mitigation REPORT

SOUTH AFRICA'S GREENHOUSE GAS MITIGATION POTENTIAL ANALYSIS

TECHNICAL APPENDIX F – WASTE SECTOR

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On behalf of:
Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
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The suite of reports that make up South Africa's Greenhouse Gas (GHG) Mitigation Potential Analysis include the following:

Technical Summary

Main Report

Technical Appendices:

Appendix A: Approach and Methodology

Appendix B: Macroeconomic Modelling

Appendix C: Energy Sector

Appendix D: Industry Sector

Appendix E: Transport Sector

Appendix F: Waste Sector

Appendix G: Agriculture, Forestry and Other Land Use Sector





List of Abbreviations

Acronym	Definition
AD	anaerobic digestion
BOD	biological oxygen demand
CCS	Carbon Capture and Storage
CH4	methane
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
EfW	energy from waste
EPA	United States Environmental Protection Agency
ERC	Energy Research Centre
GDP	gross domestic product
Gg/yr	gigagrams per year
GHG	greenhouse gas
GHGI	Greenhouse Gas Inventory for South Africa
GVA	gross value added
GW	gigawatt
GWh	gigawatt hour
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
kW	kilowatt
kWh	kilowatt hour
$ktCO_2e$	kilotonnes of carbon dioxide equivalent
LFG	landfill gas
MAC	marginal abatement cost
MACC	marginal abatement cost curve
MCA	multi-criteria (decision) analysis
MSFM	municipal services financial modelling
MSW	municipal solid waste
MW	megawatt
MWh	megawatt hour

Acronym	Definition
Mt	million tonnes
$MtCO_2e$	million tonnes of carbon dioxide equivalent
N_2O	nitrous oxide
NCCRP	National Climate Change Response Policy
NPV	net present value
TWG-M	Technical Working Group on Mitigation
UNFCCC	United Nations Framework Convention on Climate Change
WAM	'with additional measures' scenario
WEM	'with existing measures' scenario
WOM	'without measures' scenario
ZAR/R	South African rand

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Chapter 1: Introduction

1. Introduction

This section provides an overview of emission trends, existing policies and potential future abatement opportunities for the waste sector. It is based on an analysis of emissions sources which are currently estimated in the draft national Greenhouse Gas Inventory for South Africa (GHGI) (Department of Environmental Affairs, 2013). These are:

- 4A1 managed waste disposal sites
- 4D wastewater treatment and discharge

Emissions from managed waste disposal sites arise from methane (CH_4) contained in landfill gas (LFG) which is generated as a result of the anaerobic decomposition of organic waste deposited in the landfill. Wastewater treatment can result in emissions of both CH_4 and N_2O depending on the treatment method.

The inventory currently does not estimate emissions from the disposal of industrial waste not disposed of in the municipal waste stream, as comprehensive data on the amount of industrial waste and disposal routes for industrial waste is not available.

For the purposes of this study, therefore, emissions projections and estimates of mitigation potential presented in this appendix exclude industrial waste and focus only on municipal waste. For municipal waste, the GHGI also does not estimate emissions from:

- 4A2 unmanaged waste disposal sites
- 4A3 uncategorized waste disposal sites
- 4B biological treatment of solid waste
- 4C1 waste incineration
- 4C2 open burning of waste

Emissions from unmanaged and uncategorized waste disposal sites are likely to be significantly smaller than those from managed sites, as this type of site is more likely to be a shallow landfill site, where decomposition of waste is more aerobic and hence leads to lower methane emissions. There is little (if any) biological treatment of solid waste in South Africa at present, so the omission of this category is likely to introduce relatively little error. Small quantities of some types of waste are incinerated, but there is no large scale incineration of municipal solid waste, so again this category is expected to be a relatively small emissions source. Open burning of waste does occur, but the scale of this is unknown.

In summary, it appears likely that the current inventory underestimates emissions from this sector (by what is assumed to be a small amount). As it was not within the remit of this study to expand the scope of the current GHGI to include additional sources, the projections are also likely to underestimate future emissions.

1.1 Solid Waste Management

Waste generation per capita varies widely within South Africa depending on income and location (urban and rural). At present, not all waste is collected and managed formally, with only 61% of the population estimated to have access to kerbside removal of waste (DEA, 2011). This is highly skewed to more affluent urban communities, with significantly lower levels in urban informal areas, tribal areas and rural formal areas. Similarly, while urban areas may dispose of waste to managed landfill sites, there is significant use of unmanaged sites, open dumps and open burning in other areas. The National Waste Management Strategy (DEA, 2011) noted that a growing population and economy would lead to increased volumes of waste generated and greater complexity of the waste stream, and that this would put pressure on waste management facilities which are already in short supply. The strategy also noted that there is limited understanding of the main waste flows and the national waste balance as data reporting is not obligatory and available data is often unreliable and contradictory.

The National Waste Management Strategy sets several goals, the most relevant of which for GHG emissions and mitigation are:

Goal 1: Promote waste minimisation, reuse, recycling and recovery of waste: Focuses on implementing the waste management hierarchy, with the ultimate aim of diverting waste from landfill.

Goal 2: Ensure the effective and efficient delivery of waste services: Promotes access to at least a basic level of waste services for all and integrates the waste management hierarchy into waste services, including separation at source, and ensures that waste that cannot be reused, recycled or recovered is disposed of safely in properly-permitted landfill sites.

Chapter II: Reference Case Projections

2. Reference Case Projection: 'Without Measures'

The starting point for this analysis is a reference case projection of GHG emissions from the sector. This estimates emissions from the sector between 2000 and 2050 assuming that no measures have been put in place to mitigate emissions, and that current practices in waste management continue. The projection is referred to as the 'without measures' (WOM) projection.

2.1 Managed disposal of municipal solid waste

Emissions from the disposal of municipal solid waste (MSW) in managed waste disposal sites were estimated using the emissions model[1] used by the DEA for estimating emissions from this sector in the GHGI. The emissions model first estimates waste disposed to managed waste disposal sites as the product of population, the fraction of the population whose waste goes to managed landfill, and the amount of waste per capita deposited in landfill (that is excluding recycling). As waste deposited in landfills continues to produce LFG for several years after it has been deposited, the model considers historic as well as current and future waste disposal.

The model supplied by the DEA already forecasts emissions to 2020. This was expanded to forecast emissions to 2050. The key assumptions used were the following.

Population forecast: UN population forecast for South Africa (UN, 2011).

Fraction of waste disposed to managed landfill: current values are based on the fraction of population in urban areas (assumed to be 61% in 2010). This is assumed to rise linearly as urbanisation increases to 81% in 2050, and more waste is disposed of in managed facilities.[2]

Municipal solid waste (MSW) generation per capita: Assumed to grow at 2% p.a. to 2020 (as in the DEA model) due to rising gross domestic product (GDP) per capita. Growth then begins to slow as international data (Figure 1) indicates continued linear growth is unlikely, and that waste generation per capita will become decoupled from economic growth.

The final variable in the model is waste composition; in particular, the fraction of different types of biodegradable material such as food waste, garden waste, paper, card and wood. Although some data is available on waste composition for some municipalities, these vary considerably as they are influenced by location and affluence. No data could be found in the literature on the average composition of MSW nationally at the level of detail required for the model. For this reason, waste composition is taken as that used by the DEA in the model which is based on IPCC default data for Southern Africa.

Figure 2 compares estimates of waste generated in the model used for the GHGI and for the projections in this study, with projections made for municipal services financial modelling (MSFM) of the waste sector.[3] While estimates of the total amount of waste disposed of are higher than the estimates in the MSFM modelling, the growth rate is slightly lower. The estimate in these projections of waste deposited in 2007 is lower than that estimated by the Department of Environmental Affairs and Tourism (DEAT, 2007).

1. The model is a first order decay model developed by the IPCC for use in national inventories.
2. For this reference case, it is assumed that landfill, which is currently the predominant type of waste disposal, remains the predominant method of waste disposal. The use of other waste treatment options such as energy from waste, anaerobic digestion and composting are considered as mitigation options.
3. Carried out by PDG for the Department of Provincial and Local Government, National Treasury and the Development Bank of Southern Africa

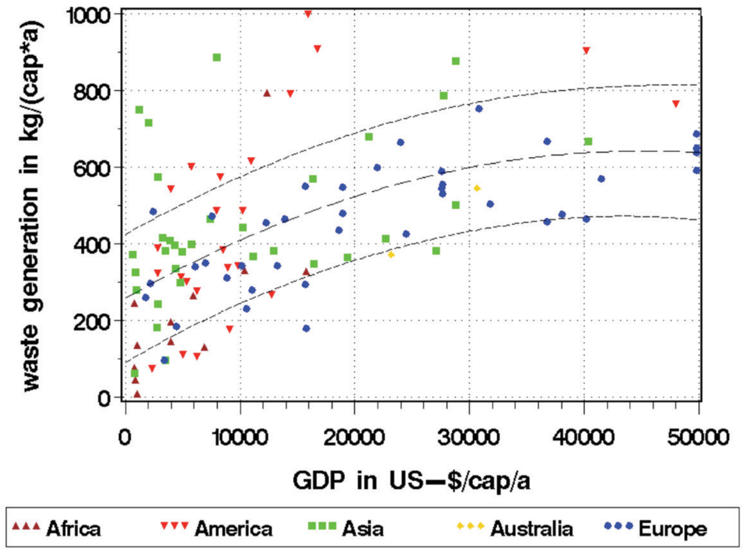

Figure 1: Municipal solid waste generation per capita (source: IEA Bioenergy, undated)

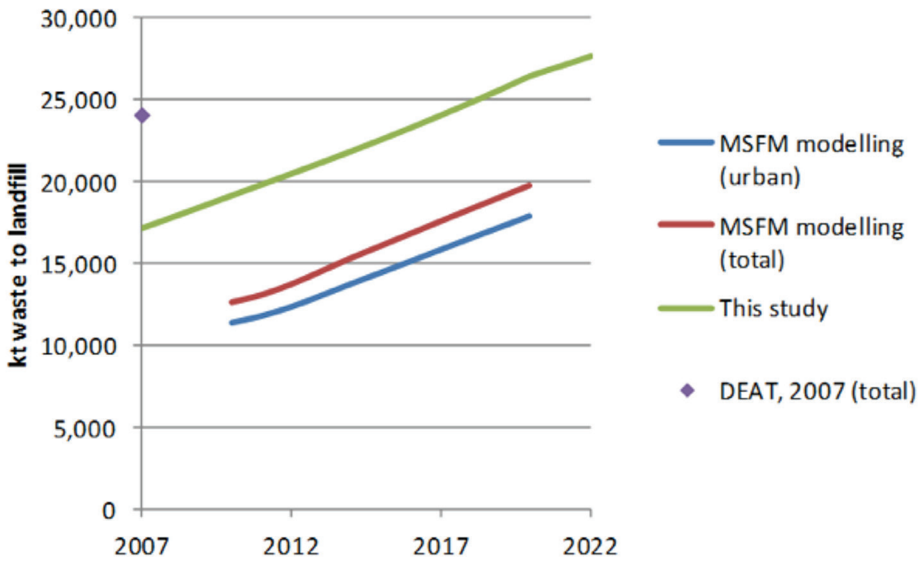

Figure 2: Comparison of projections of waste deposited to landfill

2.2 Waste Water Treatment

Waste water treatment accounted for less than 1% of national emissions in 2000, so a simple approach to estimating future emissions was taken. The current GHGI has estimated CH_4 emissions from waste water treatment based on assumptions about the degradable organic content biological oxygen demand (BOD) generated per capita,[4] emissions factors for different types of treatment systems, and the mix of treatment methods (for example septic tank, latrine, open sewer, closed sewer). A mix of these treatment types was assumed to deal with waste water in three types of areas: urban high income, urban low income and rural. These assumptions were then combined with estimates of population in these three groupings to derive total CH_4 emissions. Nitrous oxide (N_2O) emissions were estimated based on protein consumption and nitrogen content of protein. Future emissions were estimated using this same methodology but allowing for trends in urbanisation, increasing affluence and changes in the fraction of waste water treatment types to reflect South Africa's desire to provide universal access to sanitation.

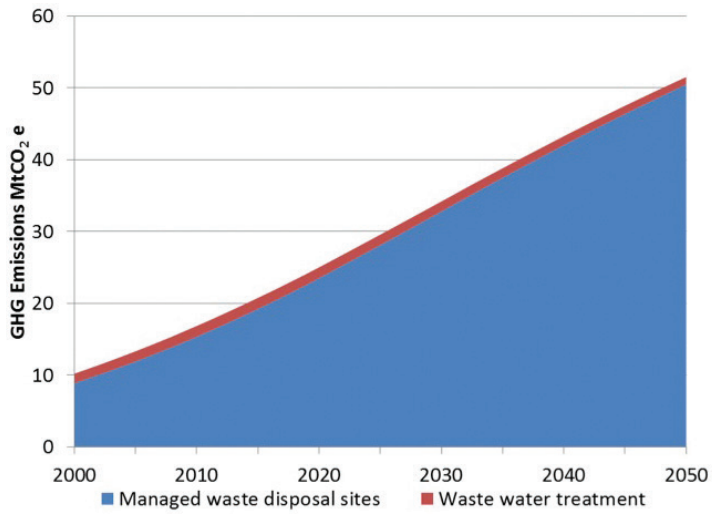

Figure 3: Waste sector reference case 'without measures' (WOM) emissions projection

Figure 3 and Table 1 show GHG emissions under the reference scenario. Emissions from managed waste disposal rise steadily, reflecting the increase in waste generated as both population and prosperity grow and as more waste is disposed of in a managed way. Wastewater treatment emissions decline after 2020 as more wastewater is treated in systems which have lower CH_4 emissions, such as closed sewers.

4. BOD generation per capita in urban areas includes an allowance for non-domestic wastewater.

Table 1: Waste sector WOM reference case: total of all GHG emissions

Emissions ($ktCO_2e$)	2000	2010	2020	2030	2040	2050
Managed waste disposal sites	8,855	15,325	23,477	32,773	41,999	50,451
Wastewater treatment and discharge	1,347	1,511	1,522	1,413	1,252	1,050
Total waste sector	**10,202**	**16,836**	**24,999**	**34,186**	**43,251**	**51,502**

3. Reference Case Projection: 'With Existing Measures'

The reference case projection described above estimates how emissions would develop to 2050 in the absence of any measures to mitigate climate change. However, in the period 2000 to date, a number of projects have been implemented under the Clean Development Mechanism to recover and use LFG to generate electricity (for example the Bisasar and Marianhill projects in the eThekwini Municipality). The impact of these projects on LFG emissions has been assessed based on data from the municipality and analysing the number of certified emissions reductions (CERs) issued by these projects. In total the projects at four landfill sites are currently estimated to reduce emissions by approximately 415 $ktCO_2e$ per year.

Emissions under a 'with existing measures' (WEM) scenario that includes this abatement are shown in Table 2. The current projects are assumed to deliver emissions reductions over a 15 year period.

Table 2: Waste sector 'with existing measures' projection: total of all GHG emissions

Emissions (kt CO_2e)	2000	2010	2020	2030	2040	2050
Managed waste disposal sites	8,855	14,910	23,063	32,358	41,584	50,036
Waste water treatment	1,347	1,511	1,522	1,413	1,252	1,050
Total	10,202	16,421	24,584	33,771	42,836	51,087

Chapter III: Identification and Analysis of Mitigation Potential

4. Identification of Mitigation Opportunities

Options identified for managed waste disposal fall into two categories. Firstly, better management of landfill sites, with recovery and flaring or use of landfill gas (LFG) and secondly, alternative waste disposal options which would allow diversion of organic waste from conventional landfill activities. While landfilling of waste is the primary means of managed waste disposal currently, there is interest in South Africa in exploring other waste management options. For example the Government is currently drafting a strategy on composting.

Table 3 below shows the full list of the initial mitigation opportunities originally identified by the Waste Task Team and includes justification for why the options were either included or excluded from the analysis. The options considered are focused on municipal solid waste. There may be other opportunities, however, for the use of waste as a fuel. For example, high calorific value wastes can be used as an alternative fuel in cement kilns, and these options are considered in the industry sector (please refer to Technical Appendix D: Industry, which covers mitigation potential for the industry sector).

Through a process of discussion, correspondence and collaboration with the Waste Task Team and other experts and specialists in the field, a final list of mitigation opportunities was agreed for evaluation:

- Managed landfill sites:
  - capping of sites with recovery of LFG and flaring
  - capping of sites with recovery of LFG and use for electricity generation
- Diversion of waste from landfill sites:
  - energy from waste (incineration of MSW with energy recovery)
  - Source-separated collection of food waste for anaerobic digestion and use of biogas for energy production
  - Household separation of food and garden waste for composting at home
  - Source-separated collection of garden waste for windrow composting
  - Source-separated collection of food and garden waste for large-scale in-vessel composting
  - Source-separated collection of dry recyclables including paper, and paper recycling.

Table 3: List of mitigation opportunities identified by the Waste Task Team

Subsector	Abatement measure/ mitigation opportunity	Motivation for inclusion or exclusion	Included?
Managed waste disposal	Landfill site management with gas recovery i.e. capping with gas recovery and flaring.	Globally a well explored and established technology used as best practice to minimise environmental impacts of landfilling waste. Considered an important mitigation measure particularly in South Africa where unmanaged landfill sites and open dumps are the primary disposal technique.	Yes
Managed waste disposal	Landfill site management, capping with gas recovery and use for electricity generation.	Considered an important mitigation measure particularly in South Africa where unmanaged landfill sites and open dumps are the primary disposal technique.	Yes
Managed waste disposal	Landfill site management, capping with gas recovery for use in heat generation network.	A practical intervention to recover value from gas recovery options. Not analysed due to restricted potential for implementation in South African sites	No
Managed waste disposal	Landfill site management, capping with gas recovery for use as a fuel source for automotive vehicles.	Still developing technology, not analysed as not considered an option for the short- to medium-term future.	No
Managed waste disposal	Incineration of MSW with energy production (energy from waste (EfW)).	Technically feasible option, currently of interest in South Africa where some feasibility studies have been carried out.	Yes
Managed waste disposal	Anaerobic digestion/ source-separated collection of food and garden waste and diversion from landfill to anaerobic digestion facility where biogas is used to produce energy.	Technically feasible option, not currently in operation in South Africa. Possibility for mitigation depending on the financial feasibility of sites.	Yes
Managed waste disposal	Diversion of food and garden waste from landfill with household separation and home composting.	Potentially low cost mitigation strategy that is currently a developing area of interest in South Africa. Can have additional benefits for soil from compost produced.	Yes
Windrow composting	Diversion of garden waste from landfill to large scale windrow composting.	Practical option that is not currently developed in South Africa.	Yes
In-vessel composting	Diversion of food and garden waste from landfill to large-scale in-vessel composting facilities.	Similarly to other composting option, technically feasible and practical option with potential for development in South Africa	Yes
Paper recycling	Additional source-separated waste collection schemes to divert dry recyclables from landfill. Increased recycling of paper.	Current recycling almost at 60%. Potential to increase if separation at source is introduced by municipalities.	Yes

Subsector	Abatement measure/ mitigation opportunity	Motivation for inclusion or exclusion	Included?
Wood recycling	Extraction of waste wood from the waste stream for recycling or energy recovery.	Some industrial wood waste is kept out of the general waste stream and used as a fuel in boilers. Potential to increase subject to economic feasibility.	No (due to lack of good quantitative data on amount of waste wood in the MSW stream).
Waste minimisation	Waste minimisation measures designed to reduce the generation of waste material.	Waste minimisation forms an important theme of waste management policy and is likely to be cost-effective, delivering economic benefits. Can also incorporate a range of measures such as minimising waste during manufacturing processes, reducing quantities of packaging, or influencing consumer behaviour e.g. to avoid excessive packaging or minimise food waste.	No (requires more definition of how measures might be implemented to enable costs and abatement potential of measures to be developed. Recognised as a key policy for tackling emissions from sector in the long term.
Wastewater treatment	Switch from anaerobic treatment with flaring to anaerobic treatment with gas use.	This may be feasible where sewage sludge is digested anaerobically at waste water treatment works. However while this is practised at some wastewater treatment plants; data are not available on how many plants use such treatment routes and what volume of wastewater is treated in this way. For example the GHGI assumes that all wastewater treatment in urban areas is aerobic.	No. Not evaluated due to lack of data to assess mitigation potential and due to small size of emissions source.
Wastewater treatment	Optimise process parameters towards low N_2O yield.	Largely controlled by need to meet ammonia and nitrate effluent standards. May not be feasible to implement. Very small emissions source.	No

The mitigation option for waste minimisation was not evaluated for the purposes of the marginal abatement cost curve (MACC) analysis due to a lack of information to evaluate how this might be achieved in practice, and of data on the costs and reductions which might be achieved. This is partly because the minimisation of waste can be achieved in a wide variety of ways (for example through better product design, reduced amounts of packaging, better management of production processes so that less waste is generated, reuse of products) and because waste minimisation strategies can be implemented in a wide range of sectors (for example manufacturing industries, the food and drink industry, the construction industry, the commercial sector and the residential sector). Strategies to achieve this can range from educational campaigns for the general public to waste minimisation clubs for industry. Without some definition of strategies and programmes which will be implemented to achieve this however, costing as a mitigation option is difficult. Despite this, the importance of waste minimisation as a means of helping to achieve both mitigation and waste management goals should not be underestimated. As well as reducing GHG emissions from the disposal of waste, it can lead to additional GHG savings by reducing the use of resources and materials.

As already mentioned previously, waste minimisation sits at the top of the waste hierarchy and is a primary goal of South Africa's National Waste Management Strategy. Waste minimisation can also often be extremely cost-effective, leading to overall cost savings from reduced use of materials and reduced waste disposal costs. It should therefore be considered in future climate change mitigation estimates for the waste sector.

5. Costing and Mitigation Potential of Measures

The key assumptions used to assess the abatement potential of each of the options are given in Table 4 below. As many of the technologies have not been implemented yet in South Africa, robust data on specific costs for projects in South Africa was difficult to obtain. International data was therefore used, although wherever possible this was cross checked against the high level data or indicative cost estimates available in-country. In some cases, with agreement from experts within South Africa, cost estimates were adjusted to reflect South African conditions. Capital and operating costs are summarised in Table 5.

- Other operating costs and revenue streams assumed in the assessment of options are:
- avoided cost of landfilling: R138 per tonne of waste
- additional cost of source-separated collection: R 240per tonne of waste
- value of electricity generated: R0.366 per kWh generated
- value of compost produced R50 per tonne

This is a low valuation of the compost produced, but it is intended to represent current conditions within South Africa where the markets for compost and digestate from anaerobic digestion are as yet undeveloped. If better markets develop (for example as a result of work undertaken under the national composting strategy) then the cost-effectiveness of composting options could improve. There are also other environmental benefits from composting in the form of the return of organic matter and nutrients to the soil, which are not reflected in the financial value of compost.

Table 4: Key assumptions for mitigation options in the waste sector

Mitigation option	Basis for estimating quantum of emission mitigation	Key data elements	Key data sources
Landfill gas (LFG) recovery – flaring	Recovery and flaring installed on 30% of sites in 2020 and 30% in 2030 and 20% in 2050, and 30% of LFG from sites is recovered and flared. Assumes that recovery with electricity generation is the preferred option for larger sites where gas generation rates are high enough to sustain gas engine.	No data on the cost of LFG flaring in South Africa could be found in literature so more detailed data from international examples was used. Data was available for a project in Namibia and showed relatively good agreement with international data. Costs cover capping and installation of gas recovery pipework as well as cost of flare, and include maintenance, operating and capital costs.	(EPA, 2011a)
LFG recovery – electricity generation	LFG recovery and generation implemented on 30% of landfill sites by 2020, 50% by 2030 and 80% in 2050. Assumes some retrofitting to newer sites, where gas generation rates are still high and installation on all newly opened sites. Leads to mitigation of 70% of LFG generated on site.	LFG recovery and electricity generation already installed at some landfill sites in SA. Only approximate cost estimates available for these projects so more detailed international data used. Relatively good agreement between data sources. Costs cover capping and installation of gas recovery pipework as well as cost of gas engine for generation, and include maintenance and operating costs as well as capital costs. An allowance is made for value of electricity produced.	(EPA, 2011b)
Energy from waste (EfW)	Typical size of 250,000 t/year; assumed to be suitable for use in larger urban areas where large quantities of waste are available within small area. Number of plants based on quantities of waste generated in these larger urban areas. GHG abatement is emissions avoided by not landfilling waste minus CO_2 emissions from combustion of fossil based material in waste (e.g. plastics). Additional GHG savings from displacing fossil fuel based electricity generation are accounted for in power sector rather than here.	Capital and operating costs were sourced from international reference cases and cross checked with data from South African feasibility studies. Value of electricity produced and avoided cost of landfilling waste also taken into account.	(AEA, 2007) (Hogg et al., 2008) (Warren et al., 2012) (WRAP, 2012)
Anaerobic digestion (AD)	It is assumed that 70% of food waste in the waste stream can be captured via source-separated collection. GHG abatement is emissions avoided by not landfilling waste.	Typical facility of 30,000 t/year. Capital and operating costs from international data. Additional cost of source-separated collection taken into account. Value of electricity and compost produced also accounted for, together with avoided cost of landfilling waste.	(Hogg et al, (2008) (Short, 2008) (Warren et al., 2012) (WRAP, 2012)

Mitigation option	Basis for estimating quantum of emission mitigation	Key data elements	Key data sources
Windrow composting	It is assumed that 70% of garden waste in the waste stream can be captured via source-separated collection. GHG abatement is emissions avoided by not landfilling waste.	Typical facility of 20,000 t/year. Capital and operating costs from international data. Additional cost of source-separated collection taken into account. Value of compost produced also accounted for, together with avoided cost of landfilling waste.	(AEA, 2007) (Hogg et al., 2008) (WRAP, 2012)
In-vessel composting	It is assumed that 70% of garden and food waste in the waste stream can be captured via source-separated collection. GHG abatement is emissions avoided by not landfilling waste.	Typical facility of 30,000 t/year. Capital and operating costs from international data. Additional cost of source-separated collection taken into account. Value of compost produced also accounted for, together with avoided cost of landfilling waste.	(Hogg et al., 2008) (Jacobs, 2008) (WRAP, 2012)
Household waste separation and composting	330l capacity bin. Assumed that households produce on average 390 kg of food waste and 65.7 kg of garden waste with home composting rates using 50% and 75% respectively of these amounts. Assumed that 50% of urban households have gardens; uptake rate for composting based on data from campaigns to increase level of composting in other countries. GHG abatement is emissions avoided by not landfilling waste.	Capital cost of compost bin as sold in South Africa currently. Value of compost produced accounted for, together with avoided cost of landfilling waste.	
Paper recycling-revenue from all dry recyclables	Use of large scale material recycling facilities taking mixed dry recyclables which have been collected in source-separated kerbside collection.	Additional cost per tonne of waste collected via the source-separated collection programme. Capital and operating costs of MRF facility with capacity of 100,000 tonnes per year. Revenue expected from the sale of dry recyclables.	(Trois & Jagath, 2011) (Lavee & Nardiyab, 2013) (WRAP, 2008a) (WRAP, 2008b)

Table 5: Capital and operating costs for mitigation options in the waste sector

Mitigation option	Capacity	Type of waste treated	Capital cost	Operating cost	Net cost *
			R million	R million/yr	R/t waste
LFG collection to electricity		Bulk MSW	73	8.4	
LFG collection and flare		Bulk MSW	42	3.7	
Anaerobic digestion	30,000 t/yr	100% food waste	122	12.2	704
Energy from waste	250,000 t/yr	Bulk MSW	1,603	57.4	160
Windrow compost-ing	20,000 t/yr	100% garden waste	23	2.7	458
In-vessel composting	30,000 t/yr	70/30 food/garden waste	67	8.5	578
Home composting	Home composting bin treats 245 kg waste/ year	80/20 food/garden waste	0.0007	0	284
Paper recycling	17,700 t paper in 30,000 t/yr materials recycling facility	Mixed dry recyclables	34	10.0	260

* *Including all capital and operating costs, avoided landfill costs, any additional costs for source-separated collection and any revenue from compost and electricity produced.*

6. Marginal Abatement Cost Curves

Marginal abatement cost curves (MACCs) provide insight into the marginal costs and associated mitigation potential at snapshots in time. They have been calculated for 2020 (Figure 4), 2030 (Figure 5) and 2050 (Figure 6).

The abatement potential and cost-effectiveness of single options in the waste sector depend on assumptions about the implementation of other options. For example, if waste is diverted away from landfill then the emissions at landfill sites are lower, and hence the abatement potential of options using landfill gas (LFG) are lower. Conversely the emissions reduction achieved by diverting waste away from landfill is lower once LFG recovery options have been implemented, leading to both lower reductions and a higher cost-effectiveness for those options.

In order to construct the MACCs, the marginal abatement cost of each of the options was calculated, assuming that there was no LFG recovery for options which involve diverting waste away from landfill. This shows that recovery of LFG with flaring, and with electricity generation have the lowest marginal abatement costs. Implementation rates for these options were therefore applied, giving reduced savings for the diversion options. It is then assumed that the waste diversion options are implemented; their abatement potential and marginal abatement cost is recalculated given the assumptions for LFG recovery. The reduction in waste going to landfill is then used to scale back the actual savings achieved by LFG recovery options. Waste diversion options are implemented in order of their marginal abatement cost, subject to limitations on their applicability, as shown in Table 4. An overall waste balance for MSW was constructed to ensure that implementation of options reflected quantities of particular types of waste available, and that waste diverted to one option, for example EfW was no longer available for others, for example paper recycling or composting.

For options which involve electricity generation, while the value of the electricity generated was included in the marginal abatement cost assessment, additional GHG savings which might be realised by avoiding the need for fossil fuel-based electricity generation were not included to avoid double-counting of emissions savings with the power sector. Inclusion of these additional GHG savings would improve the marginal abatement costs of these abatement options (anaerobic digestion, EfW and LFG recovery with electricity generation).

As discussed above, some of the mitigation options considered also have other environmental benefits, such as the return of organic matter to the soil which can be achieved through composting and anaerobic digestion. These are not reflected in the MACC, which purely identifies the lowest marginal abatement cost options in reducing GHG emissions, rather than which options may deliver the most overall environmental benefit. It is recognised that there may be a number of other drivers for the waste sector, including implementation of the waste hierarchy, which would mean that waste management options other than landfill are given a higher priority. However such an evaluation is outside the scope of this study, which purely sets out the marginal abatement cost of each option in terms of reducing GHG emissions, and finds on this basis that LFG recovery has the lowest marginal abatement cost.

In 2020 (Figure 4), the LFG recovery and generation option is the lowest marginal cost abatement option (at less than R100/tCO_2e). This option also has the greatest abatement potential (4.8 MtCO_2e). Recovery and electricity generation has a lower marginal abatement cost than recovery and flaring as the additional cost of generating equipment is more than offset by the value of the electricity produced, and the higher gas recovery rates assumed when recovery involves generation. Abatement is higher than for other options as it is assumed these technologies can be implemented relatively quickly. Paper recycling, home composting and energy from waste have significantly higher marginal abatement costs than LFG recovery, (R360 to R370/tCO_2e), and have less abatement potential. Centralised composting and anaerobic digestion are more expensive again, (R650 toR900/tCO_2e) and only produce mitigation of 0.6 MtCO_2e. The total mitigation potential identified is just below 10 MtCO_2e.

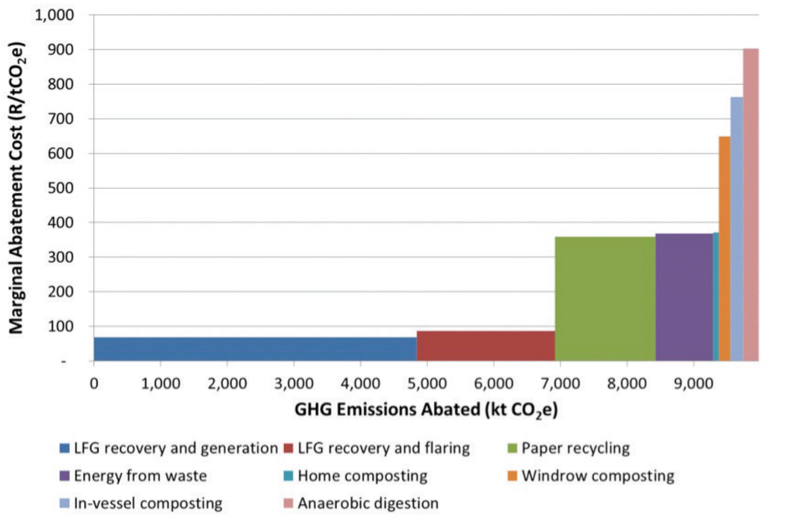

Figure 4: MACC for 2020 for the waste sector

By 2030 (Figure 5), the total mitigation potential has grown to 22.1 $MtCO_2e$, mainly due to fuller implementation of the mitigation options, but also as waste quantities generated grow, leading to increased emissions to be abated. While the marginal abatement costs of the LFG options remains the same as in 2020, the marginal abatement costs of other options worsen slightly as increased implementation of LFG recovery reduces the savings the other measures can deliver.

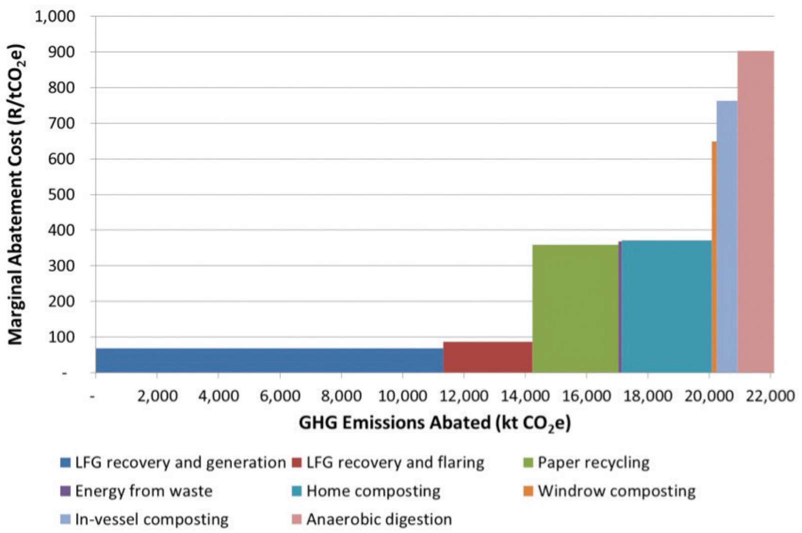

Figure 5: MACC for 2030 for the waste sector

This trend is also seen in 2050 (Figure 6). Landfill gas recovery and generation can still deliver significant abatement of 31 $MtCO_2e$ at low cost, as some residual waste is still assumed to be disposed of to landfill and all sites are assumed to have recovery of gas by 2050. The total reduction in emissions which can be achieved, if diversion options with higher marginal abatement costs are also implemented, is 39.7 $MtCO_2e$, or 78% of projected emissions in the sector.

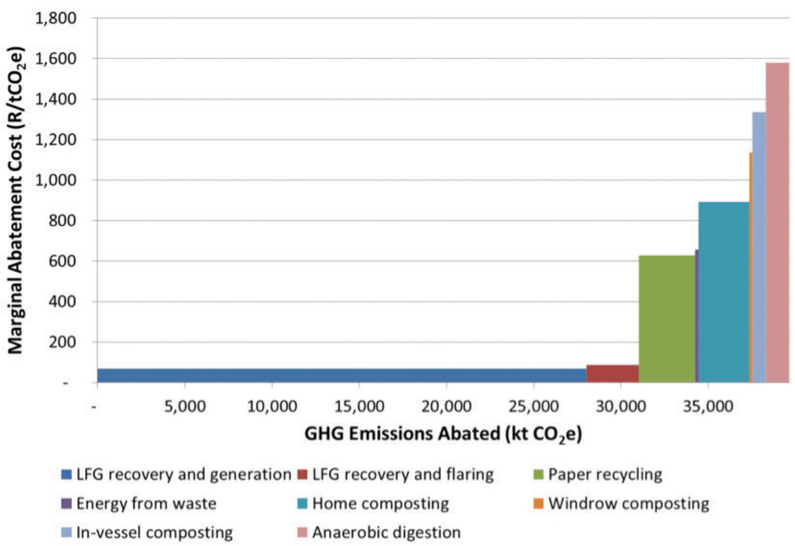

Figure 6: MACC for 2050 for the waste sector

Chapter IV: Summary

7. Technical Mitigation Potential

If all technically available mitigation potential in the waste sector were to be implemented, then the current analysis shows that GHG emissions could be reduced by 9,977 ktCO_2e in 2020; 22,122 ktCO_2e by 2030 and 39,658 ktCO_2e by 2050. This represents a total potential reduction of 41%, 66% and 78% respectively of reference emissions under the WEM projection (Figure 6 and Table 6).

Figure 3 and Table 1 show GHG emissions under the reference scenario. Emissions from managed waste disposal rise steadily, reflecting the increase in waste generated as both population and prosperity grow and as more waste is disposed of in a managed way. Wastewater treatment emissions decline after 2020 as more wastewater is treated in systems which have lower CH_4 emissions, such as closed sewers.

Table 6: Total mitigation potential for the waste sector, assuming all measures are implemented (in ktCO_2e)

Subsector	Measure	2020	2030	2050
Managed waste disposal	LFG recovery and generation	4,843	11,325	28,020
	Paper recycling	1,506	2,802	3,223
	LFG recovery and flaring	2,076	2,912	3,002
	Energy from waste	869	2,935	2,913
	Anaerobic digestion	234	1,198	1,354
	In-vessel composting	83	112	197
	Home composting programme	189	682	771
	Windrow composting	176	155	176
TOTAL		**9,977**	**22,122**	**39,658**
TOTAL % Reduction (relative to WEM)		**41%**	**66%**	**78%**

8. Projection 'With Additional Measures'

Applying all the measures identified above in the order in which they are ranked using the multi-criteria analysis (MCA), gives an emissions projection curve as shown in Figure 7.

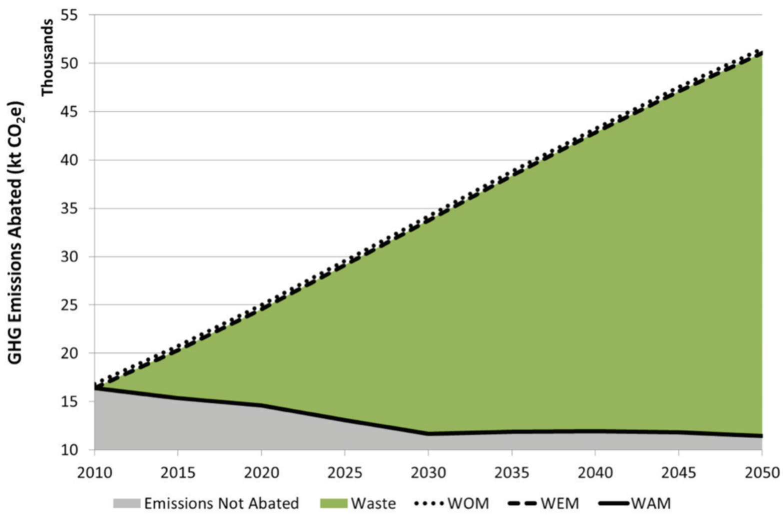

Figure 7: Emissions projection 'with additional measures' (WAM) for the waste sector

9. Impact Assessment of Individual Mitigation Measures

The impact assessment is undertaken using the multi-criteria analysis (MCA) approach described in the main report as well as in Appendix A: Methodology.

9.1 Scoring of Each Measure in Relation to Agreed Criteria

The criteria for assessing each measure are applied consistently across all sectors with the scoring and weighting options described in the main body of the report. Two methods have been applied for scoring:

- A quantitative assessment using the costs estimated for each measure and the economic models which provide figures for gross value added (the economic criterion) and jobs (part of the social criterion).
- A qualitative assessment based on scoring by the sector Task Team.

In the case of the quantitative analysis which informs the cost, economic and social criteria, the data associated with each criterion is summarised in Table 7 below.

Taking both quantitative and qualitative scores into consideration for each criterion, points are allocated to each measure with the results for the balanced weighting pathway shown in Table 8 below (zero is the worst result and 100 the best).

Table 7: Quantitative data informing the scoring of options for the waste sector

	NPV * of costs per $ktCO_2e$ mitigated	GVA ** impact per $ktCO_2e$ mitigated	Jobs created per $ktCO_2e$ mitigated	Ratio of unskilled to total jobs
	($R/ktCO_2e$)	($R/ktCO_2e$)	($Jobs/ktCO_2e$)	
LFG recovery and generation	-0.98	0.21	0.02	-0.51
LFG recovery and flaring	5.36	-0.72	0.06	-0.45
Paper recycling	37.34	-3.91	0.38	0.80
Energy from waste	164.70	-16.69	0.07	-1.40
Home composting	-55.41	8.69	-0.06	1.06
Windrow composting	120.35	-13.74	2.35	0.77
In-vessel composting	105.61	-12.21	1.21	0.79
Anaerobic digestion	157.42	-18.19	0.47	0.91

** net present value*
*** gross value added*

Table 8: Distribution of points assigned to each option for the waste sector.

Option descriptions	Cost	Economic impact	Social impact	Non-GHG environmental impact	Implementability
LFG recovery and generation	66.52	53.07	38.23	70.00	77.50
LFG recovery and flaring	65.08	51.53	40.39	70.00	92.50
Paper recycling	57.85	46.21	65.26	80.00	92.50
Energy from waste	29.06	24.96	30.87	65.00	42.50
Home composting	78.82	67.12	24.74	90.00	92.50
Windrow composting	39.08	29.86	63.95	65.00	67.50
In-vessel composting	42.42	32.42	72.08	100.00	50.00
Anaerobic digestion	30.70	22.47	71.64	85.00	25.00

Implementing a home composting programme is (perhaps predictably) the lowest marginal abatement cost option in the waste sector. It also will have a positive economic impact because the capital and operating costs associated with the measure (relative to the abatement potential) are low. But the option does not create jobs; therefore it scores poorly for social impact. In general, none of waste sector options have a notably positive social impact as they do not create many jobs. The in-vessel and home composting options both score highly for their non-GHG environmental impact, as does paper recycling (essentially because these options divert waste from landfills). Anaerobic digestion also scores highly for environmental impact because the nature of the GHG abatement achieved is to avoid emissions by not landfilling waste. As stated above, the assumption is that LFG recovery and flaring is readily implementable (and already has been proven as such). Along with the paper recycling and home-composting options, the recovery and flaring options score highly for implementability.

9.2 Net Benefit Curve

The concept of a net benefit is described in the main body of the report. The net benefit curve for the balanced weighting pathway is shown below in Figure 8.

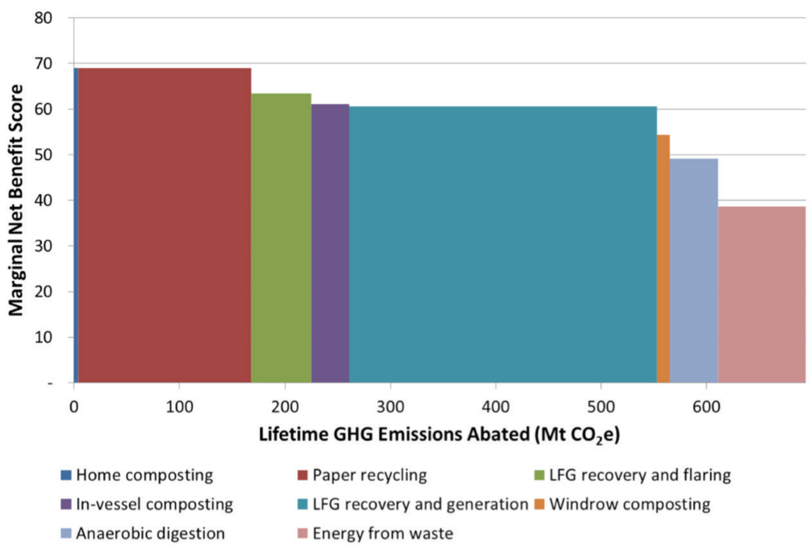

Figure 8: Net benefit curve for waste sector mitigation options

The amount of CO_2e which can be mitigated for each measure, for the full period from 2010 to 2050, is shown on the horizontal axis. In order to maximise the net benefit (as determined by the MCA analysis), the measures should be implemented in order from left to right as they appear in Figure 8.

According to the graph, the home-composting option should be implemented first since it achieves the highest integrated marginal net benefit score of 69. But the abatement achieved is insignificant, at only 5 $MtCO_2e$ over the 40 year period. The paper recycling, in-vessel composting, LFG recovery and flaring, and recovery and generation options all have an integrated marginal net benefit score above 60 and achieve significantly more mitigation; 164, 36, 56 and 292 $MtCO_2e$ over the period, respectively. Integrated marginal net benefit scores for the remaining options deteriorate rapidly, with the energy from waste option scoring 38.7, despite providing 83 $MtCO_2e$ of GHG abatement over the period.

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Notes

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