The Potential for Waste-to-Energy in the Western Cape: A 2040 Outlook

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ABSTRACT

Waste-to-Energy (WtE) technologies produce energy by processing solid, liquid and gaseous waste streams using either thermal, physical or biological methods. It was determined that in 2014 a waste quantity of approximately 8,212,496t would be generated in the Western Cape (WC), with MSW (46.8%) being the largest contributor, and the City of Cape Town (CCT) generating more than 60% of the total waste. An accelerated green model determined possible fractional waste uses of 5%, 45%, 40% and 10%, attributed to landfilling, reuse/recycling, WtE and composting, respectively. Total net CO_2 eq. emissions reduction of 13,472,164t was calculated from the model, with the biggest contributor being *Non-Recyclable MSW* (34.9%). In conclusion, it was calculated that biological WtE technologies would be the most prevalent by 2040, with a share of 82% of the total net CO_2 eq. emissions reduction, and the CCT would be the biggest role-player in enabling an accelerated WtE economy.

1. INTRODUCTION

The purpose of this paper is to present the potential for waste-to-energy (WtE), also termed energy-from-waste (EfW), in the Western Cape, South Africa. The Western Cape, referred to herein as the 'Province', is the south-western most province in the Republic of South Africa and is divided into 1 metropolitan municipality, 5 district municipalities and 24 local municipalities, depicted in Figure 1.

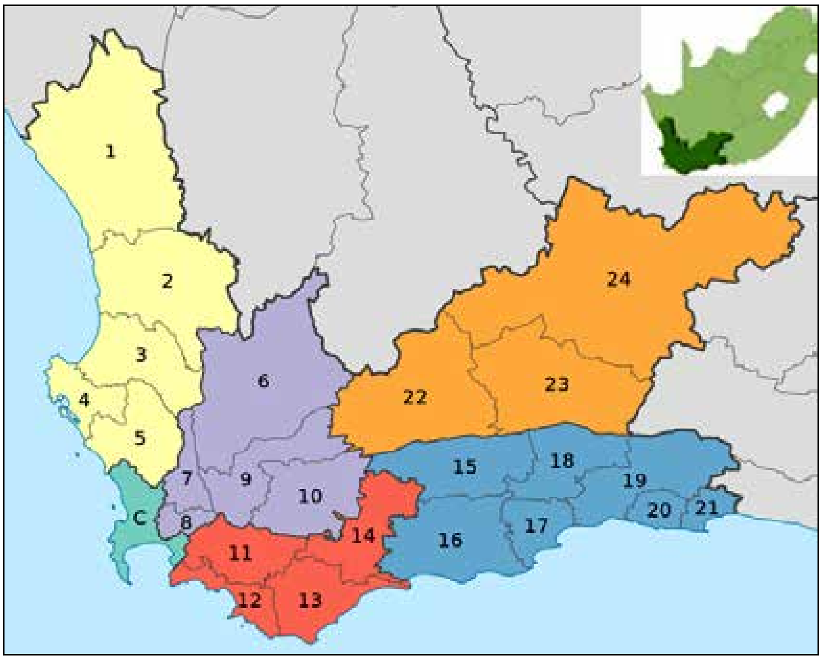


Figure 1. Map of district and local municipalities in the Western Cape, South Africa (After Statistics SA, 2013)

The national census conducted in 2011 (published in 2013) was used as the baseline source for population information measurement throughout the paper. Using this information, Table 1 provides an empirical population depiction of Figure 1, which forms the basis for waste quantity calculations throughout the paper.

Table 1. Alphabetical list of district municipalities in the Western Cape, South Africa (After Statistics SA, 2013)

No.	Map key	District/Metropolitan Municipality Name	Seat	Area (km^2)	Population (2011)	Density (ppl / km^2)
1	6–10	Cape Winelands District Municipality	Worcester	22 309	787 490	35.3
2	22–24	Central Karoo District Municipality	Beaufort West	38 854	71 011	1.8
3	C	City of Cape Town Metropolitan Municipality	Cape Town	2 460	3 740 026	1 520.3
4	15–21	Eden District Municipality	George	23 331	574 265	24.6
5	11–14	Overberg District Municipality	Bredasdorp	11 405	258 176	22.6
6	1–5	West Coast District Municipality	Moorreesburg	31 104	391 766	12.6
			Sum	129 463	5 822 734	

In order to accurately represent the potential for WtE in the Province, five principal studies were conducted, namely: (1) an overview of WtE technologies including their relative advantages, limitations, job creation potential, and capital and operating expenses, (2) an assessment of the waste quantities generated in each of the provinces five district municipalities and its single metropolitan municipality, (3) a review of existing and planned WtE projects in the Province, for both the public and private sectors, (4) the calculation of the net carbon dioxide equivalent (net CO2 eq.) emission reductions for an indicative uptake of projects over a specified timeline, and lastly (5) the modelling of a business-as-usual (BAU) scenario and an accelerated green (AG) scenario to indicate the benefit of WtE so as to align with the OneCape Vision for 2040. "OneCape 2040" is a vision for the economic development in the Province that was established by the Western Cape Economic Development Partnership (EDP). According to the EDP it is a, "deliberate attempt to stimulate a transition towards a more inclusive and resilient economic future for the Western Cape region. It articulates a vision about how we the people of the Western Cape can work together to develop our economy and our society. It seeks to set a common direction to guide planning and action and to promote a common commitment and accountability to sustained long-term progress." In light of this, the short-, medium- and long-term timeline for WtE project projection in this paper have been configured to contribute to the goals of the OneCape Vision by 2040. The transition period is between calendar years 2014 and 2040, with year 2014 being adopted as the baseline year, and year 2017, 2024 and 2040 being adopted as the short-term, medium-term, and the long-term goal marks respectively.

The underlying principles used in the assessments and calculations throughout the paper include: (1) "sustainability" and/or "sustainable development" which seek to equally consider the ecology, society and commerce in order to minimise anthropogenic impacts on the Earth, (2) "decoupling" which is largely employed as the concept of systematically decreasing the per unit dependency of economic wealth on natural resources (Fischer-Kowalski & Swilling, 2011), and (3) "waste equals food", a term underpinned by the cradle-to-cradle use of resources by mankind. In addition to these principles, the National Waste Management Strategy (2011) was used as a guide to inform the categorisation of waste streams, the calculation of net CO2 eq. emission reductions in the province, and the likely distribution of waste streams in the modelling exercise.

2. WASTE-TO-ENERGY TECHNOLOGIES

This section presents a brief overview of the range of existing WtE technologies that were studied. There are a plethora of tried and tested WtE technologies in many developed countries; however, their suitability in South Africa, and more particularly the Western Cape, is largely unknown. When evaluating different waste-to-energy technologies it is critical not to assess their applicability as a function of their efficiencies, product maturity or robustness. Rather, there are two principal elements that must first be thoroughly assessed, namely: (1) the characterisation and security of potential waste feedstocks; and (2) The size and scale of provincial energy demands.

In light of this, Figure 2 displays a WtE Lattice, which represents: (1) ten general waste feedstocks, (2) several potential process technologies listed under three fundamental process categories, and finally (3) five direct energy outputs.

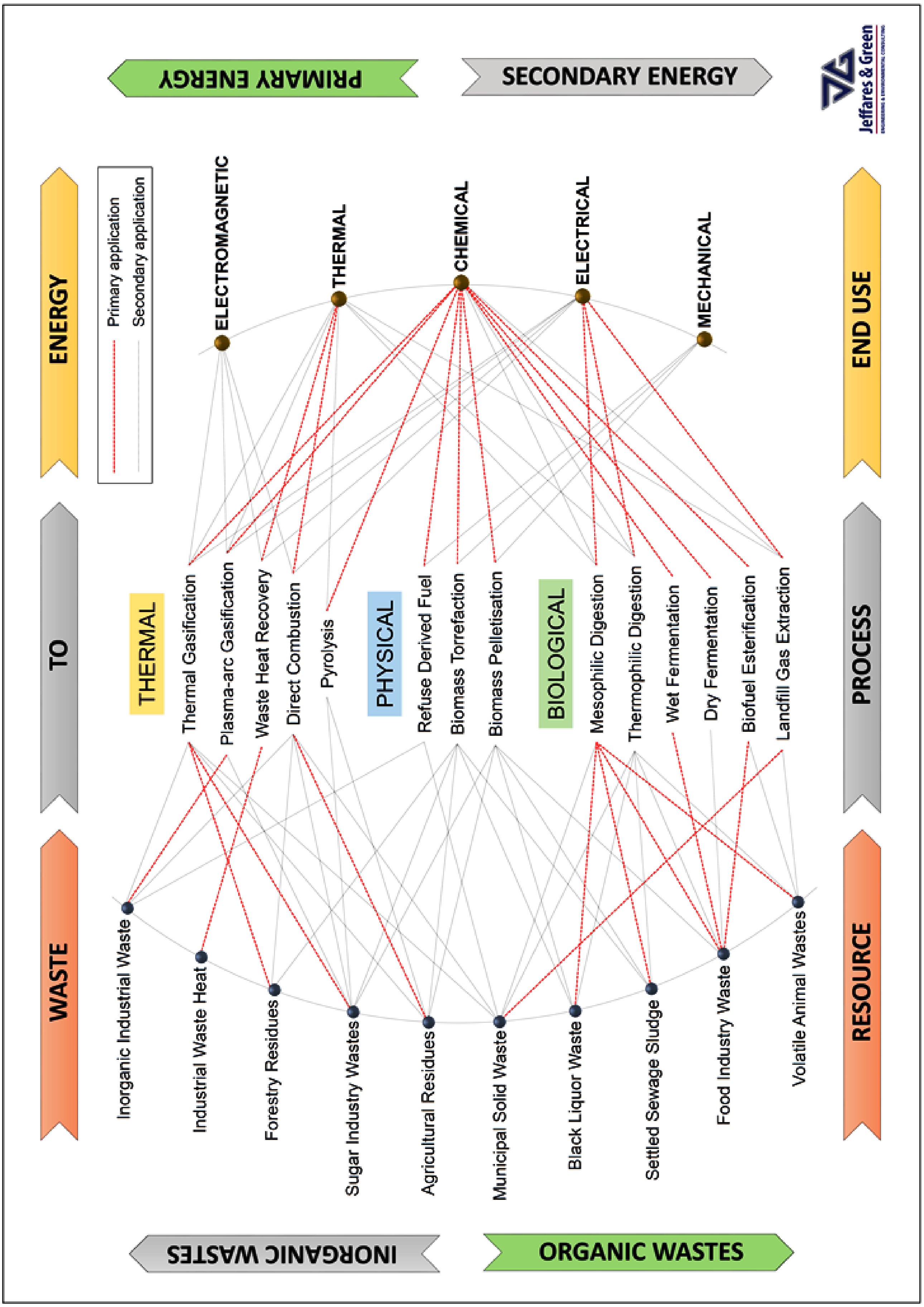


Figure 2. The WtE Lattice depicts potential relationships between waste resources and energy outputs

2.1 Feedstocks Inputs and Energy Outputs

The ten general waste feedstocks considered for the study include:

1. Forestry Residues. These are small trees, branches, tops and un-merchantable wood that are typically generated through operations such as the clearing and thinning of plantations, clearing and grubbing for construction, processing wood for pulp and timber products, and the natural and anthropogenic attrition of forests.
2. Inorganic Industrial Waste. A large portion of waste generated by industries that is inorganic. Examples include non-recyclable plastic and cardboard packaging, other mainstream packaging materials, ferrous and non-ferrous metals, and textiles.
3. Industrial Waste Heat. Waste heat is generated in numerous industrial processes each day. These energy losses arise from standard inefficiencies in mechanical machinery and equipment as well as thermodynamic limitations on these items and their respective processes. Various processes are available to recycle or re-use this energy to minimize losses.
4. Sugar Industry Waste. This waste is a by-product of the processing of sugar cane and glucose-rich substances. The by-products are collectively referred to as “bagasse” which has a significant source of energy stored in its biomass.
5. Agricultural Residues. This waste resource includes large quantities of annually produced crop and harvest process residues that are left in an agricultural field or orchard after harvesting and are largely underutilised. Examples of crop residues include cereal straw, husk and shells.
6. Food Industry Waste. There are large quantities of residues and by-products produced by the food industry each year, which can be used primarily as biomass energy sources. Food industry waste includes, inter alia: high-calorie process liquids, meat by-products, starch processing waste, fruit and vegetable scraps and peels, fibres and pulp, coffee and tea extracts and filter residues.
7. Municipal Solid Waste (MSW). MSW is arguably the greatest resource by mass that is available for waste-to-energy projects. It is mainly comprised of household waste which varies in quantities of organic, inorganic and inert resources. The natural decomposition of MSW yields roughly 50% of methane (CH4) and an equal quantity of carbon dioxide (CO2).
8. Settled Sewage Sludge. Sewage sludge can be separated into two main streams, namely, primary sludge (PS) and waste-activated sludge (WAS). Biogas yields can be as much as 1,000 m3 from 1 tonne of PS and 350 m3 from 1 tonne of WAS. This resource also has a relatively high feedstock security index as it is generated on a daily basis at wastewater treatment works (WWTW) in cities.
9. Black Liquor Discharges. Black liquor is a highly polluting effluent that is generated in the processing of paper and pulp. The wastewater from this industry is heterogeneous and can contain elements such as raw organic materials and processed chemicals.
10. Volatile Animal Waste. Animal wastes are a good source of biomass energy, particularly the volatile fraction. The most commonly processed sources of animal waste are manures from poultry, cattle, pigs and sheep. Similar to the settled sewage sludges, animal waste has a relatively high feedstock index as it is generated on a daily basis on farmlands.

The five energy outputs that are readily generated by WtE technologies include three primary and two secondary energies, which can be used to offset the energy generated by the country’s largely fossil fuel based power plants.

1. Electromagnetic (Primary). This is energy from light (irradiation) that is generated during thermal waste-to-energy processes. This type of energy is typically utilised at source to ensure a more efficient process, or can be harnessed to generate heat or electrical energy using photovoltaic cells.
2. Thermal (Primary). This energy is derived from heat that is generated at source in the waste-to-energy process from direct mechanical friction, vibration, combustion or smelting, and can be reused at source to ensure a more efficient process.
3. Chemical (Primary). This is the potential energy of electric charges between atoms in processed biomass matter. Examples of chemical energy include natural gases such as methane and argon stored in liquid or gaseous phase, and combustible biomass from torrefaction and pelletisation processes, as well as biofuel from esterification.
4. Electrical (Secondary). This is converted electrical potential energy created through the flow of power in a conductor. It is regarded as a secondary source of energy, as it is typically generated through primary sources of energy such as electromagnetic and thermal energy.
5. Mechanical (Secondary). This is the sum of potential and kinetic energy of an object or system. It is the energy of an objects position and motion. Simply put, mechanical energy is the ability to do work, and is also a secondary energy source.

3. WASTE (RE)SOURCES ASSESSMENT

3.1 Consolidation of District Municipality Waste Characterisations

One of the critical tasks to adequately assessing the potential for WtE in the Western Cape is the acquisition of credible waste quantity information. This includes the flow of materials and other waste resources in municipalities, commercial and industrial environments, and in agricultural areas, where such information is obtainable. The information that has been gathered is presented on a municipal level. According to Collins & Mbebe (2013) the quantity of municipal solid waste (MSW) generated in the Western Cape amounted to approximately 3.81mil tonnes in 2010, based on four different waste quantification methods. In addition, their report highlights projections of 4.7mil tonnes and 5.2mil tonnes for 2015 and 2020, respectively. The CCT's solid waste typically comprises 70% of the total waste in the province, with the Cape Winelands and Eden district municipalities the next biggest contributors. It is clear from the CCT's dominance as the highest solid waste generator that most of the potential for waste-to-energy in the province will fall within the metropolitan municipality. Understanding the characterisation of the province's waste stream is equally as important as estimating its relative waste quantities. According to the National Environmental Management: Waste Act (Act 59 of 2008), "the Act", waste is broadly classified as being either "General" or "Hazardous". Within the general waste classification, the Western Cape IWMP (2012) characterises solid waste in seven broad categories, namely: (1) paper, (2) plastic, (3) metals, (4) glass, (5) greens/organics, (6) builder's rubble, and (7) miscellaneous.

3.2 Waste Quantity Calculations

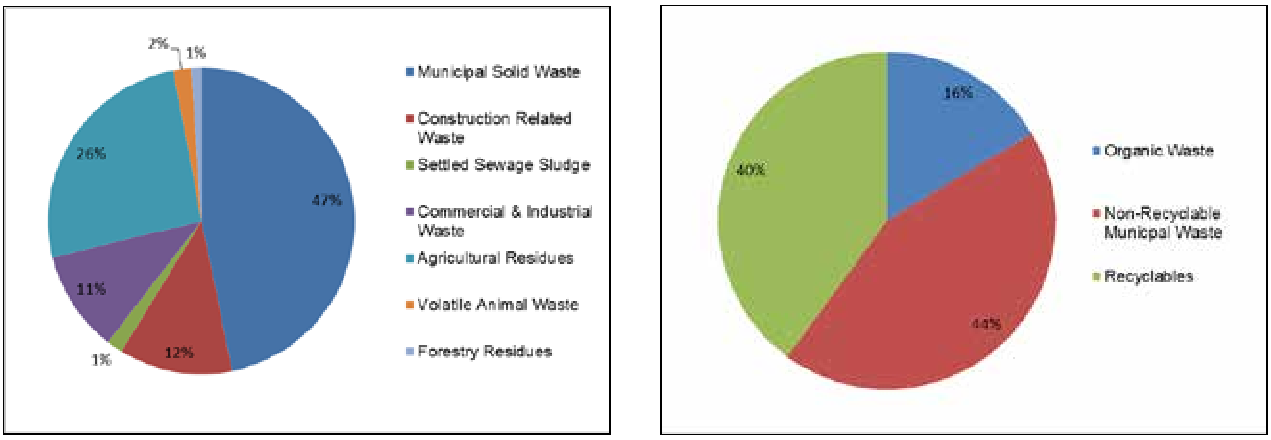
Due to the vast amount of reported waste information for South Africa and the Western Cape, several sources can often provide a diverse picture of the different waste streams that are generated in the Province. In order to calculate the quantities of waste from each waste stream, different information from various sources were used. As shown in the WtE *Lattice*, waste that is prevalent for WtE projects can be separated into a minimum of 10 different groupings. The groupings that were relevant to waste streams in the Western Cape are highlighted in Table 2 below.

Table 2. Summary of Waste Source Quantities for Western Cape for 2014

Waste Classification	SA (t)	WC (t)
Municipal Solid Waste	19 209 200	3 841 840
Organic Waste	3 146 785	629 357
Non-Recyclable Municipal Waste	8 391 427	1 678 285
Recyclables	7 670 988	1 534 198
Paper	1 805 073	361 015
Plastic	1 361 952	272 390
Glass	998 920	199 784
Metals	3 248 364	649 673
Tyres	256 679	51 336
Construction Related Waste	4 918 066	983 613
Settled Sewage Sludge	700 793	140 159
Commercial & Industrial Waste	4 405 499	881 100
Agricultural Residues	3 500 000	2 125 082
Volatile Animal Waste	348 094	149 681
Forestry Residues	211 679	91 022
TOTAL CLASSIFIED WASTE	33 293 331	8 212 496

The basis for the waste quantities calculation relied on information taken from the National Waste Information Baseline Report (DEA, 2012) that provided varying data, from total quantities of waste produced in South Africa in 2011 to breakdowns and percentages of the different types of waste that exist in the total waste stream for the country. Due to the fact that this report was based on the extrapolation of studies of waste occurring in Cape Town and Johannesburg, it was considered a reasonable basis for calculations of waste generated in the Province in 2014. According to the National Waste Information Baseline Report

(DEA, 2012), 108 million tonnes of waste was produced in South Africa is 2011, of which 20% was generated in the Western Cape and of which 55% is general waste. General waste is a term used to describe waste including the first four main waste streams highlighted in Table 2. Making use of these numbers, it is estimated that 11.8mil tonnes of waste was generated in the Western Cape in 2011. In order to make this number relevant to a 2014 baseline, the data was extrapolated using population growth rates as suggested in the Western Cape IWMP: Status Quo Report (2010, DEADP), and in-line with the growth rates presented in the National Census (2011). Making use of a growth rate of 1.34%, a total waste generation of 12.5mil tonnes was calculated for 2014 in the province. Comparing this data to other predictions, it was found to be an overestimate and was therefore reduced to more closely match those figures quoted by Collins & Mbebe (2013) and the DEADP (2010). This was achieved by applying a reduction factor across all the waste figures which resulted in the calculation of the figures under the WC column in Table 2.



a) Total Waste Characterisation b) MSW Characterisation

Figure 3. Fractional Waste Quantity Information for the Western Cape (2014)

4. MODELLING EXERCISE

4.1 Feasible Waste Reduction Targets

In line with the notion of *decoupling*, the potential of WtE is largely linked to the acquisition and management of all notable waste feedstocks. Feedstocks that can be readily decoupled from existing disposal and treatment infrastructure, and redirected for beneficial use, are most valuable. When defining waste quantity projections in the short-, medium- and long-terms, it is critical to be realistic to what fraction of waste can be decoupled and redirected in the Western Cape. Basic questions such as, “what is possible or viable?” and “what is favourable for economic feasibility?” should first be considered. In terms of identifying a benchmark, one of the world’s best case studies of the rapid insurgence waste-to-energy infrastructure is Sweden. Figure 4 depicts a ten year window of Sweden’s ability to reduce significant quantities of waste sent to landfill, and increase both reused and recycled materials and waste-to-energy resources.

Other notable trends displayed in Figure 4 include:

- An 81.5% reduction in waste sent to landfill over a ten year period;
- Similar quantities of waste reused/recycled as is used for waste-to-energy, with similar annual increases over the ten year period;
- A rapid decline in waste sent to landfill from 2002 – 2005, largely due to stricter regulation, including a tax on all landfilled wastes, and an ordinance and ban on landfilling combustible and organic wastes;
- A linear increase in waste reused/recycled and used for waste-to-energy, as a result of accurate infrastructure capacity planning.

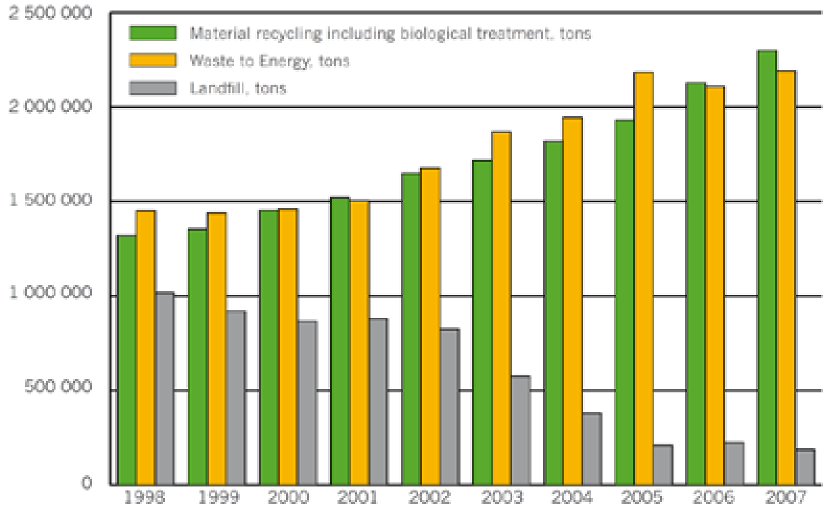


Figure 4. Ten year Swedish waste treatment methods (After Avfall Sverige, 2009)

Table 3. Waste disposal and beneficial use percentages (After Goldsmith-Jones et al., 2009)

Country/Province	Waste (kg/pp/yr)	Landfill (%)	Reuse / Recycling (%)	Waste-to-Energy (%)	Compost (%)
Sweden	518	4	47	37	12
Denmark	801	5	53	24	17
Germany	564	1	35	46	18
France	541	34	36	16	14
Netherlands	630	3	38	32	28
United Kingdom	572	57	9	22	12
Canada	1037	74	2	24	
South Africa*	381	88	10	1	2
Western Cape*	675	83	10	2	5

* Department of Environmental Affairs (2012).

The statistics tabulated in Table 3 above clearly illustrate the accepted ideology that waste is a valuable resource in the likes of Sweden, Denmark, Germany and Netherlands. This is not the case in South Africa or in the Western Cape. More importantly however, for the purpose of this study, the results provide an indication and gauge of the fraction of waste that can *realistically* be attributed to processes such as reuse, recycling and waste-to-energy. What could be considered a reasonable fractional split between waste-to-energy and reuse/recycling in the Western Cape is dependent largely on national regulations and incentives, and to a lesser extent, the socioeconomic environment. In estimating the potential for waste-to-energy in the Western Cape, one must attribute fractions of the existing waste streams to landfill, reuse and recycling, waste-to-energy, and composting, as above.

4.2 Carbon Measurement Criteria

For the purpose of calculating carbon reduction potential, what is considerably more critical is determining the elements that are linked to the “life-cycle” of a waste process and therefore included in the calculations, i.e. the inclusion of an increase/decrease in transportation of waste as a result of redirecting waste from landfill to a WtE facility. All carbon reductions are measured in carbon dioxide equivalents, represented as “CO_2 eq.”, which includes carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The relevant CO_2 eq. analysis methods are based on current acceptable international carbon measuring standards, including the measurement standards issued by the United Nations Framework Convention on Climate Change (UNFCCC), used to calculate Certified Emission Reductions (CERs) for emerging market Cleaner Development Mechanism (CDM) projects.

4.3 Modelling of Two Scenarios

This subsection presents two broad modelling scenarios, namely: (1) a "Business-as-Usual" (BAU) model, based primarily on existing practice in the Western Cape in the 21st Century, and (2) an "Accelerated Green" (AG) model, which represents the maximum contribution of solid, liquid and gaseous waste resources to the Western Cape's energy footprint over short- (3 years), medium- (10 years) and long-term (26 years to OneCape 2040) periods. The information presented in this section follows on from the waste stream inferences made in the preceding carbon reduction section, and therefore the same fractional disposal and beneficial use quantities are used throughout this modelling exercise.

4.3.1 Business-as-Usual Model

The modelling exercise required the establishment of baseline data for the year of 2014. This baseline was estimated making use of calculated waste quantity data and demographic data as well current and predicted trends in the uptake of alternative waste disposal methods and WtE projects. After consulting relevant literature, in particular the National Waste Baseline Information Report (Department of Environmental Affairs, 2011) and the Western Cape Integrated Waste Management Plan: Status Quo Report (DEADP, 2010), the following fractional disposal and beneficial use quantities were determined as a baseline for 2014: 675 kg/pp/yr, 83% to landfill, 10% reused or recycled, 2% for WtE and 5% for composting. The BAU case has been modelled with the underlying ideology that waste is perceived by society to have little-to-no value and should, in general, be landfilled. The following parameters were used in determining a BAU model:

- Measured quantities of waste currently sent to landfill;
- Extrapolated quantities of waste material that is recycled/re-used;
- Predicted quantities of compostable waste; and
- Uptake of existing and planned WtE projects in the Province.

Table 4. Fractional waste disposal per destination predicted by BAU model

Year Description	Waste to Landfill (%)	Waste to Recyc./Re-use (%)	Waste-to-Energy (%)	Waste to Composting (%)
2014 (Baseline)	83.0	10.0	2.0	5.0
2017 (Short-term)	82.1	10.2	2.5	5.2
2024 (Medium-term)	79.9	10.8	3.5	5.8
2040 (OneCape)	75.0	12.0	6.0	7.0
Change	*-9.6*	*+20*	*+200*	*+40*

With reference to Table 4, it was assumed that there would be significant increases in the percentage of waste that will be sent for Recycling/Re-use (20% increase), waste-to-energy (200% increase), and Composting (40% increase) to 2040 in the BAU model; however, due to landfill practices remaining the most financially viable option in the short-term, and as a result of relatively low rates for disposal of general waste over the long-term, these increase only translated to a 9.6% decrease in landfilling is by 2040.

4.3.2 Accelerated Green (AG) Model

The AG model attempts to depict a significant move from a largely landfill-oriented Province to a resource-oriented Province from 2014 to 2040, to contribute to the goals of OneCape 2040 Vision. The principle of decoupling, has been utilised in constructing the AG model. Decoupling in this instance, refers to the systematic reduction of waste sent to landfill per unit of waste produced and/or per unit of economic activity (Fischer-Kowalski & Swilling, 2011). The results of this model are displayed in Table 5 and Figure 5.

Table 5. Fractional waste disposal per destination predicted by model.

Year Description	Waste to Landfill (%)	Waste to Recyc./Re-use (%)	Waste-to-Energy (%)	Waste to Composting (%)
2014 (Baseline)	83.0	10.0	5.0	2.0
2017 (Short-term)	78.6	10.5	6.5	4.4
2024 (Medium-term)	51.8	28.3	10.0	10.0
2040 (OneCape)	5.0	45.0	40.0	10.0

Up to 2017, a linear uptake of alternate waste disposal projects is observed in the short-term. This uptake is largely in composting which is well established and growing in the Province, and in WtE where prioritising planned biological process initiatives results in as much as a 5% decrease in waste being sent to landfill. By 2024, the current waste management practice based on the National Waste Management Hierarchy (Department of Environmental Affairs, 2011), has led to the prioritisation of Reuse/Recycling initiatives while Composting initiatives have reached their peak in terms of the maximum greens and organic waste suitable for composting.

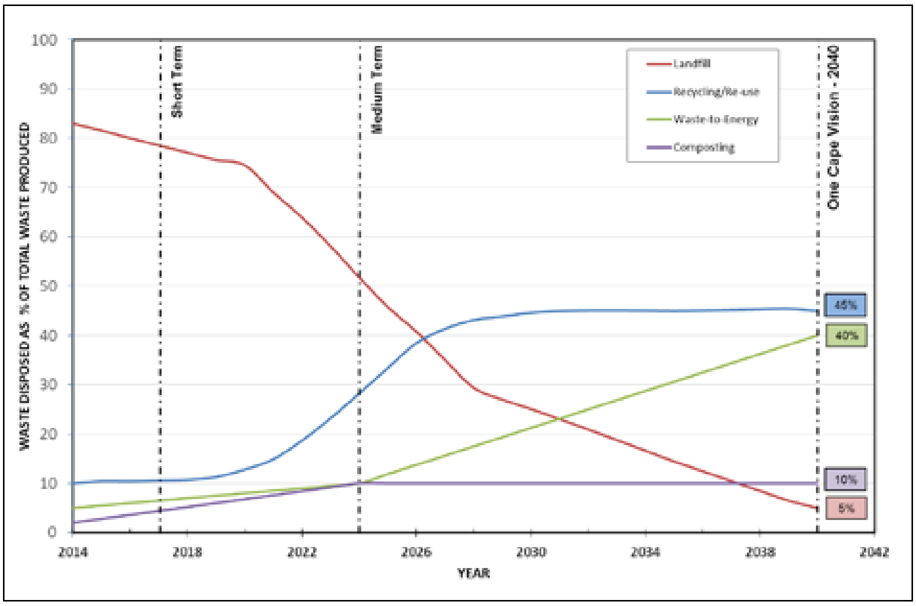


Figure 5. Graphical representation of AG model

Planned WtE initiatives have also maintained their slow but steady uptake and now account for up to 10% of the total waste generated in the Western Cape. At this point, a shift in policy would allow for the prioritisation of waste used as feedstock for WtE initiatives, since the quantity of waste being Reused/Recycled has been exhausted. This results in a long-term trend of increasing growth in the WtE sector which is strongly supported by Reuse/Recycling initiatives in relocating waste away from landfills. A shift in policy also has the effect of rapidly decreasing the amount of waste to being sent to landfill between 2020 and 2028, coupled with the Province's investment in alternate waste management practices.

4.4 Net CO2 eq. Emissions Reduction Potential

A critical part of the modelling process was to allow for the prediction of net CO_2 eq. emissions reduction possible by 2040 as well as the potential contribution that WtE processes add to this reduction. This estimate was generated by making use of the U.S. EPA Waste Reduction Model (WARM) as well as a model specifically built for this purpose which predicts reductions in CO_2 eq. emissions due to changes in waste management behaviour. The U.S. EPA initially created WARM to aid in the tracking of greenhouse gas (GHG) emission reductions from several different waste management practices that are used in the United States. The model aims to calculate GHG emissions of baseline and alternative waste management practices including recycling, WtE, composting as well as the most common waste management practice of landfilling. The model calculates emissions in metric tons of carbon equivalence (MTCE), metric tons of carbon dioxide equivalence (MTCO2E), while catering for various material types commonly found in municipal solid waste. By increasing waste quantities to their predicted 2040 equivalents, an analysis between the BAU and AG models was conducted in order to predict the net CO_2 reduction possible. The results of this analysis are highlighted in Table 6, which presents the net CO_2 eq. emissions reduction potential for the year 2040 if the AG model was adopted:

Table 6. CO_2 eq. emissions reduction potential according to management practice (tCO2e/yr)

Model	Landfill (t)	Recycling (t)	WtE (t)	Compost (t)	Total (t)
BAU - AG 3 2040	3 221 794	7 220 224	2 981 840	48 307	13 472 164

5. CONCLUSION

At the outset of the paper the *Waste-to-Energy Lattice* demonstrated the linkages between numerous waste (re)sources, and primary and secondary energy outputs. The 2011 National Census was used as a baseline year from which waste quantities would be formulated and subsequently projected, to the baseline year 2014. It was determined that a total quantity of approx. 8,212,496 tonnes of waste would be generated in 2014, with MSW (3,841,840), Agricultural Residues (2,125,082) and Recyclables (1,534,198) as the three largest contributors, whilst the CCT would generate the largest quantity of waste amongst the district municipalities at +60% in any given year. In order to conceptualise a realistic future for the inception and growth of WtE projects in the Province, a study was conducted of successful transitions from largely landfill-oriented policy to the culture of reuse, recycling and WtE, on namely the Netherlands, Sweden, Germany and Denmark. From this study, fractional waste disposal and beneficial uses of 5%, 45%, 40% and 10% were attributed to landfilling, reuse/recycling, WtE and composting, respectively, for the AG model. A total net CO_2 eq. emissions reduction of 13,472,164t was calculated for 2040 using the AG model, which in carbon savings terms is equivalent to removing over 2.6 million cars from the Province's roads. The biggest waste stream contributors to the total net CO_2 eq. emissions reduction would be non-recyclable MSW (34.9%), commercial and industrial waste (21.0%) and recyclable metals (15.5%). Using the total net CO_2 eq. emissions reduction as a yardstick for the uptake of WtE projects, it was calculated that biological WtE projects would be the most subscribed to by 2040 with a share of 82% of the total net CO_2 eq. emissions reduction. The CCT remains the biggest role-player in enabling an accelerated WtE largely due to the significant quantity of waste streams that are generated in the metro, the centralised distribution of these waste streams, and the high population density in and around the City.

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