachate: A review. Critical reviews in Environmental science and technology, volume 32(4), pp 297-336

Lakhan, L., 2015. A Comparison of Single and Multi-Stream Recycling Systems in Ontario, Canada. [Online] available at. www.mdpi.com/2079-9276/4/2/384/pdf. Accessed on 1st November 2015.

Lashermes, G., Houot, S., Barriuso, E., 2012. Dissipation pathways of organic pollutants during the composting of organic waste. Chemosphere, volume 87, pp 137 – 143.

Li, Z., Lu, H., Ren, L., He, L., 2013. Experimental and modelling approaches for food waste composting: A review. Sino-Canada Resources and Environmental Research Academy, North China Electric Power University, Beijing China

Liang, C., Das, K.C., McClendon, R.W., 2003. The influence of temperature and moisture contents regimes on the aerobic microbial activity of a biosolids composting blend. Bioresour. Technol, volume 86, pp 131 – 137.

López-Real, J., Foster, M., 1985. Plant pathogen survival during composting of agricultural waste. Composting of Agricultural Wastes. Elsevier Applied Science, London, pp. 291 – 299.

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.

Luoranen, M., Soukka, R., Denafas, G., Horttanainen, M., 2009. Comparison of energy and material recovery of household waste management from the environmental point of view – Case Kaunas, Lithuania. Applied Thermal Engineering, volume 29, pp 938 – 944.

Maharaj, Y., 2014. Life cycle assessment of municipal solid waste management in Newcastle local Municipality. Master of science in engineering thesis. University of KwaZulu-Natal. Durban.

Marchetti, R., 2007. Long Term Emissions from Waste Using Leaching Columns. Msc Thesis. University of KwaZulu-Natal, RSA.

Mata-Alvarez, J., Mace, S., and Llabres, S., 2000. Anaerobic digestion of organic solid wastes: An overview of research achievements and perspectives. Bioresource Technol, volume 3(16).

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 Kwa – Zulu Natal. Durban.

Mgingqizane, N., 2004. Report on the Recycling Status Survey and Waste Analysis in the Following Areas – Umlazi, Inanada, Hillcrest, Tongaat and Amamzimtoti. DSW Internal report. DSW, Durban, RSA.

Moller, 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.

Monnet. F., 2003. An introduction to anaerobic digestion of organic wastes. Remade. Scotland.

Moodley, L., Winn, R., Parkin, J., 2011. Buffer zones: The long term interface. EThekwini Municipality, Department of Cleansing and Solid Waste.

Moodley, L.,2005. Organic composting using the Dome Aeration technology. B.Sc dissertation, University of KwaZulu-Natal, South Africa

Msunduzi local municipality, 2014. Integrated waste management plan 2014 – 2018.

Nahman, A., De Lange, W., Oelofse, S., Godfrey, F., 2012. The cost of household food waste in South Africa. Waste Management, volume 32(11), pp 2147 – 2153.

Newcastle local municipality (NLM), 2011. Newcastle municipality integrated development plan 2012 – 2017. Newcastle municipality: office of the municipal manager.

Norbu, T., Visvanathan, C., Basnayake, B., 2005. Pretreatment of municipal solid waste prior to landfilling. Waste Management, volume 25, pp 997 – 1003

NRC., 2011. Sustainability and the U.S. EPA. The National Academies Press, Washington D.C., USA.

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.H.H., Godfrey, I., 2008. Defining waste in South Africa: moving beyond the age of waste. South African journal of science, volume 104.

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

Pace, M.G., Miller, B.E., Farrell- Poe, K.L., 1995. The composting process. Utah State University Extension.

Paper recycling association of South Africa, 2015. Paper recycling in south Africa facts and statistics July 2015. [online] available at http://www.recyclepaper.co.za/wp-content/uploads/2015/08/LB413-PRASA-A4-July_2015-summary.pdf. Accessed on 4th September 2015.

Parkin, J., 2011. Durban's gas to electricity project DNA CDM workshop. Durban. 17 November 2011

Paul, J.G., Flora, R.J., Buquiran, M., Palma, J.D., Cadiz, L., 2007. Composting as a suited tool to enhance waste management in rural areas in the Philippines. Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, Santa Margherita di Pula, Cagliari, Sardinia, Italy, October 2007.

Payne, G.J., 2005. Buffelsdraai landfill a new regional landfill for the eThekwini council. Thekwini GeoCivils cc.

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

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

Recycling revolution, 2010. Recycling benefits: the main reasons why.

Reinhart, D.R., Grosh, C.J., 1998. Analysis of Florida MSW landfill leachate quality. Florida centre for solid and hazardous waste management. Gainesville, Florida.

Reliance composting, 2015. Reliance composting product price list. [online]. Available at http://www.reliance.co.za/productpricelist.html. Accessed on 24th September 2015.

Republic of South Africa (1989). Environmental Conservation Act, Act 73 of 1989. Government Gazette, 1 June 1989.

Republic of South Africa, 2000. White paper on integrated pollution and waste management for South Africa. a policy on pollution prevention, waste minimisation, impact management and remediation. Government Gazette Vol. 417, No. 20978

Republic of South Africa, 2014. National Environmental Management: Waste Amendment Act. Government Gazette Vol. 588, No. 37714, 2 June 2014. Government Printers, Pretoria.

Revans, A., Ross, D., Gregory, B., Meadows, M., Harries, C. & Gronow, J., 1998. Long term fate of metals in landfills in Sardinia. Seventh international waste management and landfill symposium. CISA. Cagliari, Italy.

Rigamonti, L., Grosso, M., Giugliano, M., 2009. Life cycle assessment for optimising the level of separated collection in integrated MSW management systems. Waste Management, volume 29, pp 934 – 944.

Risse, M., Faucette, B., 2000. Food waste composting, institutional and industrial application. Cooperative Extension Service, the University of Georgia College of Agricultural and Environmental Sciences.

Robinson, H.D., 1995. The technical aspects of controlled waste management: A review of the composition of leachate from domestic wastes in landfill sites. Report for the UK Department of Environmental Waste Science and Research. Aspinwall & Company. London.

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

Schubeler, 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

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.

Sibanye Recycling, 2015. Personal communication

SKC Engineers, Haultec, 2002. Master plan 2002 for solid waste management in eThekwini municipality area. Durban

Smårs, S., Gustafsson, L., Beck-Friis, B., Jönsson, H., 2002. Improvement of the composting time for household waste during an initial low PH phase by mesophilic temperature control. Bioresour Technol, volume 84, pp 237–241.

Smith, A., Brown, K., Ogilvie, S., Rushton, K., Bates, J., 2001. Waste management options and climate change: Final report to the European Commission.

South African plastic recyclers organization, 2012. Plastics recycling survey. Plastics SA.

South African Waste Information Centre, 2015. Waste Tonnage reports. Available at http://sawic.environment.gov.za/?menu=15. Accessed on 12th February 2016.

Statistics South Africa, 2011. EThekwini metropolitan municipality. Available at http://www.statssa.gov.za/?page_id=1021&id=ethekwini-municipality. Accessed on 5th December 2015

Statistics South Africa, 2011. Msunduzi local municipality. Available at http://www.statssa.gov.za/?page_id=993&id=the-msunduzi-municipality. Accessed on 5th December 2015

Statistics South Africa, 2011. Newcastle local municipality. Available at http://www.statssa.gov.za/?page_id=993&id=newcastle-municipality. Accessed on 5th December 2015

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

Stuart., P., 2008. The advantages and disadvantages of anaerobic digestion as a renewable energy source. Loughborough University

Svenskt Gastekniskt Center (SGS), 2012. Basic data on biogas. Swedish gas centre. 2nd edition.

Taiwo, O.E., Otieno, F.A.O., Venter, C., 2007. Polokwane declaration – what progress has been made and are the set targets achievable. Department of Civil Engineering, Tshwane University of Technology, South Africa.
Tchobanoglous, G., Theisen, H., Vigil, S., 1993. Integrated solid waste management: engineering principles and management issues. 2nd edition. McGraw Hill Inc. New York.

The Anderson Centre., 2010. A detailed economic assessment of anaerobic digestion technology and its suitability to UK farming and waste systems. The Anderson Centre

The glass recycling company, 2015. [online] available at http://www.theglassrecyclingcompany.co.za/who-we-are/. Accessed on June 18th 2015.

The International Solid Waste Association (ISWA), 1992. 1000 terms in solid waste management. ISWA. Denmark.

The United Nations (UN), 2007. Glossary of environmental statistics: studies in methods – Series F, No 67. United Nations. New York.

Tiquia, S.M., 1996. Further composting of pig-manure disposed from the pig-on litter (POL) system in Hong Kong. Ph.D. Dissertation. The University of Hong Kong. Pokfulam Road, Hong Kong

Toerien, D.F., Hattingh, W.H.J., 1969. Anaerobic Digestion: Microbiology. Water SA, volume 3, pp 385

Trois, C., 2014. Towards an effective clean development mechanism: energy efficiency programmes in KZN. [Public lecture for the DAAD fifth German Southern African lecture series. UKZN UNITE/School of engineering. 6th March 2013.

Trois, C., Simelane, O., 2010. Implementing separate waste collection and mechanical biological waste treatment in South Africa: A comparison with Austria and England. Waste management, volume 30(8), pp 1457 – 1463.

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

U.S. Environmental Protection Agency (USEPA), 1993. Markets for compost. Washington, D.C.: Office of Policy, Planning and Evaluation; Office of Solid Waste and Emergency Response.

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

United States Environmental Protection Agency (US EPA), 2012. A framework for sustainability indicators at EPA. National Risk Management Research Laboratory. Office of Research and Development.

van Haaren, R., 2009. Large scale aerobic composting of source separated organic wastes: a comparative study of impacts, costs and contextual effects. Masters of science thesis. Columbia university.

Verma, S., 2002. Anaerobic digestion of biodegradable organics in municipal solid wastes. Master of science degree in earth resource engineering. Columbia university.

Villeneuve, J., Michel, P., Fournet, D., Lafon, C., Ménard, Y., Wavrer, P., Guyonnet, D., 2009. Process-based analysis of waste management systems: A case study. Waste Management, volume 29, pp 2 – 11.

Vlyssides, A. G., Karlis, P. K., 2003. Thermal-alkaline solubilisation of waste activated sludge as a pre-treatment stage for anaerobic digestion. Bioresource Technology, Article in Press

Wamken ISE, 2007. Potential for greenhouse gas abatement from waste management and resource recovery activities in Australia. Final report. Sydney

WRAP, 2006. Environmental benefits of recycling – an international review of life cycle comparisons for key materials in the UK recycling sector.

Yang, Y., Tsukahara, K., Yagishita, T., and Sawayama, S., 2004. Performance of a fixedbed reactor packed with carbon felt during anaerobic digestion of cellulose. Bioresource Technol. pp 197 – 201.

Yuen, S.T.S., Styles, J.R., McMahon, T.A., 2004. Process based landfills achieved by leachate recirculation – A critical review and summary. Centre for Environmental Applied Hydrology report. University of Melbourne.

Zero Waste International Alliance (ZWIA). 2010. Zero waste definition. [online]. Available at: http://www.zwia.org. Accessed: 26 February 2015.

Appendix A – Waste fraction tonnages

Table A1 – eThekwini input quantity waste fractions

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL		
W.R.O.S.E		
	PERCENTAGES	WASTE DISPOSED (TONS)
WASTE MATERIAL OR	WASTE STREAM	ETHEKWENI
WASTE FRACTION	ANALYSIS	2015
newspaper	1.62	16183.59912
general mixed paper (CWM)	3.75	37462.035
scrap boxes and cardboard (K4)	10.76	107491.0658
low density polyethylene (LDPE)	3.13	31268.31188
high density polyethelene (HDPE)	1.45	14485.3202
Polyethelene terephthalate (PET)	1.64	16383.39664
polypropylene (PP)	5.73	57241.98948
polyvinyl chloride (PVC)	0	0
polystyrene (PS)	0	0
glass	7.21	72027.00596
steel cans/tin	3.46	34564.97096
aluminium cans	0	0
biogenic food waste	28.22	281914.3007
garden refuse green	0	0
garden refuse wood	18	179817.768
other	15.03	150147.8363
TOTAL WASTE DISPOSED/DIVERTED	100	998987.6
TONNAGE REPORTS		998987.6
RECYCLED TONS		376055.0
RR %		27%

Table A2 – Msunduzi input quantity waste fractions

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E		
WASTE MATERIAL OR	PERCENTAGES	WASTE DISPOSED (TONS)
WASTE FRACTION	WASTE STREAM	MSUNDUZI
	ANALYSIS	2015
newspaper	6.64	9915.6448
general mixed paper (CWM)	4.88	7287.4016
scrap boxes and cardboard (K4)	3.23	4823.4236
low density polyethylene (LDPE)	1.3	1941.316
high density polyethelene (HDPE)	1.13	1687.4516
Polyethelene terephthalate (PET)	2.01	3001.5732
polypropylene (PP)	1.71	2553.5772
polyvinyl chloride (PVC)	1.92	2867.1744
polystyrene (PS)	0.57	851.1924
glass	7.18	10722.0376
steel cans/tin	4.17	6227.1444
aluminium cans	0.84	1254.3888
biogenic food waste	33.64	50235.2848
garden refuse green	0.74	1105.0568
garden refuse wood	0.02	29.8664
other	30.02	44829.4664
TOTAL WASTE DISPOSED/DIVERTED	100	149332
TONNAGE REPORTS		149332
RECYCLED TONS		17490.3
RR %		10%

Table A3 – Newcastle input quantity waste fractions

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL		
W.R.O.S.E		
WASTE MATERIAL OR	PERCENTAGES	WASTE DISPOSED (TONS)
WASTE FRACTION	WASTE STREAM	NEWCASTLE
	ANALYSIS	2015
newspaper	3	580.98
general mixed paper (CWM)	16	3098.56
scrap boxes and cardboard (K4)	10	1936.6
low density polyethylene (LDPE)	3	580.98
high density polyethelene (HDPE)	3	580.98
Polyethelene terephthalate (PET)	2	387.32
polypropylene (PP)	3	580.98
polyvinyl chloride (PVC)	1	193.66
polystyrene (PS)	1	193.66
glass	12	2323.92
steel cans/tin	3	580.98
aluminium cans	3	580.98
biogenic food waste	11	2130.26
garden refuse green	4	774.64
garden refuse wood	4	774.64
other	21	4066.86
TOTAL WASTE DISPOSED/DIVERTED	100	19366
TONNAGE REPORTS		19366
RECYCLED TONS		5869
RR %		23%

Appendix B – WROSE input and output data

Table B1 – EThekwini 2015 scenario 1

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper	16183.59912					
general mixed paper (CWM)	37462.035					
scrap boxes and cardboard (K4)	107491.0658					
low density polyethylene (LDPE)	31268.31188					
high density polyethelene (HDPE)	14485.3202					
Polyethelene terephthalate (PET)	16383.39664					
polypropylene (PP)	57241.98948					
polyvinyl chloride (PVC)	0					
polystyrene (PS)	0					
glass	72027.00596					
steel cans/tin	34564.97096					
aluminium cans	0					
biogenic food waste	281914.3007					
garden refuse green	0					
garden refuse wood	179817.768					
other	150147.8363					
TOTAL WASTE DISPOSED/DIVERTED	998987.6	0	0	0	0	0
						998987.6

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper	-3746.265459					
general mixed paper (CWM)	65658.75309					
scrap boxes and cardboard (K4)	199060.8214					
low density polyethylene (LDPE)	1378.696165					
high density polyethelene (HDPE)	638.6931118					
Polyethelene terephthalate (PET)	722.3839333					
polypropylene (PP)	2523.938987					
polyvinyl chloride (PVC)	0					
polystyrene (PS)	0					
glass	3175.846439					
steel cans/tin	1524.053908					
aluminium cans	0					
biogenic food waste	478566.1415					
garden refuse green	0					
garden refuse wood	-51535.92695					
other	6620.384462					
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	704587.5206	0	0	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						704587.5206

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper	16447.39179					
general mixed paper (CWM)	38072.66617					
scrap boxes and cardboard (K4)	109243.1701					
low density polyethylene (LDPE)	31777.98536					
high density polyethelene (HDPE)	14721.43092					
Polyethelene terephthalate (PET)	16650.44601					
polypropylene (PP)	58175.03391					
polyvinyl chloride (PVC)	0					
polystyrene (PS)	0					
glass	73201.04616					
steel cans/tin	35128.37999					
aluminium cans	0					
biogenic food waste	286509.5038					
garden refuse green	0					
garden refuse wood	182748.7976					
other	152595.246					
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	1015271.098	0	0	0	0	0
LANDFILL TRANSPORT EMISSIONS	11328.51938	0	0	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						1026599.617

Table B2 – EThekwini 2015 scenario 2A

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL						
W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper		16183.59912				
general mixed paper (CWM)		37462.035				
scrap boxes and cardboard (K4)		107491.0658				
low density polyethylene (LDPE)		31268.31188				
high density polyethelene (HDPE)		14485.3202				
Polyethelene terephthalate (PET)		16383.39664				
polypropylene (PP)		57241.98948				
polyvinyl chloride (PVC)		0				
polystyrene (PS)		0				
glass		72027.00596				
steel cans/tin		34564.97096				
aluminium cans		0				
biogenic food waste		281914.3007				
garden refuse green		0				
garden refuse wood		179817.768				
other		150147.8363				
TOTAL WASTE DISPOSED/DIVERTED	0	998987.6	0	0	0	0
						998987.6

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL						
W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper		-13022.73231				
general mixed paper (CWM)		16517.92531				
scrap boxes and cardboard (K4)		54504.74873				
low density polyethylene (LDPE)		1378.696165				
high density polyethelene (HDPE)		638.6931118				
Polyethelene terephthalate (PET)		722.3839333				
polypropylene (PP)		2523.938987				
polyvinyl chloride (PVC)		0				
polystyrene (PS)		0				
glass		3175.846439				
steel cans/tin		1524.053908				
aluminium cans		0				
biogenic food waste		198884.6302				
garden refuse green		0				
garden refuse wood		126857.6663				
other		66203.84462				
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	459909.6955	0	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						459909.6955

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL						
W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper		1637.780231				
general mixed paper (CWM)		3791.157942				
scrap boxes and cardboard (K4)		10878.09585				
low density polyethylene (LDPE)		3164.353162				
high density polyethelene (HDPE)		1465.914404				
Polyethelene terephthalate (PET)		1657.99974				
polypropylene (PP)		5792.889335				
polyvinyl chloride (PVC)		0				
polystyrene (PS)		0				
glass		7289.133003				
steel cans/tin		3497.975061				
aluminium cans		0				
biogenic food waste		28529.72723				
garden refuse green		0				
garden refuse wood		18197.55812				
other		15194.96103				
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	101097.5451	0	0	0	0
LANDFILL TRANSPORT EMISSIONS	0	11328.51938	0	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						112426.0645

Table B3 – EThekwini 2015 scenario 2B

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			16183.59912			
general mixed paper (CWM)			37462.035			
scrap boxes and cardboard (K4)			107491.0658			
low density polyethylene (LDPE)			31268.31188			
high density polyethelene (HDPE)			14485.3202			
Polyethelene terephthalate (PET)			16383.39664			
polypropylene (PP)			57241.98948			
polyvinyl chloride (PVC)			0			
polystyrene (PS)			0			
glass			72027.00596			
steel cans/tin			34564.97096			
aluminium cans			0			
biogenic food waste			281914.3007			
garden refuse green			0			
garden refuse wood			179817.768			
other			150147.8363			
TOTAL WASTE DISPOSED/DIVERTED	0	0	998987.6	0	0	0
						998987.6

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-16768.99777			
general mixed paper (CWM)			-4129.481326			
scrap boxes and cardboard (K4)			-9479.086735			
low density polyethylene (LDPE)			1378.696165			
high density polyethelene (HDPE)			638.6931118			
Polyethelene terephthalate (PET)			722.3839333			
polypropylene (PP)			2523.938987			
polyvinyl chloride (PVC)			0			
polystyrene (PS)			0			
glass			3175.846439			
steel cans/tin			1524.053908			
aluminium cans			0			
biogenic food waste			133625.6109			
garden refuse green			0			
garden refuse wood			-162536.385			
other			66203.84462			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	16879.11727	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						16879.11727

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-2338.530073			
general mixed paper (CWM)			-5413.264058			
scrap boxes and cardboard (K4)			-15532.459			
low density polyethylene (LDPE)			-4518.271067			
high density polyethelene (HDPE)			-2093.128769			
Polyethelene terephthalate (PET)			-2367.400814			
polypropylene (PP)			-8271.46748			
polyvinyl chloride (PVC)			0			
polystyrene (PS)			0			
glass			-10407.90236			
steel cans/tin			-4994.638304			
aluminium cans			0			
biogenic food waste			-40736.61645			
garden refuse green			0			
garden refuse wood			-25983.66748			
other			-21696.36234			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	-144353.7082	0	0	0
LANDFILL TRANSPORT EMISSIONS	0	0	11328.51938	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-133025.1888

Table B4 – EThekwini 2015 scenario 3A

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			11814.02736	4369.571762		
general mixed paper (CWM)			27347.28555	10114.74945		
scrap boxes and cardboard (K4)			78468.478	29022.58776		
low density polyethylene (LDPE)			22825.86767	8442.444208		
high density polyethelene (HDPE)			10574.28375	3911.036454		
Polyethelene terephthalate (PET)			11959.87955	4423.517093		
polypropylene (PP)			41786.65232	15455.33716		
polyvinyl chloride (PVC)			0	0		
polystyrene (PS)			0	0		
glass			52579.71435	19447.29161		
steel cans/tin			25232.4288	9332.542159		
aluminium cans			0	0		
biogenic food waste			281914.3007			
garden refuse green			0			
garden refuse wood			179817.768			
other			150147.8363			
TOTAL WASTE DISPOSED/DIVERTED	0	0	894468.5224	104519.0777	0	0
						998987.6

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-12241.36837	-13245.7243		
general mixed paper (CWM)			-3014.521368	-39358.08652		
scrap boxes and cardboard (K4)			-6919.733317	-99814.78332		
low density polyethylene (LDPE)			1006.448201	-15913.60049		
high density polyethelene (HDPE)			466.2459716	-3793.837084		
Polyethelene terephthalate (PET)			527.3402713	-5509.983452		
polypropylene (PP)			1842.47546	-25895.614		
polyvinyl chloride (PVC)			0	0		
polystyrene (PS)			0	0		
glass			2318.3679	-6002.349769		
steel cans/tin			1112.559353	-18620.12862		
aluminium cans			0	0		
biogenic food waste			133625.6109			
garden refuse green			0			
garden refuse wood			-162536.385			
other			66203.84462			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	22390.88466	-228154.1076	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-205763.2229

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-1707.126953	-7036.321409		
general mixed paper (CWM)			-3951.682762	-5750.235062		
scrap boxes and cardboard (K4)			-11338.69507	-15024.99368		
low density polyethylene (LDPE)			-3298.337879	-7255.436552		
high density polyethelene (HDPE)			-1527.984001	-2813.599625		
Polyethelene terephthalate (PET)			-1728.202595	-8105.652721		
polypropylene (PP)			-6038.17126	-12200.44315		
polyvinyl chloride (PVC)			0	0		
polystyrene (PS)			0	0		
glass			-7597.768724	-5641.659296		
steel cans/tin			-3646.085962	-24142.35331		
aluminium cans			0	0		
biogenic food waste			-29737.73001			
garden refuse green			0			
garden refuse wood			-18968.07726			
other			-15838.34451			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	-105378.207	-87970.69481	0	0
LANDFILL TRANSPORT EMISSIONS	0	0	10143.27304	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-183205.6288

Table B5 – EThekwini 2015 scenario 3B

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			6958.947622	9224.651498		
general mixed paper (CWM)			16108.67505	21353.35995		
scrap boxes and cardboard (K4)			46221.15828	61269.90748		
low density polyethylene (LDPE)			13445.37411	17822.93777		
high density polyethelene (HDPE)			6228.687686	8256.632514		
Polyethelene terephthalate (PET)			7044.860555	9338.536085		
polypropylene (PP)			24614.05548	32627.934		
polyvinyl chloride (PVC)			0	0		
polystyrene (PS)			0	0		
glass			30971.61256	41055.3934		
steel cans/tin			14862.93751	19702.03345		
aluminium cans			0	0		
biogenic food waste			281914.3007			
garden refuse green			0			
garden refuse wood			179817.768			
other			150147.8363			
TOTAL WASTE DISPOSED/DIVERTED	0	0	778336.2139	220651.3862	0	0
						998987.6

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-7210.669041	-27963.19575		
general mixed paper (CWM)			-1775.67697	-83089.29377		
scrap boxes and cardboard (K4)			-4076.007296	-210720.0981		
low density polyethylene (LDPE)			592.8393512	-33595.37881		
high density polyethelene (HDPE)			274.6380381	-8009.211622		
Polyethelene terephthalate (PET)			310.6250913	-11632.18729		
polypropylene (PP)			1085.293764	-54668.51845		
polyvinyl chloride (PVC)			0	0		
polystyrene (PS)			0	0		
glass			1365.613969	-12671.62729		
steel cans/tin			655.3431805	-39309.16043		
aluminium cans			0	0		
biogenic food waste			133625.6109			
garden refuse green			0			
garden refuse wood			-162536.385			
other			66203.84462			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	28515.07065	-481658.6715	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-453143.6009

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-1005.567931	-14854.45631		
general mixed paper (CWM)			-2327.703545	-12139.38513		
scrap boxes and cardboard (K4)			-6678.957371	-31719.4311		
low density polyethylene (LDPE)			-1942.856559	-15317.03272		
high density polyethelene (HDPE)			-900.0453706	-5939.821431		
Polyethelene terephthalate (PET)			-1017.98235	-17111.93352		
polypropylene (PP)			-3556.731016	-25756.4911		
polyvinyl chloride (PVC)			0	0		
polystyrene (PS)			0	0		
glass			-4475.398015	-11910.16962		
steel cans/tin			-2147.694471	-50967.19032		
aluminium cans			0	0		
biogenic food waste			-40736.61645			
garden refuse green			0			
garden refuse wood			-25983.66748			
other			-21696.36234			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	-112469.5829	-185715.9113	0	0
LANDFILL TRANSPORT EMISSIONS	0	0	8826.332665	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-289359.1615

Table B6 – EThekwini 2015 scenario 4

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			6958.947622	9224.651498		
general mixed paper (CWM)			16108.67505	21353.35995		
scrap boxes and cardboard (K4)			46221.15828	61269.90748		
low density polyethylene (LDPE)			13445.37411	17822.93777		
high density polyethelene (HDPE)			6228.687686	8256.632514		
Polyethelene terephthalate (PET)			7044.860555	9338.536085		
polypropylene (PP)			24614.05548	32627.934		
polyvinyl chloride (PVC)			0	0		
polystyrene (PS)			0	0		
glass			30971.61256	41055.3934		
steel cans/tin			14862.93751	19702.03345		
aluminium cans			0	0		
biogenic food waste					451062.8812	
garden refuse green			0			
garden refuse wood			179817.768			
other			150147.8363			
TOTAL WASTE DISPOSED/DIVERTED	0	0	496421.9131	220651.3862	451062.8812	0
						1168136.18

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-7210.669041	-27963.19575		
general mixed paper (CWM)			-1775.67697	-83089.29377		
scrap boxes and cardboard (K4)			-4076.007296	-210720.0981		
low density polyethylene (LDPE)			592.8393512	-33595.37881		
high density polyethelene (HDPE)			274.6380381	-8009.211622		
Polyethelene terephthalate (PET)			310.6250913	-11632.18729		
polypropylene (PP)			1085.293764	-54668.51845		
polyvinyl chloride (PVC)			0	0		
polystyrene (PS)			0	0		
glass			1365.613969	-12671.62729		
steel cans/tin			655.3431805	-39309.16043		
aluminium cans			0	0		
biogenic food waste					-122616.9336	
garden refuse green			0			
garden refuse wood			-162536.385			
other			66203.84462			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	-105110.5403	-481658.6715	-122616.9336	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-709386.1454

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-1005.567931	-14854.45631		
general mixed paper (CWM)			-2327.703545	-12139.38513		
scrap boxes and cardboard (K4)			-6678.957371	-31719.4311		
low density polyethylene (LDPE)			-1942.856559	-15317.03272		
high density polyethelene (HDPE)			-900.0453706	-5939.821431		
Polyethelene terephthalate (PET)			-1017.98235	-17111.93352		
polypropylene (PP)			-3556.731016	-25756.4911		
polyvinyl chloride (PVC)			0	0		
polystyrene (PS)			0	0		
glass			-4475.398015	-11910.16962		
steel cans/tin			-2147.694471	-50967.19032		
aluminium cans			0	0		
biogenic food waste					-122616.9336	
garden refuse green			0			
garden refuse wood			-25983.66748			
other			-21696.36234			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	-71732.96645	-185715.9113	-122616.9336	0
LANDFILL TRANSPORT EMISSIONS	0	0	5629.424495	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-374436.3868

Table B7 – EThekwini 2015 scenario 5

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL						
W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			6958.947622	9224.651498		
general mixed paper (CWM)			16108.67505	21353.35995		
scrap boxes and cardboard (K4)			46221.15828	61269.90748		
low density polyethylene (LDPE)			13445.37411	17822.93777		
high density polyethelene (HDPE)			6228.687686	8256.632514		
Polyethelene terephthalate (PET)			7044.860555	9338.536085		
polypropylene (PP)			24614.05548	32627.934		
polyvinyl chloride (PVC)			0	0		
polystyrene (PS)			0	0		
glass			30971.61256	41055.3934		
steel cans/tin			14862.93751	19702.03345		
aluminium cans			0	0		
biogenic food waste						281914.3007
garden refuse green						0
garden refuse wood						179817.768
other			150147.8363			
TOTAL WASTE DISPOSED/DIVERTED	0	0	316604.1451	220651.3862	0	461732.0687
						998987.6

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL						
W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-7210.669041	-27963.19575		
general mixed paper (CWM)			-1775.67697	-83089.29377		
scrap boxes and cardboard (K4)			-4076.007296	-210720.0981		
low density polyethylene (LDPE)			592.8393512	-33595.37881		
high density polyethelene (HDPE)			274.6380381	-8009.211622		
Polyethelene terephthalate (PET)			310.6250913	-11632.18729		
polypropylene (PP)			1085.293764	-54668.51845		
polyvinyl chloride (PVC)			0	0		
polystyrene (PS)			0	0		
glass			1365.613969	-12671.62729		
steel cans/tin			655.3431805	-39309.16043		
aluminium cans			0	0		
biogenic food waste						-46613.58521
garden refuse green						0
garden refuse wood						-23785.81244
other			66203.84462			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	57425.84471	-481658.6715	0	-70399.39765
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-494632.2245

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL						
W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-1005.567931	-14854.45631		
general mixed paper (CWM)			-2327.703545	-12139.38513		
scrap boxes and cardboard (K4)			-6678.957371	-31719.4311		
low density polyethylene (LDPE)			-1942.856559	-15317.03272		
high density polyethelene (HDPE)			-900.0453706	-5939.821431		
Polyethelene terephthalate (PET)			-1017.98235	-17111.93352		
polypropylene (PP)			-3556.731016	-25756.4911		
polyvinyl chloride (PVC)			0	0		
polystyrene (PS)			0	0		
glass			-4475.398015	-11910.16962		
steel cans/tin			-2147.694471	-50967.19032		
aluminium cans			0	0		
biogenic food waste						52154.14563
garden refuse green						0
garden refuse wood						33266.28708
other			-21696.36234			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	-45749.29897	-185715.9113	0	85420.43271
LANDFILL TRANSPORT EMISSIONS	0	0	3590.291006	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-142454.4865

Table B8 – Msunduzi 2015 scenario 1

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR WASTE FRACTION	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper	9915.6448					
general mixed paper (CWM)	7287.4016					
scrap boxes and cardboard (K4)	4823.4236					
low density polyethylene (LDPE)	1941.316					
high density polyethelene (HDPE)	1687.4516					
Polyethelene terephthalate (PET)	3001.5732					
polypropylene (PP)	2553.5772					
polyvinyl chloride (PVC)	2867.1744					
polystyrene (PS)	851.1924					
glass	10722.0376					
steel cans/tin	6227.1444					
aluminium cans	1254.3888					
biogenic food waste	50235.2848					
garden refuse green	1105.0568					
garden refuse wood	29.8664					
other	44829.4664					
TOTAL WASTE DISPOSED/DIVERTED	149332	0	0	0	0	0
						149332

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR WASTE FRACTION	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper	-2295.32611					
general mixed paper (CWM)	12772.44288					
scrap boxes and cardboard (K4)	8932.413658					
low density polyethylene (LDPE)	85.59735925					
high density polyethelene (HDPE)	74.40385843					
Polyethelene terephthalate (PET)	132.3466862					
polypropylene (PP)	112.5934495					
polyvinyl chloride (PVC)	126.4207152					
polystyrene (PS)	37.53114983					
glass	472.7607996					
steel cans/tin	274.5699908					
aluminium cans	55.3090629					
biogenic food waste	85277.35682					
garden refuse green	-194.8986026					
garden refuse wood	-8.559735925					
other	1976.640557					
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	107831.6025	0	0	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						107831.6025

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR WASTE FRACTION	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper	10077.26981					
general mixed paper (CWM)	7406.186246					
scrap boxes and cardboard (K4)	4902.045405					
low density polyethylene (LDPE)	1972.959451					
high density polyethelene (HDPE)	1714.957061					
Polyethelene terephthalate (PET)	3050.498843					
polypropylene (PP)	2595.200508					
polyvinyl chloride (PVC)	2913.909343					
polystyrene (PS)	865.0668361					
glass	10896.80681					
steel cans/tin	6328.646854					
aluminium cans	1274.835337					
biogenic food waste	51054.11994					
garden refuse green	1123.069226					
garden refuse wood	30.35322232					
other	45560.1867					
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	151766.1116	0	0	0	0	0
LANDFILL TRANSPORT EMISSIONS	1532.14632	0	0	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						153298.2579

Table B9 – Msunduzi 2015 scenario 2A

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper		9915.6448				
general mixed paper (CWM)		7287.4016				
scrap boxes and cardboard (K4)		4823.4236				
low density polyethylene (LDPE)		1941.316				
high density polyethelene (HDPE)		1687.4516				
Polyethelene terephthalate (PET)		3001.5732				
polypropylene (PP)		2553.5772				
polyvinyl chloride (PVC)		2867.1744				
polystyrene (PS)		851.1924				
glass		10722.0376				
steel cans/tin		6227.1444				
aluminium cans		1254.3888				
biogenic food waste		50235.2848				
garden refuse green		1105.0568				
garden refuse wood		29.8664				
other		44829.4664				
TOTAL WASTE DISPOSED/DIVERTED	0	149332	0	0	0	0
						149332

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper		-7978.990765				
general mixed paper (CWM)		3213.193178				
scrap boxes and cardboard (K4)		2445.77993				
low density polyethylene (LDPE)		85.59735925				
high density polyethelene (HDPE)		74.40385843				
Polyethelene terephthalate (PET)		132.3466862				
polypropylene (PP)		112.5934495				
polyvinyl chloride (PVC)		126.4207152				
polystyrene (PS)		37.53114983				
glass		472.7607996				
steel cans/tin		274.5699908				
aluminium cans		55.3090629				
biogenic food waste		35439.94049				
garden refuse green		-596.8769705				
garden refuse wood		21.0701192				
other		19766.40557				
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	53682.05463	0	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						53682.05463

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper		1003.463254				
general mixed paper (CWM)		737.4850419				
scrap boxes and cardboard (K4)		488.1304683				
low density polyethylene (LDPE)		196.4611792				
high density polyethelene (HDPE)		170.7701019				
Polyethelene terephthalate (PET)		303.7592078				
polypropylene (PP)		258.4220126				
polyvinyl chloride (PVC)		290.1580493				
polystyrene (PS)		86.14067088				
glass		1085.070205				
steel cans/tin		630.1870133				
aluminium cans		126.9441466				
biogenic food waste		5083.810822				
garden refuse green		111.8317482				
garden refuse wood		3.02247968				
other		4536.742				
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	15112.3984	0	0	0	0
LANDFILL TRANSPORT EMISSIONS	0	1532.14632	0	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						16644.54472

Table B10 – Msunduzi 2015 scenario 2B

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL						
W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			9915.6448			
general mixed paper (CWM)			7287.4016			
scrap boxes and cardboard (K4)			4823.4236			
low density polyethylene (LDPE)			1941.316			
high density polyethelene (HDPE)			1687.4516			
Polyethelene terephthalate (PET)			3001.5732			
polypropylene (PP)			2553.5772			
polyvinyl chloride (PVC)			2867.1744			
polystyrene (PS)			851.1924			
glass			10722.0376			
steel cans/tin			6227.1444			
aluminium cans			1254.3888			
biogenic food waste			50235.2848			
garden refuse green			1105.0568			
garden refuse wood			29.8664			
other			44829.4664			
TOTAL WASTE DISPOSED/DIVERTED	0	0	149332	0	0	0
						149332

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL						
W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-10274.31688			
general mixed paper (CWM)			-803.2982945			
scrap boxes and cardboard (K4)			-425.3530314			
low density polyethylene (LDPE)			85.59735925			
high density polyethelene (HDPE)			74.40385843			
Polyethelene terephthalate (PET)			132.3466862			
polypropylene (PP)			112.5934495			
polyvinyl chloride (PVC)			126.4207152			
polystyrene (PS)			37.53114983			
glass			472.7607996			
steel cans/tin			274.5699908			
aluminium cans			55.3090629			
biogenic food waste			23811.21002			
garden refuse green			-694.3262718			
garden refuse wood			-26.99609023			
other			19766.40557			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	32724.8581	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						32724.8581

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL						
W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-1432.810674			
general mixed paper (CWM)			-1053.029531			
scrap boxes and cardboard (K4)			-696.9847102			
low density polyethylene (LDPE)			-280.520162			
high density polyethelene (HDPE)			-243.8367562			
Polyethelene terephthalate (PET)			-433.7273274			
polypropylene (PP)			-368.9919054			
polyvinyl chloride (PVC)			-414.3067008			
polystyrene (PS)			-122.9973018			
glass			-1549.334433			
steel cans/tin			-899.8223658			
aluminium cans			-181.2591816			
biogenic food waste			-7258.998654			
garden refuse green			-159.6807076			
garden refuse wood			-4.3156948			
other			-6477.857895			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	-21578.474	0	0	0
LANDFILL TRANSPORT EMISSIONS	0	0	1532.14632	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-20046.32768

Table B11 – Msunduzi 2015 scenario 3A

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			8924.08032	991.56448		
general mixed paper (CWM)			6558.66144	728.74016		
scrap boxes and cardboard (K4)			4341.08124	482.34236		
low density polyethylene (LDPE)			1747.1844	194.1316		
high density polyethelene (HDPE)			1518.70644	168.74516		
Polyethelene terephthalate (PET)			2701.41588	300.15732		
polypropylene (PP)			2298.21948	255.35772		
polyvinyl chloride (PVC)			2580.45696	286.71744		
polystyrene (PS)			766.07316	85.11924		
glass			9649.83384	1072.20376		
steel cans/tin			5604.42996	622.71444		
aluminium cans			1128.94992	125.43888		
biogenic food waste			50235.2848			
garden refuse green			1105.0568			
garden refuse wood			29.8664			
other			44829.4664			
TOTAL WASTE DISPOSED/DIVERTED	0	0	144018.7674	5313.23256	0	0
						149332

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-9246.885188	-3005.784192		
general mixed paper (CWM)			-722.9684651	-2835.64298		
scrap boxes and cardboard (K4)			-382.8177282	-1658.876822		
low density polyethylene (LDPE)			77.03762333	-365.9287108		
high density polyethelene (HDPE)			66.96347258	-163.6884885		
Polyethelene terephthalate (PET)			119.1120176	-373.8793886		
polypropylene (PP)			101.3341045	-427.855108		
polyvinyl chloride (PVC)			113.7786437	-480.3987178		
polystyrene (PS)			33.77803484	-142.6183693		
glass			425.4847196	-330.9325597		
steel cans/tin			247.1129917	-1242.429208		
aluminium cans			49.77815661	-1259.663908		
biogenic food waste			23811.21002			
garden refuse green			-694.3262718			
garden refuse wood			-26.99609023			
other			19766.40557			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	33738.00162	-12287.69845	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						21450.30316

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-1289.529606	-1596.716282		
general mixed paper (CWM)			-947.7265781	-414.288781		
scrap boxes and cardboard (K4)			-627.2862392	-249.7086398		
low density polyethylene (LDPE)			-252.4681458	-166.836697		
high density polyethelene (HDPE)			-219.4530806	-121.3952681		
Polyethelene terephthalate (PET)			-390.3545947	-550.0082732		
polypropylene (PP)			-332.0927149	-201.5793842		
polyvinyl chloride (PVC)			-372.8760307	-280.9830912		
polystyrene (PS)			-110.6975716	-83.4168552		
glass			-1394.40099	-311.0463108		
steel cans/tin			-809.8401292	-1610.899985		
aluminium cans			-163.1332634	-2397.224804		
biogenic food waste			-6533.098788			
garden refuse green			-143.7126368			
garden refuse wood			-3.88412532			
other			-5830.072105			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	-19420.6266	-7984.104371	0	0
LANDFILL TRANSPORT EMISSIONS	0	0	1477.632554	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-25927.09842

Table B12 – Msunduzi 2015 scenario 3B

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL						
W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			5949.38688	3966.25792		
general mixed paper (CWM)			4372.44096	2914.96064		
scrap boxes and cardboard (K4)			2894.05416	1929.36944		
low density polyethylene (LDPE)			1164.7896	776.5264		
high density polyethelene (HDPE)			1012.47096	674.98064		
Polyethelene terephthalate (PET)			1800.94392	1200.62928		
polypropylene (PP)			1532.14632	1021.43088		
polyvinyl chloride (PVC)			1720.30464	1146.86976		
polystyrene (PS)			510.71544	340.47696		
glass			6433.22256	4288.81504		
steel cans/tin			3736.28664	2490.85776		
aluminium cans			752.63328	501.75552		
biogenic food waste			50235.2848			
garden refuse green			1105.0568			
garden refuse wood			29.8664			
other			44829.4664			
TOTAL WASTE DISPOSED/DIVERTED	0	0	128079.0698	21252.93024	0	0
						149332

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL						
W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-6164.590125	-12023.13677		
general mixed paper (CWM)			-481.9789767	-11342.57192		
scrap boxes and cardboard (K4)			-255.2118188	-6635.507289		
low density polyethylene (LDPE)			51.35841555	-1463.714843		
high density polyethelene (HDPE)			44.64231506	-654.7539541		
Polyethelene terephthalate (PET)			79.40801174	-1495.517554		
polypropylene (PP)			67.55606969	-1711.420432		
polyvinyl chloride (PVC)			75.85242912	-1921.594871		
polystyrene (PS)			22.5186899	-570.4734773		
glass			283.6564797	-1323.730239		
steel cans/tin			164.7419945	-4969.716834		
aluminium cans			33.18543774	-5038.65563		
biogenic food waste			23811.21002			
garden refuse green			-694.3262718			
garden refuse wood			-26.99609023			
other			19766.40557			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	36777.43216	-49150.79381	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-12373.36166

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL						
W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-859.6864042	-6386.865129		
general mixed paper (CWM)			-631.8177187	-1657.155124		
scrap boxes and cardboard (K4)			-418.1908261	-998.8345591		
low density polyethylene (LDPE)			-168.3120972	-667.3467882		
high density polyethelene (HDPE)			-146.3020537	-485.5810724		
Polyethelene terephthalate (PET)			-260.2363964	-2200.033093		
polypropylene (PP)			-221.3951432	-806.3175367		
polyvinyl chloride (PVC)			-248.5840205	-1123.932365		
polystyrene (PS)			-73.79838108	-333.6674208		
glass			-929.6006599	-1244.185243		
steel cans/tin			-539.8934195	-6443.599939		
aluminium cans			-108.755509	-9588.899216		
biogenic food waste			-7258.998654			
garden refuse green			-159.6807076			
garden refuse wood			-4.3156948			
other			-6477.857895			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	-18507.42558	-31936.41749	0	0
LANDFILL TRANSPORT EMISSIONS	0	0	1314.091256	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-49129.75181

Table B13 – Msunduzi 2015 scenario 4

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			5949.38688	3966.25792		
general mixed paper (CWM)			4372.44096	2914.96064		
scrap boxes and cardboard (K4)			2894.05416	1929.36944		
low density polyethylene (LDPE)			1164.7896	776.5264		
high density polyethelene (HDPE)			1012.47096	674.98064		
Polyethelene terephthalate (PET)			1800.94392	1200.62928		
polypropylene (PP)			1532.14632	1021.43088		
polyvinyl chloride (PVC)			1720.30464	1146.86976		
polystyrene (PS)			510.71544	340.47696		
glass			6433.22256	4288.81504		
steel cans/tin			3736.28664	2490.85776		
aluminium cans			752.63328	501.75552		
biogenic food waste					80376.45568	
garden refuse green			1105.0568			
garden refuse wood			29.8664			
other			44829.4664			
TOTAL WASTE DISPOSED/DIVERTED	0	0	77843.78496	21252.93024	80376.45568	0
						179473.1709

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-6164.590125	-12023.13677		
general mixed paper (CWM)			-481.9789767	-11342.57192		
scrap boxes and cardboard (K4)			-255.2118188	-6635.507289		
low density polyethylene (LDPE)			51.35841555	-1463.714843		
high density polyethelene (HDPE)			44.64231506	-654.7539541		
Polyethelene terephthalate (PET)			79.40801174	-1495.517554		
polypropylene (PP)			67.55606969	-1711.420432		
polyvinyl chloride (PVC)			75.85242912	-1921.594871		
polystyrene (PS)			22.5186899	-570.4734773		
glass			283.6564797	-1323.730239		
steel cans/tin			164.7419945	-4969.716834		
aluminium cans			33.18543774	-5038.65563		
biogenic food waste					-21849.53571	
garden refuse green			-694.3262718			
garden refuse wood			-26.99609023			
other			19766.40557			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	12966.22214	-49150.79381	-21849.53571	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-58034.10739

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-859.6864042	-6386.865129		
general mixed paper (CWM)			-631.8177187	-1657.155124		
scrap boxes and cardboard (K4)			-418.1908261	-998.8345591		
low density polyethylene (LDPE)			-168.3120972	-667.3467882		
high density polyethelene (HDPE)			-146.3020537	-485.5810724		
Polyethelene terephthalate (PET)			-260.2363964	-2200.033093		
polypropylene (PP)			-221.3951432	-806.3175367		
polyvinyl chloride (PVC)			-248.5840205	-1123.932365		
polystyrene (PS)			-73.79838108	-333.6674208		
glass			-929.6006599	-1244.185243		
steel cans/tin			-539.8934195	-6443.599939		
aluminium cans			-108.755509	-9588.899216		
biogenic food waste					-21849.53571	
garden refuse green			-159.6807076			
garden refuse wood			-4.3156948			
other			-6477.857895			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	-11248.42693	-31936.41749	-21849.53571	0
LANDFILL TRANSPORT EMISSIONS	0	0	798.6772337	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-64235.70289

Table B14 – Msunduzi 2015 scenario 5

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			5949.38688	3966.25792		
general mixed paper (CWM)			4372.44096	2914.96064		
scrap boxes and cardboard (K4)			2894.05416	1929.36944		
low density polyethylene (LDPE)			1164.7896	776.5264		
high density polyethelene (HDPE)			1012.47096	674.98064		
Polyethelene terephthalate (PET)			1800.94392	1200.62928		
polypropylene (PP)			1532.14632	1021.43088		
polyvinyl chloride (PVC)			1720.30464	1146.86976		
polystyrene (PS)			510.71544	340.47696		
glass			6433.22256	4288.81504		
steel cans/tin			3736.28664	2490.85776		
aluminium cans			752.63328	501.75552		
biogenic food waste						50235.2848
garden refuse green						1105.0568
garden refuse wood						29.8664
other			44829.4664			
TOTAL WASTE DISPOSED/DIVERTED	0	0	76708.86176	21252.93024	0	51370.208
						149332

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-6164.590125	-12023.13677		
general mixed paper (CWM)			-481.9789767	-11342.57192		
scrap boxes and cardboard (K4)			-255.2118188	-6635.507289		
low density polyethylene (LDPE)			51.35841555	-1463.714843		
high density polyethelene (HDPE)			44.64231506	-654.7539541		
Polyethelene terephthalate (PET)			79.40801174	-1495.517554		
polypropylene (PP)			67.55606969	-1711.420432		
polyvinyl chloride (PVC)			75.85242912	-1921.594871		
polystyrene (PS)			22.5186899	-570.4734773		
glass			283.6564797	-1323.730239		
steel cans/tin			164.7419945	-4969.716834		
aluminium cans			33.18543774	-5038.65563		
biogenic food waste						-8306.236053
garden refuse green						-146.173952
garden refuse wood						-3.95064735
other			19766.40557			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	13687.5445	-49150.79381	0	-8456.360653
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-43919.60997

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-859.6864042	-6386.865129		
general mixed paper (CWM)			-631.8177187	-1657.155124		
scrap boxes and cardboard (K4)			-418.1908261	-998.8345591		
low density polyethylene (LDPE)			-168.3120972	-667.3467882		
high density polyethelene (HDPE)			-146.3020537	-485.5810724		
Polyethelene terephthalate (PET)			-260.2363964	-2200.033093		
polypropylene (PP)			-221.3951432	-806.3175367		
polyvinyl chloride (PVC)			-248.5840205	-1123.932365		
polystyrene (PS)			-73.79838108	-333.6674208		
glass			-929.6006599	-1244.185243		
steel cans/tin			-539.8934195	-6443.599939		
aluminium cans			-108.755509	-9588.899216		
biogenic food waste						9293.527688
garden refuse green						204.435508
garden refuse wood						5.525284
other			-6477.857895			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	-11084.43052	-31936.41749	0	9503.48848
LANDFILL TRANSPORT EMISSIONS	0	0	787.0329217	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-32730.32661

Table B15 – Newcastle 2015 scenario 1

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper	580.98					
general mixed paper (CWM)	3098.56					
scrap boxes and cardboard (K4)	1936.6					
low density polyethylene (LDPE)	580.98					
high density polyethelene (HDPE)	580.98					
Polyethelene terephthalate (PET)	387.32					
polypropylene (PP)	580.98					
polyvinyl chloride (PVC)	193.66					
polystyrene (PS)	193.66					
glass	2323.92					
steel cans/tin	580.98					
aluminium cans	580.98					
biogenic food waste	2130.26					
garden refuse green	774.64					
garden refuse wood	774.64					
other	4066.86					
TOTAL WASTE DISPOSED/DIVERTED	19366	0	0	0	0	0
						19366

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper	-134.4883354					
general mixed paper (CWM)	5430.767068					
scrap boxes and cardboard (K4)	3586.355611					
low density polyethylene (LDPE)	25.61682579					
high density polyethelene (HDPE)	25.61682579					
Polyethelene terephthalate (PET)	17.07788386					
polypropylene (PP)	25.61682579					
polyvinyl chloride (PVC)	8.53894193					
polystyrene (PS)	8.53894193					
glass	102.4673032					
steel cans/tin	25.61682579					
aluminium cans	25.61682579					
biogenic food waste	3616.241908					
garden refuse green	-136.6230709					
garden refuse wood	-222.0124902					
other	179.3177805					
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	12584.26567	0	0	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						12584.26567

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper	590.449974					
general mixed paper (CWM)	3149.066528					
scrap boxes and cardboard (K4)	1968.16658					
low density polyethylene (LDPE)	590.449974					
high density polyethelene (HDPE)	590.449974					
Polyethelene terephthalate (PET)	393.633316					
polypropylene (PP)	590.449974					
polyvinyl chloride (PVC)	196.816658					
polystyrene (PS)	196.816658					
glass	2361.799896					
steel cans/tin	590.449974					
aluminium cans	590.449974					
biogenic food waste	2164.983238					
garden refuse green	787.266632					
garden refuse wood	787.266632					
other	4133.149818					
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	19681.6658	0	0	0	0	0
LANDFILL TRANSPORT EMISSIONS	282.7436	0	0	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						19964.4094

Table B16 – Newcastle 2015 scenario 2A

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL						
W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper		580.98				
general mixed paper (CWM)		3098.56				
scrap boxes and cardboard (K4)		1936.6				
low density polyethylene (LDPE)		580.98				
high density polyethelene (HDPE)		580.98				
Polyethelene terephthalate (PET)		387.32				
polypropylene (PP)		580.98				
polyvinyl chloride (PVC)		193.66				
polystyrene (PS)		193.66				
glass		2323.92				
steel cans/tin		580.98				
aluminium cans		580.98				
biogenic food waste		2130.26				
garden refuse green		774.64				
garden refuse wood		774.64				
other		4066.86				
TOTAL WASTE DISPOSED/DIVERTED	0	19366	0	0	0	0
						19366

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL						
W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper		-467.5070707				
general mixed paper (CWM)		1366.230709				
scrap boxes and cardboard (K4)		981.978322				
low density polyethylene (LDPE)		25.61682579				
high density polyethelene (HDPE)		25.61682579				
Polyethelene terephthalate (PET)		17.07788386				
polypropylene (PP)		25.61682579				
polyvinyl chloride (PVC)		8.53894193				
polystyrene (PS)		8.53894193				
glass		102.4673032				
steel cans/tin		25.61682579				
aluminium cans		25.61682579				
biogenic food waste		1502.85378				
garden refuse green		-418.4081546				
garden refuse wood		546.4922835				
other		1793.177805				
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	5569.524874	0	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						5569.524874

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL						
W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper		58.795176				
general mixed paper (CWM)		313.574272				
scrap boxes and cardboard (K4)		195.98392				
low density polyethylene (LDPE)		58.795176				
high density polyethelene (HDPE)		58.795176				
Polyethelene terephthalate (PET)		39.196784				
polypropylene (PP)		58.795176				
polyvinyl chloride (PVC)		19.598392				
polystyrene (PS)		19.598392				
glass		235.180704				
steel cans/tin		58.795176				
aluminium cans		58.795176				
biogenic food waste		215.582312				
garden refuse green		78.393568				
garden refuse wood		78.393568				
other		411.566232				
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	1959.8392	0	0	0	0
LANDFILL TRANSPORT EMISSIONS	0	282.7436	0	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						2242.5828

Table B17 – Newcastle 2015 scenario 2B

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			580.98			
general mixed paper (CWM)			3098.56			
scrap boxes and cardboard (K4)			1936.6			
low density polyethylene (LDPE)			580.98			
high density polyethelene (HDPE)			580.98			
Polyethelene terephthalate (PET)			387.32			
polypropylene (PP)			580.98			
polyvinyl chloride (PVC)			193.66			
polystyrene (PS)			193.66			
glass			2323.92			
steel cans/tin			580.98			
aluminium cans			580.98			
biogenic food waste			2130.26			
garden refuse green			774.64			
garden refuse wood			774.64			
other			4066.86			
TOTAL WASTE DISPOSED/DIVERTED	0	0	19366	0	0	0
						19366

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-601.9954061			
general mixed paper (CWM)			-341.5576772			
scrap boxes and cardboard (K4)			-170.7788386			
low density polyethylene (LDPE)			25.61682579			
high density polyethelene (HDPE)			25.61682579			
Polyethelene terephthalate (PET)			17.07788386			
polypropylene (PP)			25.61682579			
polyvinyl chloride (PVC)			8.53894193			
polystyrene (PS)			8.53894193			
glass			102.4673032			
steel cans/tin			25.61682579			
aluminium cans			25.61682579			
biogenic food waste			1009.729883			
garden refuse green			-486.71969			
garden refuse wood			-700.1932383			
other			1793.177805			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	766.3700383	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						766.3700383

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-83.95161			
general mixed paper (CWM)			-447.74192			
scrap boxes and cardboard (K4)			-279.8387			
low density polyethylene (LDPE)			-83.95161			
high density polyethelene (HDPE)			-83.95161			
Polyethelene terephthalate (PET)			-55.96774			
polypropylene (PP)			-83.95161			
polyvinyl chloride (PVC)			-27.98387			
polystyrene (PS)			-27.98387			
glass			-335.80644			
steel cans/tin			-83.95161			
aluminium cans			-83.95161			
biogenic food waste			-307.82257			
garden refuse green			-111.93548			
garden refuse wood			-111.93548			
other			-587.66127			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	-2798.387	0	0	0
LANDFILL TRANSPORT EMISSIONS	0	0	282.7436	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-2515.6434

Table B18 – Newcastle 2015 scenario 3A

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			447.3546	133.6254		
general mixed paper (CWM)			2385.8912	712.6688		
scrap boxes and cardboard (K4)			1491.182	445.418		
low density polyethylene (LDPE)			447.3546	133.6254		
high density polyethelene (HDPE)			447.3546	133.6254		
Polyethelene terephthalate (PET)			298.2364	89.0836		
polypropylene (PP)			447.3546	133.6254		
polyvinyl chloride (PVC)			149.1182	44.5418		
polystyrene (PS)			149.1182	44.5418		
glass			1789.4184	534.5016		
steel cans/tin			447.3546	133.6254		
aluminium cans			447.3546	133.6254		
biogenic food waste			2130.26			
garden refuse green			774.64			
garden refuse wood			774.64			
other			4066.86			
TOTAL WASTE DISPOSED/DIVERTED	0	0	16693.492	2672.508	0	0
						19366

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-463.5364627	-405.0660578		
general mixed paper (CWM)			-262.9994115	-2773.106781		
scrap boxes and cardboard (K4)			-131.4997057	-1531.886182		
low density polyethylene (LDPE)			19.72495586	-251.8774396		
high density polyethelene (HDPE)			19.72495586	-129.6211385		
Polyethelene terephthalate (PET)			13.14997057	-110.9635504		
polypropylene (PP)			19.72495586	-223.8910574		
polyvinyl chloride (PVC)			6.574985286	-74.63035247		
polystyrene (PS)			6.574985286	-74.63035247		
glass			78.89982344	-164.9723581		
steel cans/tin			19.72495586	-266.6071144		
aluminium cans			19.72495586	-1341.873377		
biogenic food waste			1009.729883			
garden refuse green			-486.71969			
garden refuse wood			-700.1932383			
other			1793.177805			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	961.7837243	-7349.125762	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-6387.342037

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-64.6427397	-215.1769816		
general mixed paper (CWM)			-344.7612784	-405.1522128		
scrap boxes and cardboard (K4)			-215.475799	-230.5928986		
low density polyethylene (LDPE)			-64.6427397	-114.8376688		
high density polyethelene (HDPE)			-64.6427397	-96.13011276		
Polyethelene terephthalate (PET)			-43.0951598	-163.2367886		
polypropylene (PP)			-64.6427397	-105.4838908		
polyvinyl chloride (PVC)			-21.5475799	-43.650964		
polystyrene (PS)			-21.5475799	-43.650964		
glass			-258.5709588	-155.0589142		
steel cans/tin			-64.6427397	-345.6755473		
aluminium cans			-64.6427397	-2553.674932		
biogenic food waste			-237.0233789			
garden refuse green			-86.1903196			
garden refuse wood			-86.1903196			
other			-452.4991779			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	-2154.75799	-4472.321875	0	0
LANDFILL TRANSPORT EMISSIONS	0	0	243.7249832	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-6383.354882

Table B19 – Newcastle 2015 scenario 3B

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			273.0606	307.9194		
general mixed paper (CWM)			1456.3232	1642.2368		
scrap boxes and cardboard (K4)			910.202	1026.398		
low density polyethylene (LDPE)			273.0606	307.9194		
high density polyethelene (HDPE)			273.0606	307.9194		
Polyethelene terephthalate (PET)			182.0404	205.2796		
polypropylene (PP)			273.0606	307.9194		
polyvinyl chloride (PVC)			91.0202	102.6398		
polystyrene (PS)			91.0202	102.6398		
glass			1092.2424	1231.6776		
steel cans/tin			273.0606	307.9194		
aluminium cans			273.0606	307.9194		
biogenic food waste			2130.26			
garden refuse green			774.64			
garden refuse wood			774.64			
other			4066.86			
TOTAL WASTE DISPOSED/DIVERTED	0	0	13207.612	6158.388	0	0
						19366

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-282.9378409	-933.4130898		
general mixed paper (CWM)			-160.5321083	-6390.202583		
scrap boxes and cardboard (K4)			-80.26605415	-3529.998594		
low density polyethylene (LDPE)			12.03990812	-580.4132304		
high density polyethelene (HDPE)			12.03990812	-298.6921887		
Polyethelene terephthalate (PET)			8.026605415	-255.6986161		
polypropylene (PP)			12.03990812	-515.9228714		
polyvinyl chloride (PVC)			4.013302707	-171.9742905		
polystyrene (PS)			4.013302707	-171.9742905		
glass			48.15963249	-380.1536947		
steel cans/tin			12.03990812	-614.3555245		
aluminium cans			12.03990812	-3092.142999		
biogenic food waste			1009.729883			
garden refuse green			-486.71969			
garden refuse wood			-700.1932383			
other			1793.177805			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	1216.671141	-16934.94197	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-15718.27083

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
WASTE FRACTION	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-39.4572567	-495.8426098		
general mixed paper (CWM)			-210.4387024	-933.6116208		
scrap boxes and cardboard (K4)			-131.524189	-531.3662446		
low density polyethylene (LDPE)			-39.4572567	-264.6259324		
high density polyethelene (HDPE)			-39.4572567	-221.5172164		
Polyethelene terephthalate (PET)			-26.3048378	-376.154339		
polypropylene (PP)			-39.4572567	-243.0715744		
polyvinyl chloride (PVC)			-13.1524189	-100.587004		
polystyrene (PS)			-13.1524189	-100.587004		
glass			-157.8290268	-357.3096718		
steel cans/tin			-39.4572567	-796.5566959		
aluminium cans			-39.4572567	-5884.555278		
biogenic food waste			-307.82257			
garden refuse green			-111.93548			
garden refuse wood			-111.93548			
other			-587.66127			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	-1908.499934	-10305.78519	0	0
LANDFILL TRANSPORT EMISSIONS	0	0	192.8311352	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-12021.45399

Table B20 – Newcastle 2015 scenario 4

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR WASTE FRACTION	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			273.0606	307.9194		
general mixed paper (CWM)			1456.3232	1642.2368		
scrap boxes and cardboard (K4)			910.202	1026.398		
low density polyethylene (LDPE)			273.0606	307.9194		
high density polyethelene (HDPE)			273.0606	307.9194		
Polyethelene terephthalate (PET)			182.0404	205.2796		
polypropylene (PP)			273.0606	307.9194		
polyvinyl chloride (PVC)			91.0202	102.6398		
polystyrene (PS)			91.0202	102.6398		
glass			1092.2424	1231.6776		
steel cans/tin			273.0606	307.9194		
aluminium cans			273.0606	307.9194		
biogenic food waste					3408.416	
garden refuse green			774.64			
garden refuse wood			774.64			
other			4066.86			
TOTAL WASTE DISPOSED/DIVERTED	0	0	11077.352	6158.388	3408.416	0
						20644.156

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR WASTE FRACTION	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-282.9378409	-933.4130898		
general mixed paper (CWM)			-160.5321083	-6390.202583		
scrap boxes and cardboard (K4)			-80.26605415	-3529.998594		
low density polyethylene (LDPE)			12.03990812	-580.4132304		
high density polyethelene (HDPE)			12.03990812	-298.6921887		
Polyethelene terephthalate (PET)			8.026605415	-255.6986161		
polypropylene (PP)			12.03990812	-515.9228714		
polyvinyl chloride (PVC)			4.013302707	-171.9742905		
polystyrene (PS)			4.013302707	-171.9742905		
glass			48.15963249	-380.1536947		
steel cans/tin			12.03990812	-614.3555245		
aluminium cans			12.03990812	-3092.142999		
biogenic food waste					-926.5438054	
garden refuse green			-486.71969			
garden refuse wood			-700.1932383			
other			1793.177805			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	206.9412577	-16934.94197	-926.5438054	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-17654.54452

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR WASTE FRACTION	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-39.4572567	-495.8426098		
general mixed paper (CWM)			-210.4387024	-933.6116208		
scrap boxes and cardboard (K4)			-131.524189	-531.3662446		
low density polyethylene (LDPE)			-39.4572567	-264.6259324		
high density polyethelene (HDPE)			-39.4572567	-221.5172164		
Polyethelene terephthalate (PET)			-26.3048378	-376.154339		
polypropylene (PP)			-39.4572567	-243.0715744		
polyvinyl chloride (PVC)			-13.1524189	-100.587004		
polystyrene (PS)			-13.1524189	-100.587004		
glass			-157.8290268	-357.3096718		
steel cans/tin			-39.4572567	-796.5566959		
aluminium cans			-39.4572567	-5884.555278		
biogenic food waste					-926.5438054	
garden refuse green			-111.93548			
garden refuse wood			-111.93548			
other			-587.66127			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	-1600.677364	-10305.78519	-926.5438054	0
LANDFILL TRANSPORT EMISSIONS	0	0	161.7293392	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-12671.27702

Table B21 – Newcastle 2015 scenario 5

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR WASTE FRACTION	QUANTITY OF WASTE DISPOSED/TREATED/DIVERTED BY (TONS)					
	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			273.0606	307.9194		
general mixed paper (CWM)			1456.3232	1642.2368		
scrap boxes and cardboard (K4)			910.202	1026.398		
low density polyethylene (LDPE)			273.0606	307.9194		
high density polyethelene (HDPE)			273.0606	307.9194		
Polyethelene terephthalate (PET)			182.0404	205.2796		
polypropylene (PP)			273.0606	307.9194		
polyvinyl chloride (PVC)			91.0202	102.6398		
polystyrene (PS)			91.0202	102.6398		
glass			1092.2424	1231.6776		
steel cans/tin			273.0606	307.9194		
aluminium cans			273.0606	307.9194		
biogenic food waste						2130.26
garden refuse green						774.64
garden refuse wood						774.64
other			4066.86			
TOTAL WASTE DISPOSED/DIVERTED	0	0	9528.072	6158.388	0	3679.54
						19366

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR WASTE FRACTION	GREEN HOUSE GAS EMMISIONS/REDUCTION US EPA					
	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-282.9378409	-933.4130898		
general mixed paper (CWM)			-160.5321083	-6390.202583		
scrap boxes and cardboard (K4)			-80.26605415	-3529.998594		
low density polyethylene (LDPE)			12.03990812	-580.4132304		
high density polyethelene (HDPE)			12.03990812	-298.6921887		
Polyethelene terephthalate (PET)			8.026605415	-255.6986161		
polypropylene (PP)			12.03990812	-515.9228714		
polyvinyl chloride (PVC)			4.013302707	-171.9742905		
polystyrene (PS)			4.013302707	-171.9742905		
glass			48.15963249	-380.1536947		
steel cans/tin			12.03990812	-614.3555245		
aluminium cans			12.03990812	-3092.142999		
biogenic food waste						-352.2313546
garden refuse green						-102.4673032
garden refuse wood						-102.4673032
other			1793.177805			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	1393.854186	-16934.94197	0	-557.165961
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-16098.25375

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E						
WASTE MATERIAL OR WASTE FRACTION	GREEN HOUSE GAS EMMISIONS/REDUCTION ELENA FRIEDRICH					
	LANDFILL	LANDFILL GAS REC/FLARING	LANDFILL GAS REC/ELEC GEN	RECYCLING	ANAEROBIC DIGESTION	ANAEROBIC COMPOSTING
newspaper			-39.4572567	-495.8426098		
general mixed paper (CWM)			-210.4387024	-933.6116208		
scrap boxes and cardboard (K4)			-131.524189	-531.3662446		
low density polyethylene (LDPE)			-39.4572567	-264.6259324		
high density polyethelene (HDPE)			-39.4572567	-221.5172164		
Polyethelene terephthalate (PET)			-26.3048378	-376.154339		
polypropylene (PP)			-39.4572567	-243.0715744		
polyvinyl chloride (PVC)			-13.1524189	-100.587004		
polystyrene (PS)			-13.1524189	-100.587004		
glass			-157.8290268	-357.3096718		
steel cans/tin			-39.4572567	-796.5566959		
aluminium cans			-39.4572567	-5884.555278		
biogenic food waste						394.0981
garden refuse green						143.3084
garden refuse wood						143.3084
other			-587.66127			
STRATEGY GHG EMISSIONS/ REDUCTIONS (MTCO2EQ)	0	0	-1376.806404	-10305.78519	0	680.7149
LANDFILL TRANSPORT EMISSIONS	0	0	139.1098512	0	0	0
TOTAL GHG EMISSIONS/REDUCTION (MTCO2EQ)						-10862.76684

Appendix C – Landfill space savings output data

Table C1 – EThekwini scenario 3A landfill space savings

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E		
WASTE MATERIAL OR WASTE FRACTION	QUANTITY OF WASTE DIVERTED (M3)	
	MIXED MSW DENSITY (M3)	US EPA LANDFILL FACTORS (M3)
newspaper	3641.309802	9210.733057
general mixed paper (CWM)	8428.957875	21321.14134
scrap boxes and cardboard (K4)	24185.4898	61177.46154
low density polyethylene (LDPE)	7035.370173	21249.01011
high density polyethelene (HDPE)	3259.197045	18578.42175
Polyethelene terephthalate (PET)	3686.264244	21012.83563
polypropylene (PP)	12879.44763	73416.79766
polyvinyl chloride (PVC)	0	0
polystyrene (PS)	0	0
glass	16206.07634	11712.41364
steel cans/tin	7777.118466	28103.29487
aluminium cans	0	0
biogenic food waste		
garden refuse green		
garden refuse wood		
other		
LSS SAVINGS	87099.23138	265782.1096
AVG LSS SAVING		176440.6705

Table C2 – EThekwini scenario 3B landfill space savings

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E		
WASTE MATERIAL OR WASTE FRACTION	QUANTITY OF WASTE DIVERTED (M3)	
	MIXED MSW DENSITY (M3)	US EPA LANDFILL FACTORS (M3)
newspaper	7687.209582	19444.8809
general mixed paper (CWM)	17794.46663	45011.29838
scrap boxes and cardboard (K4)	51058.25624	129152.4188
low density polyethylene (LDPE)	14852.44814	44859.02135
high density polyethelene (HDPE)	6880.527095	39221.11258
Polyethelene terephthalate (PET)	7782.113404	44360.43078
polypropylene (PP)	27189.945	154991.0173
polyvinyl chloride (PVC)	0	0
polystyrene (PS)	0	0
glass	34212.82783	24726.20658
steel cans/tin	16418.36121	59329.17805
aluminium cans	0	0
biogenic food waste		
garden refuse green		
garden refuse wood		
other		
LSS SAVINGS	183876.1551	561095.5647
AVG LSS SAVING		372485.8599

Table C3 – EThekwini scenario 4 landfill space savings

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E		
WASTE MATERIAL OR WASTE FRACTION	QUANTITY OF WASTE DIVERTED (M3)	
	MIXED MSW DENSITY (M3)	US EPA LANDFILL FACTORS (M3)
newspaper	7687.209582	19444.8809
general mixed paper (CWM)	17794.46663	45011.29838
scrap boxes and cardboard (K4)	51058.25624	129152.4188
low density polyethylene (LDPE)	14852.44814	44859.02135
high density polyethelene (HDPE)	6880.527095	39221.11258
Polyethelene terephthalate (PET)	7782.113404	44360.43078
polypropylene (PP)	27189.945	154991.0173
polyvinyl chloride (PVC)	0	0
polystyrene (PS)	0	0
glass	34212.82783	24726.20658
steel cans/tin	16418.36121	59329.17805
aluminium cans	0	0
biogenic food waste	375885.7343	380322.834
garden refuse green		
garden refuse wood		
other		
LSS SAVINGS	559761.8894	941418.3987
AVG LSS SAVING		750590.1441

Table C4 – EThekwini scenario 5 landfill space savings

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E		
WASTE MATERIAL OR WASTE FRACTION	QUANTITY OF WASTE DIVERTED (M3)	
	MIXED MSW DENSITY (M3)	US EPA LANDFILL FACTORS (M3)
newspaper	7687.209582	19444.8809
general mixed paper (CWM)	17794.46663	45011.29838
scrap boxes and cardboard (K4)	51058.25624	129152.4188
low density polyethylene (LDPE)	14852.44814	44859.02135
high density polyethelene (HDPE)	6880.527095	39221.11258
Polyethelene terephthalate (PET)	7782.113404	44360.43078
polypropylene (PP)	27189.945	154991.0173
polyvinyl chloride (PVC)	0	0
polystyrene (PS)	0	0
glass	34212.82783	24726.20658
steel cans/tin	16418.36121	59329.17805
aluminium cans	0	0
biogenic food waste	234928.5839	237701.7713
garden refuse green	0	0
garden refuse wood	149848.14	202156.0067
other	0	0
LSS SAVINGS	568652.8791	1000953.343
AVG LSS SAVING		784803.1109

Table C5 – Msunduzi scenario 3A landfill space savings

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL		
W.R.O.S.E		
WASTE MATERIAL OR WASTE FRACTION	QUANTITY OF WASTE DIVERTED (M3)	
	MIXED MSW DENSITY (M3)	US EPA LANDFILL FACTORS (M3)
newspaper	826.3037333	2090.144351
general mixed paper (CWM)	607.2834667	1536.130185
scrap boxes and cardboard (K4)	401.9519667	1016.741906
low density polyethylene (LDPE)	161.7763333	488.6149354
high density polyethelene (HDPE)	140.6209667	801.5825951
Polyethelene terephthalate (PET)	250.1311	1425.823908
polypropylene (PP)	212.7981	1213.01437
polyvinyl chloride (PVC)	238.9312	2613.531197
polystyrene (PS)	70.9327	141.4187524
glass	893.5031333	645.750277
steel cans/tin	518.9287	1875.19405
aluminium cans	104.5324	846.1307251
biogenic food waste		
garden refuse green		
garden refuse wood		
other		
LSS SAVINGS	4427.6938	14694.07725
AVG LSS SAVING		9560.885526

Table C6 – Msunduzi scenario 3B landfill space savings

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL		
W.R.O.S.E		
WASTE MATERIAL OR WASTE FRACTION	QUANTITY OF WASTE DIVERTED (M3)	
	MIXED MSW DENSITY (M3)	US EPA LANDFILL FACTORS (M3)
newspaper	3305.214933	8360.577403
general mixed paper (CWM)	2429.133867	6144.520742
scrap boxes and cardboard (K4)	1607.807867	4066.967622
low density polyethylene (LDPE)	647.1053333	1954.459742
high density polyethelene (HDPE)	562.4838667	3206.33038
Polyethelene terephthalate (PET)	1000.5244	5703.295632
polypropylene (PP)	851.1924	4852.057478
polyvinyl chloride (PVC)	955.7248	10454.12479
polystyrene (PS)	283.7308	565.6750098
glass	3574.012533	2583.001108
steel cans/tin	2075.7148	7500.776199
aluminium cans	418.1296	3384.522901
biogenic food waste		
garden refuse green		
garden refuse wood		
other		
LSS SAVINGS	17710.7752	58776.30901
AVG LSS SAVING		38243.5421

Table C7 – Msunduzi scenario 4 landfill space savings

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL		
W.R.O.S.E		
WASTE MATERIAL OR WASTE FRACTION	QUANTITY OF WASTE DIVERTED (M3)	
	MIXED MSW DENSITY (M3)	US EPA LANDFILL FACTORS (M3)
newspaper	3305.214933	8360.577403
general mixed paper (CWM)	2429.133867	6144.520742
scrap boxes and cardboard (K4)	1607.807867	4066.967622
low density polyethylene (LDPE)	647.1053333	1954.459742
high density polyethelene (HDPE)	562.4838667	3206.33038
Polyethelene terephthalate (PET)	1000.5244	5703.295632
polypropylene (PP)	851.1924	4852.057478
polyvinyl chloride (PVC)	955.7248	10454.12479
polystyrene (PS)	283.7308	565.6750098
glass	3574.012533	2583.001108
steel cans/tin	2075.7148	7500.776199
aluminium cans	418.1296	3384.522901
biogenic food waste	66980.37973	67771.04189
garden refuse green		
garden refuse wood		
other		
LSS SAVINGS	84691.15493	126547.3509
AVG LSS SAVING		105619.2529

Table C8 – Msunduzi scenario 5 landfill space savings

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL		
W.R.O.S.E		
WASTE MATERIAL OR WASTE FRACTION	QUANTITY OF WASTE DIVERTED (M3)	
	MIXED MSW DENSITY (M3)	US EPA LANDFILL FACTORS (M3)
newspaper	3305.214933	8360.577403
general mixed paper (CWM)	2429.133867	6144.520742
scrap boxes and cardboard (K4)	1607.807867	4066.967622
low density polyethylene (LDPE)	647.1053333	1954.459742
high density polyethelene (HDPE)	562.4838667	3206.33038
Polyethelene terephthalate (PET)	1000.5244	5703.295632
polypropylene (PP)	851.1924	4852.057478
polyvinyl chloride (PVC)	955.7248	10454.12479
polystyrene (PS)	283.7308	565.6750098
glass	3574.012533	2583.001108
steel cans/tin	2075.7148	7500.776199
aluminium cans	418.1296	3384.522901
biogenic food waste	41862.73733	42356.90118
garden refuse green	920.8806667	1242.334795
garden refuse wood	24.88866667	33.57661608
other	0	0
LSS SAVINGS	60519.28187	102409.1216
AVG LSS SAVING		81464.20173

Table C9 – Newcastle scenario 3A landfill space savings

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E		
WASTE MATERIAL OR WASTE FRACTION	QUANTITY OF WASTE DIVERTED (M3)	
	MIXED MSW DENSITY (M3)	US EPA LANDFILL FACTORS (M3)
newspaper	111.3545	281.6724283
general mixed paper (CWM)	593.8906667	1502.252951
scrap boxes and cardboard (K4)	371.1816667	938.9080944
low density polyethylene (LDPE)	111.3545	336.3252876
high density polyethelene (HDPE)	111.3545	634.7547681
Polyethelene terephthalate (PET)	74.23633333	423.1698454
polypropylene (PP)	111.3545	634.7547681
polyvinyl chloride (PVC)	37.11816667	406.0143111
polystyrene (PS)	37.11816667	74.00260843
glass	445.418	321.9113467
steel cans/tin	111.3545	402.3891833
aluminium cans	111.3545	901.3517707
biogenic food waste		
garden refuse green		
garden refuse wood		
other		
LSS SAVINGS	2227.09	6857.507363
AVG LSS SAVING		4542.298682

Table C10 – Newcastle scenario 3A landfill space savings

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E		
WASTE MATERIAL OR WASTE FRACTION	QUANTITY OF WASTE DIVERTED (M3)	
	MIXED MSW DENSITY (M3)	US EPA LANDFILL FACTORS (M3)
newspaper	256.5995	649.0712479
general mixed paper (CWM)	1368.530667	3461.713322
scrap boxes and cardboard (K4)	855.3316667	2163.570826
low density polyethylene (LDPE)	256.5995	775.0104452
high density polyethelene (HDPE)	256.5995	1462.69577
Polyethelene terephthalate (PET)	171.0663333	975.1305133
polypropylene (PP)	256.5995	1462.69577
polyvinyl chloride (PVC)	85.53316667	935.5981952
polystyrene (PS)	85.53316667	170.5277499
glass	1026.398	741.7957119
steel cans/tin	256.5995	927.2446398
aluminium cans	256.5995	2077.027993
biogenic food waste		
garden refuse green		
garden refuse wood		
other		
LSS SAVINGS	5131.99	15802.08218
AVG LSS SAVING		10467.03609

Table C11 – Newcastle scenario 4 landfill space savings

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E		
WASTE MATERIAL OR WASTE FRACTION	QUANTITY OF WASTE DIVERTED (M3)	
	MIXED MSW DENSITY (M3)	US EPA LANDFILL FACTORS (M3)
newspaper	256.5995	649.0712479
general mixed paper (CWM)	1368.530667	3461.713322
scrap boxes and cardboard (K4)	855.3316667	2163.570826
low density polyethylene (LDPE)	256.5995	775.0104452
high density polyethelene (HDPE)	256.5995	1462.69577
Polyethelene terephthalate (PET)	171.0663333	975.1305133
polypropylene (PP)	256.5995	1462.69577
polyvinyl chloride (PVC)	85.53316667	935.5981952
polystyrene (PS)	85.53316667	170.5277499
glass	1026.398	741.7957119
steel cans/tin	256.5995	927.2446398
aluminium cans	256.5995	2077.027993
biogenic food waste	2840.346667	2873.875211
garden refuse green		
garden refuse wood		
other		
LSS SAVINGS	7972.336667	18675.9574
AVG LSS SAVING		13324.14703

Table C12 – Newcastle scenario 5 landfill space savings

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL W.R.O.S.E		
WASTE MATERIAL OR WASTE FRACTION	QUANTITY OF WASTE DIVERTED (M3)	
	MIXED MSW DENSITY (M3)	US EPA LANDFILL FACTORS (M3)
newspaper	256.5995	649.0712479
general mixed paper (CWM)	1368.530667	3461.713322
scrap boxes and cardboard (K4)	855.3316667	2163.570826
low density polyethylene (LDPE)	256.5995	775.0104452
high density polyethelene (HDPE)	256.5995	1462.69577
Polyethelene terephthalate (PET)	171.0663333	975.1305133
polypropylene (PP)	256.5995	1462.69577
polyvinyl chloride (PVC)	85.53316667	935.5981952
polystyrene (PS)	85.53316667	170.5277499
glass	1026.398	741.7957119
steel cans/tin	256.5995	927.2446398
aluminium cans	256.5995	2077.027993
biogenic food waste	1775.216667	1796.172007
garden refuse green	645.5333333	870.871276
garden refuse wood	645.5333333	870.871276
other	0	0
LSS SAVINGS	8198.273333	19339.99674
AVG LSS SAVING		13769.13504

Appendix D – Discounted cash flow economic analysis

Table D1 – WACC calculation

Weighted Average Cost Of Capital	
DEBT:EQUITY RATIO	50%
COST OF DEBT	9%
WEIGHTED COST OF	4.5%
BASIC RISK FREE RA	8%
BUSINESS RISK	7%
SECTOR RISK	1.0
WEIGHTED COST OF	7.5%
WACC	**12.0%**

Weighted cost of debt = cost of debt (9%) x debt: equity ratio (50%) = 4.5%

Weighted cost of equity = (basic risk free rate (8%) + business risk (7%)) x sector risk (1.0) x debt to equity ratio (50%) = 7.5%

Weighted average cost of capital (WACC) = weighted cost of debt (4.5%) + weighted cost of equity (7.5%) = 12%

All values used were based on assumptions and available data.

Table D2 – EThekwini LFG best case scenario discounted cash flow analysis

LFG PLANT

ECONOMIC FEASIBILITY OF BEST CASE

ASSUMPTIONS:		
1	Project life	10
2	Payback period	10
3	Debt Interest rate	9.0%
4	Debt percentage	50.0%

ESTIMATED REVENUE:	
Production Cost/KWH	R 0.90
Raw Materials/KWH	R 0.00
GM/KWH	R 0.90
KWH/H	6082.1
KWH/m	4379123.726
KWH/y	52549484.71
REVENUE/YEAR =	R 47 294 536

YEAR	RAMP UP	REVENUE	CAPITAL THROUGH DEBT	CAPITAL RECOVERY	INTEREST	OPERATING COSTS	GROSS PROFIT BEFORE TAX	DEPRE-CIATION
0			**-R 33 451 640**				-R 33 451 640	
1	80%	R 37 835 628.99		-R 2 201 790	-R 3 010 648	-R 5 352 262	R 27 270 929	R 13 380 656
2	85%	R 40 200 355.80		-R 2 399 951	-R 2 812 486	-R 5 686 779	R 29 301 140	R 13 380 656
3	90%	R 42 565 082.62		-R 2 615 947	-R 2 596 491	-R 6 021 295	R 31 331 350	R 13 380 656
4	95%	R 44 929 809.43		-R 2 851 382	-R 2 361 056	-R 6 355 812	R 33 361 560	R 13 380 656
5	100%	R 47 294 536.24		-R 3 108 006	-R 2 104 431	-R 6 690 328	R 35 391 771	R 13 380 656
6	100%	R 47 294 536.24		-R 3 387 727	-R 1 824 711	-R 6 690 328	R 35 391 771	R 0
7	100%	R 47 294 536.24		-R 3 692 622	-R 1 519 815	-R 6 690 328	R 35 391 771	R 0
8	100%	R 47 294 536.24		-R 4 024 958	-R 1 187 479	-R 6 690 328	R 35 391 771	R 0
9	100%	R 47 294 536.24		-R 4 387 204	-R 825 233	-R 6 690 328	R 35 391 771	R 0
10	100%	R 47 294 536.24		-R 4 782 053	-R 430 385	-R 6 690 328	R 35 391 771	R 0
				-R 33 451 640	**-R 18 242 351**	**IRR =**	**87.69%**	

ESTIMATED CAPITAL COST:	R	66 903 279.15
ESTIMATED OPERATING COST:	R	6 690 327.91

TONS/DAY	2736.9523
REQUIRED MW	6.082

Table D3 – EThekwini MRF best case scenario discounted cash flow analysis

MRF PLANT

ECONOMIC FEASIBILITY OF BEST CASE

ASSUMPTIONS:			ESTIMATED REVENUE:					
				Tons/year	Sale price/ton	Raw material/ton	GM/Ton	REVENUE
1	Project life	10	Newspaper	9224.65	R 400.00	R 0.00	R 400.00	R 3 689 860.60
2	Payback period	10	CWM	21353.36	R 100.00	R0.00	R 100.00	R 2 135 336.00
3	Debt Interest rate	9.0%	K4	61269.91	R 500.00	R0.00	R 500.00	R 30 634 953.74
4	Debt percentage	50.0%	LDPE	17822.94	R 2 500.00	R0.00	R 2 500.00	R 44 557 344.43
			HDPE	8256.63	R 2 500.00	R0.00	R 2 500.00	R 20 641 581.29
			PET	9338.54	R 1 500.00	R0.00	R 1 500.00	R 14 007 804.13
			PP	32627.93	R 3 500.00	R0.00	R 3 500.00	R 114 197 769.01
			PVC	0.00	R 1 500.00	R0.00	R 1 500.00	R 0.00
			PS	0.00	R 1 500.00	R0.00	R 1 500.00	R 0.00
			Glass	41055.39	R 380.00	R0.00	R 380.00	R 15 601 049.49
			FE Cans	19702.03	R 1 000.00	R0.00	R 1 000.00	R 19 702 033.45
			AL Cans	0.00	R 4 000.00	R0.00	R 4 000.00	R 0.00
			Total Recycled	220651.39	**REVENUE/YEAR =**	**R 265 167 732**		

YEAR	RAMP UP	REVENUE	CAPITAL THROUGH DEBT	CAPITAL RECOVERY	INTEREST	OPERATING COSTS	GROSS PROFIT BEFORE TAX	DEPRE-CIATION
0			**-R 44 770 328**				-R 44 770 328	
1	80%	R 212 134 185.70		-R 2 946 787	-R 4 029 329	-R 19 446 069	R 185 712 000	R 17 908 131
2	85%	R 225 392 572.31		-R 3 211 998	-R 3 764 119	-R 20 661 448	R 197 755 008	R 17 908 131
3	90%	R 238 650 958.92		-R 3 501 078	-R 3 475 039	-R 21 876 827	R 209 798 015	R 17 908 131
4	95%	R 251 909 345.52		-R 3 816 175	-R 3 159 942	-R 23 092 207	R 221 841 022	R 17 908 131
5	100%	R 265 167 732.13		-R 4 159 630	-R 2 816 486	-R 24 307 586	R 233 884 030	R 17 908 131
6	100%	R 265 167 732.13		-R 4 533 997	-R 2 442 119	-R 24 307 586	R 233 884 030	R 0
7	100%	R 265 167 732.13		-R 4 942 057	-R 2 034 060	-R 24 307 586	R 233 884 030	R 0
8	100%	R 265 167 732.13		-R 5 386 842	-R 1 589 275	-R 24 307 586	R 233 884 030	R 0
9	100%	R 265 167 732.13		-R 5 871 658	-R 1 104 459	-R 24 307 586	R 233 884 030	R 0
10	100%	R 265 167 732.13		-R 6 400 107	-R 576 010	-R 24 307 586	R 233 884 030	R 0
				-R 44 770 328	**-R 24 414 827**	**IRR =**	**421.19%**	

ESTIMATED CAPITAL COST:	R	89 540 655.17
ESTIMATED OPERATING COST:	R	24 307 585.98

dollar/rand exchange		13.63
Capital cost calculation	$	6 569 380.42
operating cost calculation	$	1 783 388.55

Table D4 – EThekwini AD best case scenario discounted cash flow analysis

ANAEROBIC DIGESTER PLANT

ECONOMIC FEASIBILITY OF BEST CASE

ASSUMPTIONS:

1	Project life	10
2	Payback period	10
3	Debt Interest rate	9.0%
4	Debt percentage	50.0%

ESTIMATED REVENUE:

Production Cost/KWH	R 0.96	Sale price/Ton of digestate	R 250.00
Raw Materials/KWH	R 0.00	Raw Material/Ton of digestate	R 0.00
GM/KWH	R 0.96	GM/Ton of Digestate	R 250.00
KWH/H	26844.1	Tons of digestate/day	741.4732293
KWH/m	19327735.51	Tons of digestate/month	22244.19688
KWH/y	231932826.1	Tons of digestate/year	266930.3625
REVENUE/YEAR =	**R 289 388 104**		

YEAR	RAMP UP	REVENUE	CAPITAL THROUGH DEBT	CAPITAL RECOVERY	INTEREST	OPERATING COSTS	GROSS PROFIT BEFORE TAX	DEPRE-CIATION
0			**-R 353 366 820**				-R 353 366 820	
1	80%	R 231 510 482.97		-R 23 258 636	-R 31 803 014	-R 22 346 174	R 154 102 659	R 141 346 728
2	85%	R 245 979 888.16		-R 25 351 913	-R 29 709 737	-R 23 742 810	R 167 175 428	R 141 346 728
3	90%	R 260 449 293.34		-R 27 633 585	-R 27 428 064	-R 25 139 446	R 180 248 198	R 141 346 728
4	95%	R 274 918 698.53		-R 30 120 608	-R 24 941 042	-R 26 536 082	R 193 320 967	R 141 346 728
5	100%	R 289 388 103.71		-R 32 831 463	-R 22 230 187	-R 27 932 718	R 206 393 736	R 141 346 728
6	100%	R 289 388 103.71		-R 35 786 294	-R 19 275 355	-R 27 932 718	R 206 393 736	R 0
7	100%	R 289 388 103.71		-R 39 007 061	-R 16 054 589	-R 27 932 718	R 206 393 736	R 0
8	100%	R 289 388 103.71		-R 42 517 696	-R 12 543 953	-R 27 932 718	R 206 393 736	R 0
9	100%	R 289 388 103.71		-R 46 344 289	-R 8 717 361	-R 27 932 718	R 206 393 736	R 0
10	100%	R 289 388 103.71		-R 50 515 275	-R 4 546 375	-R 27 932 718	R 206 393 736	R 0
				-R 353 366 820	**-R 192 703 302**	**IRR =**	**48.55%**	

ESTIMATED CAPITAL COST:	R	706 733 639.22
ESTIMATED OPERATING COST:	R	27 932 717.81
dollar/rand exchange		13.63
Capital cost calculation	$	51 851 330.83
operating cost calculation	$	2 049 355.67
kwh/day		644 257.85
kwh/h		26 844.08
MW		26.84

amount of wet feedstock tons/year	451 062.88
amount of wet feedstock tons/day	1 235.79
m3 biogas/ton of wet food waste	204.00
m3 biogas/day	252 100.90
biogas calorific value mj/m3	23.00
conversion 1kwh = 3.6mj	
biogas calorific value kwh/m3	6.39
biogas to electricity efficiency	0.40
output energy/cubic metre of biogas kwh/m3	2.56

Table D5 – EThekwini AC best case scenario discounted cash flow analysis

AEROBIC COMPOSTING PLANT

ECONOMIC FEASIBILITY OF BEST AND WACC CASE

ASSUMPTIONS:		
1	Project life	10
2	Payback period	10
3	Debt Interest rate	9.0%
4	Debt percentage	50.0%

ESTIMATED REVENUE:	
Sale price/Ton of compost	R 210.00
Raw Material/Ton of compost	R 0.00
GM/Ton of compost	R 210.00
Tons of compost/day	961.9418098
Tons of compost/month	28858.2543
Tons of compost/year	346299.0515
REVENUE/YEAR =	R 72 722 801

YEAR	RAMP UP	REVENUE	CAPITAL THROUGH DEBT	CAPITAL RECOVERY	INTEREST	OPERATING COSTS	GROSS PROFIT BEFORE TAX	DEPRE-CIATION
0			-R 7 027 885				-R 7 027 885	
1	80%	R 58 178 240.66		-R 462 576	-R 632 510	-R 56 165 089	R 918 066	R 2 811 154
2	85%	R 61 814 380.70		-R 504 208	-R 590 878	-R 59 675 407	R 1 043 888	R 2 811 154
3	90%	R 65 450 520.74		-R 549 587	-R 545 499	-R 63 185 725	R 1 169 710	R 2 811 154
4	95%	R 69 086 660.78		-R 599 049	-R 496 036	-R 66 696 043	R 1 295 532	R 2 811 154
5	100%	R 72 722 800.82		-R 652 964	-R 442 122	-R 70 206 361	R 1 421 354	R 2 811 154
6	100%	R 72 722 800.82		-R 711 731	-R 383 355	-R 70 206 361	R 1 421 354	R 0
7	100%	R 72 722 800.82		-R 775 786	-R 319 299	-R 70 206 361	R 1 421 354	R 0
8	100%	R 72 722 800.82		-R 845 607	-R 249 479	-R 70 206 361	R 1 421 354	R 0
9	100%	R 72 722 800.82		-R 921 712	-R 173 374	-R 70 206 361	R 1 421 354	R 0
10	100%	R 72 722 800.82		-R 1 004 666	-R 90 420	-R 70 206 361	R 1 421 354	R 0
				-R 7 027 885	-R 3 832 552	IRR =	11.98%	

ESTIMATED CAPITAL COST:	R	14 055 770.74
ESTIMATED OPERATING COST:	R	70 206 361.05

Table D6 – Msunduzi LFG best case scenario discounted cash flow analysis

LFG PLANT

ECONOMIC FEASIBILITY OF BEST CASE

ASSUMPTIONS:		
1	Project life	10
2	Payback period	10
3	Debt Interest rate	9.0%
4	Debt percentage	50.0%

ESTIMATED REVENUE:	
Production Cost/KWH	R 0.90
Raw Materials/KWH	R 0.00
GM/KWH	R 0.90
KWH/H	909.2
KWH/m	654606.0274
KWH/y	7855272.329
REVENUE/YEAR =	**R 7 069 745**

YEAR	RAMP UP	REVENUE	CAPITAL THROUGH DEBT	CAPITAL RECOVERY	INTEREST	OPERATING COSTS	GROSS PROFIT BEFORE TAX	DEPRE-CIATION
0			**-R 5 000 463**				-R 5 000 463	
1	80%	R 5 655 796.08		-R 329 131	-R 450 042	-R 800 074	R 4 076 549	R 2 000 185
2	85%	R 6 009 283.33		-R 358 753	-R 420 420	-R 850 079	R 4 380 032	R 2 000 185
3	90%	R 6 362 770.59		-R 391 040	-R 388 132	-R 900 083	R 4 683 515	R 2 000 185
4	95%	R 6 716 257.84		-R 426 234	-R 352 938	-R 950 088	R 4 986 997	R 2 000 185
5	100%	R 7 069 745.10		-R 464 595	-R 314 577	-R 1 000 093	R 5 290 480	R 2 000 185
6	100%	R 7 069 745.10		-R 506 409	-R 272 764	-R 1 000 093	R 5 290 480	R 0
7	100%	R 7 069 745.10		-R 551 985	-R 227 187	-R 1 000 093	R 5 290 480	R 0
8	100%	R 7 069 745.10		-R 601 664	-R 177 508	-R 1 000 093	R 5 290 480	R 0
9	100%	R 7 069 745.10		-R 655 814	-R 123 359	-R 1 000 093	R 5 290 480	R 0
10	100%	R 7 069 745.10		-R 714 837	-R 64 335	-R 1 000 093	R 5 290 480	R 0
				-R 5 000 463	**-R 2 726 927**	**IRR =**	**87.69%**	

ESTIMATED CAPITAL COST:	R	10 000 925.42
ESTIMATED OPERATING COST:	R	1 000 092.54

TONS/DAY	409.1288
REQUIRED MW	0.909

Table D7 – Msunduzi MRF best case scenario discounted cash flow analysis

MRF PLANT

ECONOMIC FEASIBILITY OF BEST CASE

ASSUMPTIONS:

1	Project life	10
2	Payback period	10
3	Debt Interest rate	9.0%
4	Debt percentage	50.0%

ESTIMATED REVENUE:

	Tons/year	Sale price/ton	Raw material/ton	GM/Ton	REVENUE
Newspaper	3966.26	R 400.00	R 0.00	R 400.00	R 1 586 503.17
CWM	2914.96	R 100.00	R0.00	R 100.00	R 291 496.06
K4	1929.37	R 500.00	R0.00	R 500.00	R 964 684.72
LDPE	776.53	R 2 500.00	R0.00	R 2 500.00	R 1 941 316.00
HDPE	674.98	R 2 500.00	R0.00	R 2 500.00	R 1 687 451.60
PET	1200.63	R 1 500.00	R0.00	R 1 500.00	R 1 800 943.92
PP	1021.43	R 3 500.00	R0.00	R 3 500.00	R 3 575 008.08
PVC	1146.87	R 1 500.00	R0.00	R 1 500.00	R 1 720 304.64
PS	340.48	R 1 500.00	R0.00	R 1 500.00	R 510 715.44
Glass	4288.82	R 380.00	R0.00	R 380.00	R 1 629 749.72
FE Cans	2490.86	R 1 000.00	R0.00	R 1 000.00	R 2 490 857.76
AL Cans	501.76	R 4 000.00	R0.00	R 4 000.00	R 2 007 022.08
Total Recycled	21252.93	**REVENUE/YEAR =**	**R 20 206 053**		

YEAR	RAMP UP	REVENUE	DEBT	RECOVERY	INTEREST	COSTS	BEFORE TAX	DEPRE-CIATION
0			**-R 17 427 165**				-R 17 427 165	
1	80%	R 16 164 842.55		-R 1 147 058	-R 1 568 445	-R 10 392 292	R 3 057 048	R 6 970 866
2	85%	R 17 175 145.21		-R 1 250 293	-R 1 465 210	-R 11 041 810	R 3 417 833	R 6 970 866
3	90%	R 18 185 447.87		-R 1 362 819	-R 1 352 683	-R 11 691 328	R 3 778 617	R 6 970 866
4	95%	R 19 195 750.53		-R 1 485 473	-R 1 230 030	-R 12 340 847	R 4 139 401	R 6 970 866
5	100%	R 20 206 053.19		-R 1 619 165	-R 1 096 337	-R 12 990 365	R 4 500 186	R 6 970 866
6	100%	R 20 206 053.19		-R 1 764 890	-R 950 612	-R 12 990 365	R 4 500 186	R 0
7	100%	R 20 206 053.19		-R 1 923 730	-R 791 772	-R 12 990 365	R 4 500 186	R 0
8	100%	R 20 206 053.19		-R 2 096 866	-R 618 636	-R 12 990 365	R 4 500 186	R 0
9	100%	R 20 206 053.19		-R 2 285 584	-R 429 918	-R 12 990 365	R 4 500 186	R 0
10	100%	R 20 206 053.19		-R 2 491 287	-R 224 216	-R 12 990 365	R 4 500 186	R 0
				-R 17 427 165	**-R 9 503 643**	**IRR =**	**18.25%**	

ESTIMATED CAPITAL COST:	R	34 854 330.19
ESTIMATED OPERATING COST:	R	12 990 364.96

dollar/rand exchange		13.63
Capital cost calculation	$	2 557 177.56
operating cost calculation	$	953 071.53

Table D8 – Msunduzi AD best case scenario discounted cash flow analysis

ANAEROBIC DIGESTER PLANT

ECONOMIC FEASIBILITY OF BEST CASE

ASSUMPTIONS:

1	Project life	10
2	Payback period	10
3	Debt Interest rate	9.0%
4	Debt percentage	50.0%

ESTIMATED REVENUE:

Production Cost/KWH	R 0.96	Sale price/Ton of digestate	R 250.00
Raw Materials/KWH	R 0.00	Raw Material/Ton of digestate	R 0.00
GM/KWH	R 0.96	GM/Ton of Digestate	R 250.00
KWH/H	4783.4	Tons of digestate/day	132.1256806
KWH/m	3444076.074	Tons of digestate/month	3963.770417
KWH/y	41328912.88	Tons of digestate/year	47565.24501
REVENUE/YEAR =	**R 51 567 068**		

YEAR	RAMP UP	REVENUE	CAPITAL THROUGH DEBT	CAPITAL RECOVERY	INTEREST	OPERATING COSTS	GROSS PROFIT BEFORE TAX	DEPRE-CIATION
0			**-R 134 942 409**				-R 134 942 409	
1	80%	R 41 253 654.09		-R 8 881 922	-R 12 144 817	-R 11 542 363	R 8 684 553	R 53 976 964
2	85%	R 43 832 007.48		-R 9 681 294	-R 11 345 444	-R 12 263 761	R 10 541 509	R 53 976 964
3	90%	R 46 410 360.86		-R 10 552 611	-R 10 474 127	-R 12 985 158	R 12 398 464	R 53 976 964
4	95%	R 48 988 714.24		-R 11 502 346	-R 9 524 392	-R 13 706 556	R 14 255 420	R 53 976 964
5	100%	R 51 567 067.62		-R 12 537 557	-R 8 489 181	-R 14 427 954	R 16 112 376	R 53 976 964
6	100%	R 51 567 067.62		-R 13 665 937	-R 7 360 801	-R 14 427 954	R 16 112 376	R 0
7	100%	R 51 567 067.62		-R 14 895 872	-R 6 130 867	-R 14 427 954	R 16 112 376	R 0
8	100%	R 51 567 067.62		-R 16 236 500	-R 4 790 238	-R 14 427 954	R 16 112 376	R 0
9	100%	R 51 567 067.62		-R 17 697 785	-R 3 328 953	-R 14 427 954	R 16 112 376	R 0
10	100%	R 51 567 067.62		-R 19 290 586	-R 1 736 153	-R 14 427 954	R 16 112 376	R 0
				-R 134 942 409	**-R 73 588 822**	**IRR =**	**0.93%**	

ESTIMATED CAPITAL COST:	R	269 884 818.67
ESTIMATED OPERATING COST:	R	14 427 953.66

dollar/rand exchange	13.63
Capital cost calculation	$ 19 800 793.74
operating cost calculation	$ 1 058 543.92
kwh/day	114 802.54
kwh/h	4 783.44
MW	4.78

amount of wet feedstock tons/year	80 376.46
amount of wet feedstock tons/day	220.21
m3 biogas/ton of wet food waste	204.00
m3 biogas/day	44 922.73
biogas calorific value mj/m3	23.00
conversion 1kwh = 3.6mj	
biogas calorific value kwh/m3	6.39
biogas to electricity efficiency	0.40
output energy/cubic metre of biogas kwh/m3	2.56

Table D9 – Msunduzi AC best case scenario discounted cash flow analysis

AEROBIC COMPOSTING PLANT

ECONOMIC FEASIBILITY OF BEST AND WACC CASE

ASSUMPTIONS:		
1	Project life	10
2	Payback period	10
3	Debt Interest rate	9.0%
4	Debt percentage	50.0%

ESTIMATED REVENUE:	
Sale price/Ton of compost	R 210.00
Raw Material/Ton of compost	R 0.00
GM/Ton of compost	R 210.00
Tons of compost/day	107.0212667
Tons of compost/month	3210.638
Tons of compost/year	38527.656
REVENUE/YEAR =	R 8 090 808

YEAR	RAMP UP	REVENUE	CAPITAL THROUGH DEBT	CAPITAL RECOVERY	INTEREST	OPERATING COSTS	GROSS PROFIT BEFORE TAX	DEPRE-CIATION
0			-R 781 891				-R 781 891	
1	80%	R 6 472 646.21		-R 51 464	-R 70 370	-R 6 248 672	R 102 140	R 312 756
2	85%	R 6 877 186.60		-R 56 096	-R 65 738	-R 6 639 214	R 116 138	R 312 756
3	90%	R 7 281 726.98		-R 61 145	-R 60 690	-R 7 029 756	R 130 137	R 312 756
4	95%	R 7 686 267.37		-R 66 648	-R 55 187	-R 7 420 298	R 144 135	R 312 756
5	100%	R 8 090 807.76		-R 72 646	-R 49 188	-R 7 810 840	R 158 133	R 312 756
6	100%	R 8 090 807.76		-R 79 184	-R 42 650	-R 7 810 840	R 158 133	R 0
7	100%	R 8 090 807.76		-R 86 310	-R 35 524	-R 7 810 840	R 158 133	R 0
8	100%	R 8 090 807.76		-R 94 078	-R 27 756	-R 7 810 840	R 158 133	R 0
9	100%	R 8 090 807.76		-R 102 545	-R 19 289	-R 7 810 840	R 158 133	R 0
10	100%	R 8 090 807.76		-R 111 775	-R 10 060	-R 7 810 840	R 158 133	R 0
				-R 781 891	**-R 426 392**	**IRR =**	**11.98%**	

ESTIMATED CAPITAL COST:	R	1 563 781.07
ESTIMATED OPERATING COST:	R	7 810 840.13

Table D10 – Newcastle LFG best case scenario discounted cash flow analysis

LFG PLANT

ECONOMIC FEASIBILITY OF WACC CASE

ASSUMPTIONS:

1	Project life	10
2	Payback period	10
3	Debt Interest rate	9.0%
4	Debt percentage	50.0%

ESTIMATED REVENUE:

Production Cost/KWH	R 0.90
Raw Materials/KWH	R 0.00
GM/KWH	R 0.90
KWH/H	117.9
KWH/m	84892.05479
KWH/y	1018704.658
REVENUE/YEAR =	**R 916 834**

YEAR	RAMP UP	REVENUE	CAPITAL THROUGH DEBT	CAPITAL RECOVERY	INTEREST	OPERATING COSTS	GROSS PROFIT BEFORE TAX	DEPRE-CIATION
0			**-R 648 481**				-R 648 481	
1	80%	R 733 467.35		-R 42 683	-R 58 363	-R 103 757	R 528 664	R 259 392
2	85%	R 779 309.06		-R 46 525	-R 54 522	-R 110 242	R 568 021	R 259 392
3	90%	R 825 150.77		-R 50 712	-R 50 335	-R 116 727	R 607 378	R 259 392
4	95%	R 870 992.48		-R 55 276	-R 45 771	-R 123 211	R 646 735	R 259 392
5	100%	R 916 834.19		-R 60 251	-R 40 796	-R 129 696	R 686 092	R 259 392
6	100%	R 916 834.19		-R 65 673	-R 35 373	-R 129 696	R 686 092	R 0
7	100%	R 916 834.19		-R 71 584	-R 29 463	-R 129 696	R 686 092	R 0
8	100%	R 916 834.19		-R 78 026	-R 23 020	-R 129 696	R 686 092	R 0
9	100%	R 916 834.19		-R 85 049	-R 15 998	-R 129 696	R 686 092	R 0
10	100%	R 916 834.19		-R 92 703	-R 8 343	-R 129 696	R 686 092	R 0
				-R 648 481	**-R 353 639**	**IRR =**	**87.69%**	

ESTIMATED CAPITAL COST:	R	1 296 961.95
ESTIMATED OPERATING COST:	R	129 696.19

TONS/DAY	53.0575
REQUIRED MW	0.118

Table D11 – Newcastle MRF best case scenario discounted cash flow analysis

MRF PLANT

ECONOMIC FEASIBILITY OF BEST CASE

ASSUMPTIONS:		
1	Project life	10
2	Payback period	10
3	Debt Interest rate	9.0%
4	Debt percentage	50.0%

ESTIMATED REVENUE:	Tons/year	Sale price/ton	Raw material/ton	GM/Ton	REVENUE
Newspaper	307.92	R 400.00	R 0.00	R 400.00	R 123 167.76
CWM	1642.24	R 100.00	R0.00	R 100.00	R 164 223.68
K4	1026.40	R 500.00	R0.00	R 500.00	R 513 199.00
LDPE	307.92	R 2 500.00	R0.00	R 2 500.00	R 769 798.50
HDPE	307.92	R 2 500.00	R0.00	R 2 500.00	R 769 798.50
PET	205.28	R 1 500.00	R0.00	R 1 500.00	R 307 919.40
PP	307.92	R 3 500.00	R0.00	R 3 500.00	R 1 077 717.90
PVC	102.64	R 1 500.00	R0.00	R 1 500.00	R 153 959.70
PS	102.64	R 1 500.00	R0.00	R 1 500.00	R 153 959.70
Glass	1231.68	R 380.00	R0.00	R 380.00	R 468 037.49
FE Cans	307.92	R 1 000.00	R0.00	R 1 000.00	R 307 919.40
AL Cans	307.92	R 4 000.00	R0.00	R 4 000.00	R 1 231 677.60
Total Recycled	6158.39	**REVENUE/YEAR =**	**R 6 041 379**		

YEAR	RAMP UP	REVENUE	DEBT	RECOVERY	INTEREST	COSTS	BEFORE TAX	DEPRE-CIATION
0			**-R 15 357 277**				-R 15 357 277	
1	80%	R 4 833 102.90		-R 1 010 817	-R 1 382 155	-R 9 706 917	-R 7 266 787	R 6 142 911
2	85%	R 5 135 171.83		-R 1 101 791	-R 1 291 181	-R 10 313 600	-R 7 571 400	R 6 142 911
3	90%	R 5 437 240.77		-R 1 200 952	-R 1 192 020	-R 10 920 282	-R 7 876 014	R 6 142 911
4	95%	R 5 739 309.70		-R 1 309 038	-R 1 083 934	-R 11 526 964	-R 8 180 627	R 6 142 911
5	100%	R 6 041 378.63		-R 1 426 851	-R 966 121	-R 12 133 647	-R 8 485 240	R 6 142 911
6	100%	R 6 041 378.63		-R 1 555 268	-R 837 704	-R 12 133 647	-R 8 485 240	R 0
7	100%	R 6 041 378.63		-R 1 695 242	-R 697 730	-R 12 133 647	-R 8 485 240	R 0
8	100%	R 6 041 378.63		-R 1 847 814	-R 545 159	-R 12 133 647	-R 8 485 240	R 0
9	100%	R 6 041 378.63		-R 2 014 117	-R 378 855	-R 12 133 647	-R 8 485 240	R 0
10	100%	R 6 041 378.63		-R 2 195 387	-R 197 585	-R 12 133 647	-R 8 485 240	R 0
				-R 15 357 277	**-R 8 374 861**	**IRR =**	**#NUM!**	

ESTIMATED CAPITAL COST:	R 30 714 553.69
ESTIMATED OPERATING COST:	R 12 133 646.84

dollar/rand exchange	13.63
Capital cost calculation	$ 2 253 452.22
operating cost calculation	$ 890 216.20

Table D12 – Newcastle AD best case scenario discounted cash flow analysis

ANAEROBIC DIGESTER PLANT

ECONOMIC FEASIBILITY OF BEST CASE

ASSUMPTIONS:		
1	Project life	10
2	Payback period	10
3	Debt Interest rate	9.0%
4	Debt percentage	50.0%

ESTIMATED REVENUE:			
Production Cost/KWH	R 0.96	Sale price/Ton of digestate	R 250.00
Raw Materials/KWH	R 0.00	Raw Material/Ton of digestate	R 0.00
GM/KWH	R 0.96	GM/Ton of Digestate	R 250.00
KWH/H	202.8	Tons of digestate/day	5.602875616
KWH/m	146048.2911	Tons of digestate/month	168.0862685
KWH/y	1752579.493	Tons of digestate/year	2017.035222
REVENUE/YEAR =	**R 2 186 735**		

YEAR	RAMP UP	REVENUE	CAPITAL THROUGH DEBT	CAPITAL RECOVERY	INTEREST	OPERATING COSTS	GROSS PROFIT BEFORE TAX	DEPRE-CIATION
0			**-R 23 126 699**				-R 23 126 699	
1	80%	R 1 749 388.09		-R 1 522 201	-R 2 081 403	-R 3 440 314	-R 5 294 530	R 9 250 680
2	85%	R 1 858 724.85		-R 1 659 200	-R 1 944 405	-R 3 655 333	-R 5 400 213	R 9 250 680
3	90%	R 1 968 061.61		-R 1 808 528	-R 1 795 077	-R 3 870 353	-R 5 505 895	R 9 250 680
4	95%	R 2 077 398.36		-R 1 971 295	-R 1 632 309	-R 4 085 372	-R 5 611 578	R 9 250 680
5	100%	R 2 186 735.12		-R 2 148 712	-R 1 454 893	-R 4 300 392	-R 5 717 261	R 9 250 680
6	100%	R 2 186 735.12		-R 2 342 096	-R 1 261 509	-R 4 300 392	-R 5 717 261	R 0
7	100%	R 2 186 735.12		-R 2 552 884	-R 1 050 720	-R 4 300 392	-R 5 717 261	R 0
8	100%	R 2 186 735.12		-R 2 782 644	-R 820 961	-R 4 300 392	-R 5 717 261	R 0
9	100%	R 2 186 735.12		-R 3 033 082	-R 570 523	-R 4 300 392	-R 5 717 261	R 0
10	100%	R 2 186 735.12		-R 3 306 059	-R 297 545	-R 4 300 392	-R 5 717 261	R 0
				-R 23 126 699	**-R 12 611 799**	**IRR =**	**#NUM!**	

ESTIMATED CAPITAL COST:	R	46 253 398.38
ESTIMATED OPERATING COST:	R	4 300 391.88
dollar/rand exchange		13.63
Capital cost calculation	$	3 393 499.51
operating cost calculation	$	315 509.31
kwh/day		4 868.28
kwh/h		202.84
MW		0.20

amount of wet feedstock tons/year	3 408.42
amount of wet feedstock tons/day	9.34
m3 biogas/ton of wet food waste	204.00
m3 biogas/day	1 904.98
biogas calorific value mj/m3	23.00
conversion 1kwh = 3.6mj	
biogas calorific value kwh/m3	6.39
biogas to electricity efficiency	0.40
output energy/cubic metre of biogas kwh/m3	2.56

Table D13 – Newcastle AC best case scenario discounted cash flow analysis

AEROBIC COMPOSTING PLANT

ECONOMIC FEASIBILITY OF BEST AND WACC CASE

ASSUMPTIONS:		
1	Project life	10
2	Payback period	10
3	Debt Interest rate	9.0%
4	Debt percentage	50.0%

ESTIMATED REVENUE:	
Sale price/Ton of compost	R 210.00
Raw Material/Ton of compost	R 0.00
GM/Ton of compost	R 210.00
Tons of compost/day	7.665708333
Tons of compost/month	229.97125
Tons of compost/year	2759.655
REVENUE/YEAR =	**R 579 528**

YEAR	RAMP UP	REVENUE	CAPITAL THROUGH DEBT	CAPITAL RECOVERY	INTEREST	OPERATING COSTS	GROSS PROFIT BEFORE TAX	DEPRE-CIATION
0			**-R 56 005**				-R 56 005	
1	80%	R 463 622.04		-R 3 686	-R 5 040	-R 447 579	R 7 316	R 22 402
2	85%	R 492 598.42		-R 4 018	-R 4 709	-R 475 553	R 8 319	R 22 402
3	90%	R 521 574.80		-R 4 380	-R 4 347	-R 503 527	R 9 321	R 22 402
4	95%	R 550 551.17		-R 4 774	-R 3 953	-R 531 500	R 10 324	R 22 402
5	100%	R 579 527.55		-R 5 203	-R 3 523	-R 559 474	R 11 327	R 22 402
6	100%	R 579 527.55		-R 5 672	-R 3 055	-R 559 474	R 11 327	R 0
7	100%	R 579 527.55		-R 6 182	-R 2 544	-R 559 474	R 11 327	R 0
8	100%	R 579 527.55		-R 6 739	-R 1 988	-R 559 474	R 11 327	R 0
9	100%	R 579 527.55		-R 7 345	-R 1 382	-R 559 474	R 11 327	R 0
10	100%	R 579 527.55		-R 8 006	-R 721	-R 559 474	R 11 327	R 0
				-R 56 005	**-R 30 542**	**IRR =**	**11.98%**	

ESTIMATED CAPITAL COST:	R	112 010.35
ESTIMATED OPERATING COST:	R	559 474.06