Chapter 3
Application of the WROSE Model for Promoting Effective Decision-Making and Sustained Climate Change Stabilization in the South African Waste Sector

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3.1 Introduction

It is estimated that the waste sector in South Africa contributes with over 19 million tons of CO_{2eq} per year, or 4.1% of South Africa's total GHG emissions (DFFE 2017). In particular, the waste sector accounts for 36.5% of the total methane (CH_4) emissions in 2020. The majority of these emissions are from solid waste disposal contributing 79.2% and the remaining emissions come from wastewater. Since 2000, methane emissions from solid waste disposal have increased to 34.1%, and total GHG emissions have increased of almost 56.7% (2.7% year by year) in the past 17 years (2000–2017) (DFFE 2017). However, the waste and climate change nexus is not explicitly quantified nor addressed in current policies at national and/or local level causing a potential retarding effect on the achievement of the Nationally Determined Contributions (NDCs) and sustainability goals. At national level, GHGs from the waste sector are quantified using models and carbon emission factors developed in contexts that are not specific to South Africa (DEA 2014). There is a need to create a realistic inventory of GHG emissions from the waste sector and a comprehensive mitigation strategy for the African continent. In South Africa, the disposal of unsorted waste to landfill is still the primary waste management method across the country; however, legislative developments aim to drive integrated waste management and the circular economy, putting the disposal of waste to landfill as the least favorable waste management solution (DFFE 2018). Arguably, with almost 80% of the municipal solid waste ending up in landfill sites unsorted and untreated,

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the only reasonable "activator" of the circular economy would be an integrated waste management system, which is underpinned by an efficient separated collection at the source, followed by carefully selected and strategically localized waste treatment strategies, decentralized recycling facilities, and sustainable end-of-life disposal options. There is a need to correctly quantify the GHG emissions from the waste sector, to strengthen government's capacity in GHG monitoring and reporting, and to develop waste management strategies that, if regionally applied and correctly localized, can contribute towards the systematic reduction of GHG emissions, waste diversion, and can be a quantifiable contribution to South Africa's Nationally Determined Contributions and climate change mitigation targets (DEA 2014).

In Africa, local authorities have generally limited know-how in evaluating technology options, operate with limited resources, lack capacity and data, and function under complex institutional and social contexts which in turn increase the risk of failed inappropriate technologies and out of context installations (WMO 2018). Moreover, implementation of waste strategies is based primarily on technical and economic considerations, while environmental and socioeconomic considerations are generally subordinate to the former. In recent years, through the development of waste management legislation as well as the requirements for landfill development, local municipalities are forced to explore alternative methods of waste management (Kissoon and Trois 2022). The introduction of the waste hierarchy in South Africa as well as the National Waste Management Strategy puts the disposal of waste to landfill as an end-of-life solution (DEA 2008). This gives rise to the need for implementing alternative strategies such as recycling, recovery of biogenic waste, and the reuse of waste as a resource. However, local municipalities lack the required human capital and financial resources to implement such new systems. Up to 40% of the South African population receives little or no waste services (DEA 2008). Even though at national level there have been assessments to quantify GHG from waste, there is not a national standardized methodology specific to the South African context.

The Waste Resource Optimization Scenario Evaluation (WROSE) model/tool aims at bridging this gap as it is a waste diversion and carbon emissions reduction model that was developed by the SARChI Chair Waste and Climate Change at UKZN since 2010 (Trois and Jagath 2011) to assist municipalities and the private sector to evaluate different waste management strategies and making the best and most sustainable decision from an environmental, technical/economic, social, and institutional viewpoint.

This chapter presents the preliminary results of a study on the assessment of GHG emissions and alternative waste diversion pathways from the eight South African metropolitan municipalities using the WROSE model with the aim to develop a comprehensive waste reduction and climate change stabilization strategy for the South African waste sector. The study is intended to provide data and information to municipal waste managers about potential alternatives to landfill disposal, using their carbon footprint and potential for GHG reduction as discriminants for their choice. The chapter reports on socioeconomic drivers, waste generation, and composition data for the eight metros but details the application of the WROSE model only for the eThekwini Municipality (as representative of the other seven metros) and focuses exclusively on commercial and residential (post-consumer) municipal solid waste (MSW) as collected and disposed in urban areas in South Africa. The main aim of this project is to assess the potential annual carbon emissions reductions from optimized waste management strategies and from public sanitary engineered landfills in South Africa's eight metros and to identify feasible mitigation pathways to achieve those reductions.

The WROSE model (Kissoon and Trois 2019; Trois and Jagath 2011) was developed to assist municipal officials in the decision-making process for the implementation of appropriate waste management strategies. The model was developed in two phases: phase 1 included a scenario analysis based on environmental and economic indicators, whereas phase 2 focused on the socioeconomic and institutional aspects of the model. The WROSE model was developed in conjunction with the private sector for municipal officials looking to implement alternative waste management strategies through activating public-private partnerships. The model uses country-specific data and emission factors making it relevant to developing countries, and it covers a range of waste management technology options such as landfilling, landfilling with gas extraction and flaring, landfilling with gas recovery and electricity generation or gas upgrade, recycling, thermal treatment and incineration, anaerobic digestion, and composting. In addition, the WROSE model covers basic capital and operating cost of the waste management activities listed above. The WROSE model provides information such as GHG emission reduction potential, waste diversion rates, and landfill airspace savings realized both in terms of m^3 of airspace and in terms of the monetary value of prolonging the life of a landfill site or selling the recyclables. The model provides a detailed account of associated capital and operational costs/revenues, job creation potential and associated health risks, and the institutional framework (including possible "red tape") pertaining to the implementation of the assessed technology options. WROSE has been set up with IPCC emissions factors and follows standard methods for carbon emissions evaluation that are based on a first-order decay model (IPCC 2006). Therefore, the WROSE methodology is a reliable alternative to similar waste and carbon emission models used internationally such as WARM, WRATE, EASETECH, or GAINS (Ghinea and Gavrilescu 2010). However, since it has been developed and tested with a large number of Southern African municipalities and case studies over the past 10 years, specific emission factors have been developed and tested for a number of waste technology options for South Africa, and current research by the SARCHI Chair Waste and Climate Change is directed to test the reliability and compare these local emission factors against the results obtained using the standard approved IPCC emission factors (Friedrich and Trois 2013a, b).

3.2 Waste Management in South Africa

As a result of increased waste output brought on by fast urbanization, population growth, and economic development, South African municipalities are under pressure to provide high quality services and manage landfills (CSIR 2020). The proportion of households from which waste is removed at least once per week climbed from 58.8% in 2019 to 62.9% in 2021 (STATS-SA 2021a). According to the State of the Waste report (Department of the Environment and Energy 2018), out of the estimated 55.6 million tons of general waste produced in 2017, 0.2% was stockpiled, 34.5% was recycled or recovered, 0.1% was processed, and 65.2% was disposed in landfills. According to the State of the Waste Report Department of the Environment and Energy (2018), based on a representative sample of municipalities from each of its nine provinces, South Africa recycled 38.6% of its estimated 54.2 million tons (Mt) of general waste generated in 2017 – a sum of municipal (4.8 Mt), commercial and industrial (3.5 Mt), organic (30.5 Mt), construction and demolition (4.5 Mt), metals (4 Mt), glass (2.5 Mt), paper (2.2 Mt), plastic (1.1 Mt), tyres (0.24 Mt), and other (0.73 Mt) wastes. 38.3% of generated waste in 2017 was recovered and/or recycled, while 61.77% was landfilled or treated.

The generation of waste in South Africa is affected by numerous drivers, such as population – size, growth, and density; economy – manufacturing and industry, higher incomes, and affluence; urbanization; and globalization of the recycling market. South Africa is classified as an 'upper-middle income' country. Waste management challenges include lack of law enforcement (UNEP 2018), weak governance, low public awareness and negative attitudes, insufficient financial provision, and service backlog to address issues faced by communities (Trois and Simelane 2010).

The NWMS was developed to achieve the objectives set out in the Waste Act (SAWIC 2016). One such objective is the application of the waste hierarchy as set out by the waste act that promotes waste minimization, reuse, recycling, waste treatment, and the disposal of waste to landfill as an end-of-life method for waste management (SAWIC 2016). The National Waste Management Strategy 2020 determines three strategic pillars to improve the waste management in the country. The first pillar is waste minimization with a 5-year target of 40%, 10-year target of 55% reduction, and 15-year target of 70% reduction of waste disposed in landfills with the aim to reach in the long term "Zero waste going to Landfill." The second pillar is effective and sustainable waste services with the aim to deliver sustainable waste services to all South Africans, and the third pillar is to ensure compliance, enforcement, and awareness. South African provinces and municipalities (1) have to develop integrated waste management plans (IWMP) that integrate and optimize waste management services that support the achievement of national objectives. Figure 3.1, extracted from the South African Waste information system, presents the evolution of disposed waste tonnages in the eight metros from 2015 to 2021.

3.3 Waste Management Models and Decision-Support Tools

Waste management models are typically intended to assist decision-makers in developing integrated programs for implementing solid waste management alternatives. The majority of these decision support models are based on various methods such as cost-benefit analysis, life cycle assessment (LCA), environmental risk

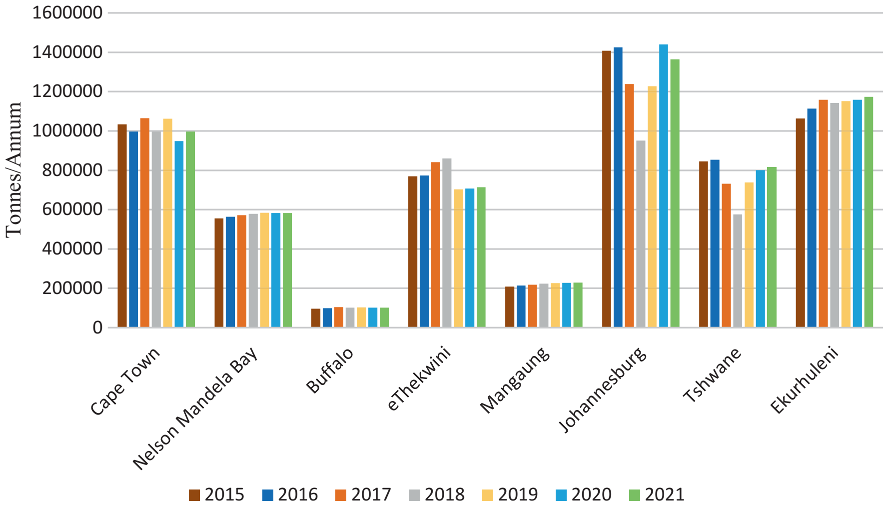

Fig. 3.1 Waste disposal data for the eight Metropolitan areas. (Source: SAWIC, 2021)

assessment, multi-criteria decision-making, and environmental impact assessment (Ghinea and Gavrilescu 2010). Several factors, including the quantity and composition of waste, socioeconomic, technological, topographical, and other variables, influence the efficiency or sustainability of waste management (Stevanović-Čarapina et al. 2019). Appropriately selecting waste processing technologies and efficient waste management strategies provide opportunities to maximize net energy production, reduce costs, increase waste diversion from landfills, reduce GHG emissions, and minimize other environmental impacts through energy and materials recovery (Levis et al. 2013).

Tables 3.1 and 3.2 compare the major features of LCA-based waste management tools most relevant to this study, including country of origin, methodological approach, database, waste stream, waste material categories, waste management process and technologies, indicators assessment, and source of references.

3.3.1 The Waste to Resource Optimization and Scenario Evaluation Model (WROSE)

The WROSE model is a zero-waste model developed in South Africa by UKZN in 2010 (Dell'Orto and Trois 2022; Kissoon 2018; Trois and Jagath 2011). The input data to the model is waste generation rate and waste composition (Table 3.2). A number of scenarios are embedded in the WROSE model, ranging from baseline (business as usual) to more complex optimized solutions (Fig. 3.2).

Table 3.1 Comparison of the waste management tools in terms of country of origin, methodological approach, database, and source of References. (Author: (Abera, 2022a))

Models	Country or region modeled	Methodological approach	Database	References
EASETECH	Denmark/ Europe	Based on the LCA and the impact categories of the LCIA methods EDIP97, EDIP2003, CML, USEtox, and IPCC 2007	Catalogues and process libraries are included in the database, such as material fraction, interface, constants and parameters, elementary exchanges, LICA (impact categories and methods such asEDIP97, EDIP2003, CML, USEtox and IPCC 2007) and material properties.	Zhao et al. (2015), Clavreul et al. (2014), Lodato et al. (2020, 2021) and Shah and Sattler (2020)
WRATE	UK/ Europe	Based on LCA in conjunction with ISO standards	Default waste stream categories, waste composition, waste property, impact assessment methods and electricity energy mix	WRATE (2014) and Shah and Sattler (2020)
GAINS	Austria/ Europe	Based on LCA	Energy database (electricity and district heat generation, energy use for primary fuel production, final energy use), activity data, control strategies, cost data and regional parameters	Amann et al. (2011) and IIASA (2021)
WARM	USA	Based on the LCA and the impact categories of the LCIA method (IPCC 2006)	Material properties, energy units, labor hours, wages, taxes and GHG emission factors	U.S.EPA (2016) and Shah and Sattler (2020)
WROSE	South Africa/ Africa	Based on life cycle assessment and multi-criteria decision analysis (MCA) methods	Emission factors, economic data, social and institutional data for South Africa	Kissoon (2018), Friedrich and Trois (2013a, b) and Trois and Jagath (2011)

Author: Abera (2022)

3.4 Methodology

3.4.1 Data Collection and Analysis: Waste Statistics and Socioeconomic Drivers

This study comprised of four different components in assessing potential zero waste strategies: a waste stream analysis to determine the waste composition and generation rates, a carbon emission/reduction assessment, a landfill airspace, and a waste

Table 3.2 Comparison of relevant waste management tools in terms of waste streams, waste fractions, and indicators (Author: (Abera, 2022a))

Models	Waste streams	Waste fractions	Waste management process and technologies	Indicators assessment
EASETECH	Municipal solid waste	Vegetable food waste, animal food waste, magazines, newsprints, advertisements, book, phone books, office paper, other clean paper, paper and carton containers, other clean cardboard, milk cartons (carton/plastics), juice cartons (carton/plastic/aluminum),kitchen towels, glass, plastic, metals and residuals	Source separation, collection, transportation, material recovery facility (MRF), anaerobic digester, incineration, composting, LFG flaring, LFG to electricity and also included life cycle cost	Global warming, stratospheric ozone depletion, human toxicity, cancer effects, human toxicity, non-cancer effects, particulate matter/respiratory inorganics, ionizing radiation, human health, photochemical ozone formation, human health, acidification, eutrophication terrestrial, eutrophication freshwater, eutrophication marine, eco-toxicity freshwater, resource depletion, mineral, fossil depletion, fossils and renewables
WRATE	MSW, household, bulky households commercial office waste, civic amenity, litter, street sweeping, co-collected trade waste, building waste and highways waste	Paper and card, plastic film, dense plastics, textiles, absorbent hygiene products, wood, combustibles, non-combustibles, glass, kitchen and garden waste, ferrous metal, non-ferrous metal, material <10 mm, electrical/electronic equipment and household hazardous waste	Collection and transportation, intermediate facilities, recycling, pyrolysis, anaerobic digestion, composting, gasification, incineration, autoclave, landfilling, landfill with flaring, landfill gas with electricity generation and also allows the user to define the new process and technologies	Climate change, acidification, eutrophication, freshwater eco-toxicity, human toxicity and abiotic resource depletion

(continued)

Table 3.2 (continued)

Models	Waste streams	Waste fractions	Waste management process and technologies	Indicators assessment
GAINS	Municipal solid waste (MSW) and industrial solid waste (INW)	Food, plastic, paper, glass, metal, wood, textile, and other waste, the industries included are food industry, pulp and paper, rubber and plastics, textiles, wood, and other manufacturing industries	Open burned, scattered and/or disposed to watercourses, unmanaged solid waste disposal site – low humidity – <5 m deep, unmanaged solid waste disposal site – high humidity – >5 m deep, compacted landfill, covered landfill, landfill gas recovery and flaring, landfill gas recovery and used, incineration (poor air quality controls), anaerobic digestion, composting and recycling	Fine particulates and ground-level ozone, risk of ecosystems damage from acidification, excess nitrogen deposition (eutrophication) and exposure to elevated levels of ozone, as well as long-term radiative forcing. Also the model calculate PM, SO_2, NOx, VOC, NH_3, CO_2, CH_4, N_2O, HFCs, PFCs and SF6
WARM	MSW, construction and demolition waste and electronic waste	Aluminum cans, mixed paper, aluminum ingot, food waste, asphalt waste, mixed plastics, mixed recyclables, newspaper, branches, glass, office paper, PET, carpe, grass, phonebooks, HDPE, electronic waste, copper wire, LDPE, poultry, corrugated cardboard, leaves, PP, LLDPE, PS, dairy products, magazines, PVC, medium density fibreboard, steel cans, mixed electronics, textbooks, drywall, mixed metals, tires, mixed MSW, construction and demolition waste, mixed organics, wood flooring, mixed paper (general) and yard trimmings	Waste collection and transportation, source reduction, recycling, anaerobic digestion, incineration, composting, landfilling, landfilling with gas recovery (electricity generation and flaring), energy impact, and economic impact	Global warming potential, energy impact, economic impact (wage and taxes) and labor hours

WROSE	MSW and source separated streams (including industrial solid waste (INW); C&D waste; organic/ biogenic waste etc.)	Newspaper, general mixed paper, scrap boxes and cardboard (K4), low density polyethylene (LDPE), high density polyethylene (HDPE), polyethylene terephthalate (PET), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), glass, steel cans/tin, aluminum cans, biogenic food waste, garden refuse green, garden refuse wood, other	Landfilling, landfill flaring, landfill gas recovery and electricity generation, recycling, anaerobic digestion and composting	Global warming potential/ CO_2eq Landfill-space savings Waste diversion rate Energy consumption Operating cost Capital cost/revenues Job creation Direct and indirect health risks Public involvement Environmental legislation License requirements Energy legislation Financial and administrative regulation

Author: Abera (2022)

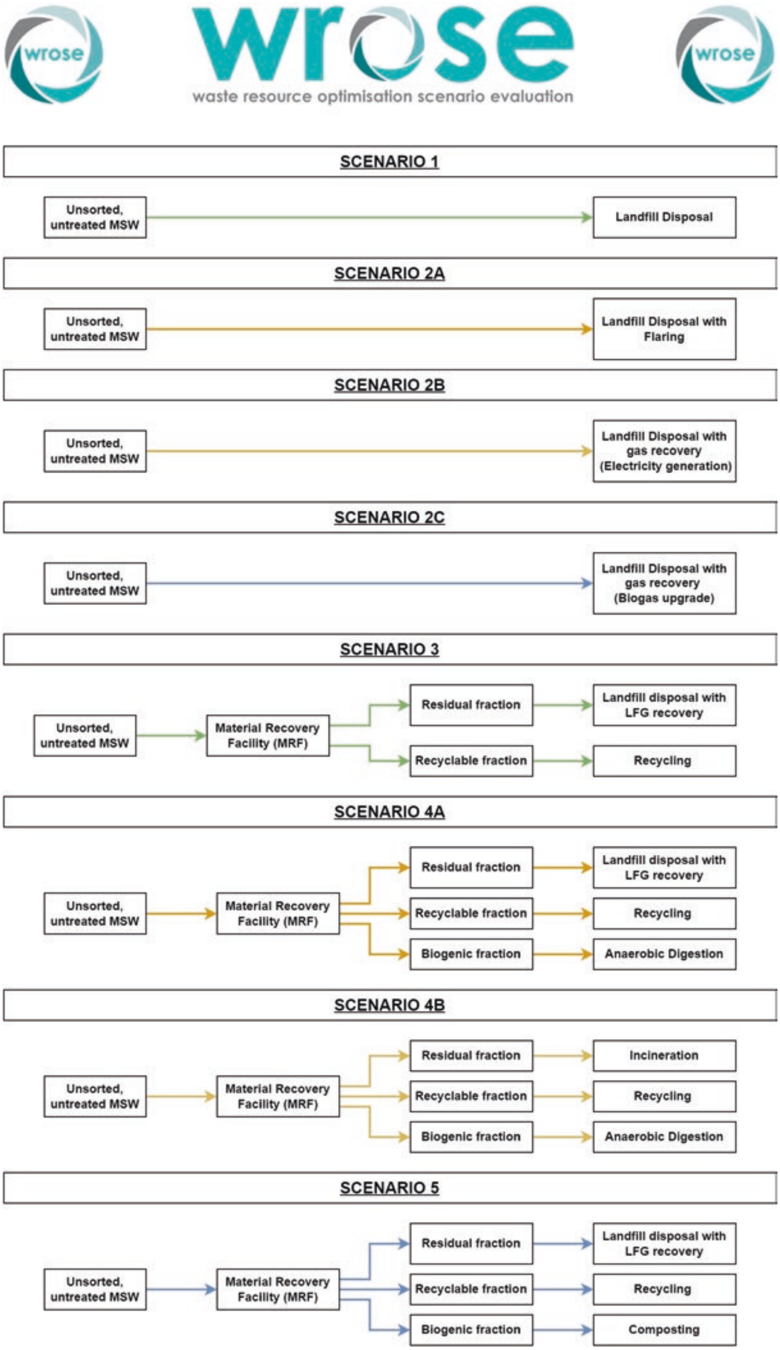

Fig. 3.2 WROSE scenarios schematic. (Dell'Orto and Trois 2022; Trois and Jagath 2011)

diversion rate assessment. Firstly, integrated waste management plans (IWMPs) were analyzed for each of the eight metros. Various datasets have been collected to estimate waste generation and disposal in South Africa's metropolitan municipalities. Reviewing the metro and province's integrated waste management plans (IWMP) and Integrated Development Plans (IDP), the South African waste information system, and different waste reports and published articles for South Africa was the initial step in the waste data collection process. Several data were collected, including population, population growth, income level, GDP, amount of garbage deposited into landfills, waste composition, waste collection rate, and the geographic location of landfill sites. The data analysis highlighted inconsistencies in the way waste categories are determined across the eight metros. To standardize the data forecasting for the study, specific waste streams were selected based on available literature as follows: mixed MSW, food waste, garden refuse, mixed paper, glass, mixed metals, LDPE, HDPE, PET, and others. Gaps in the available waste data and inconsistencies on how waste data is collected and reported in the IWMPs compounded with outdated waste characterizations for certain municipalities made it difficult to predict current waste generation trends.

3.4.2 Waste Generation

The total amount of waste generated by South African metropolitan municipalities is not precisely reported for all municipalities. Hence, quantity of waste disposed, collection rate, population, and income level have been utilized to estimate the waste generation. Equation 3.1 calculates the total waste generation for the municipalities for which waste disposal and diversion data is available:

$$W_G = \frac{(W_{DL} + W_D)}{W_C} \tag{3.1}$$

Where:

W_G is the waste generation (tons/year)
W_{DL} is the waste quantity disposed to landfills (tons/year)
W_D is the waste quantity diverted from landfills (tons/year)
W_C is the waste collection rate (%)

Equation 3.2 calculates the total amount of waste generated in municipalities where waste disposal and diversion rates are unavailable.

$$W_G = \sum\left(W_{gX} * P_X * 365 * 10^3,\ \text{for}\, X = 1,2,3\ldots N\right) \tag{3.2}$$

Where:

W_G is the total waste generation (tons/year)
W_{gX} is the waste generation per capita (Kg/day)
P_X is the population for each income level categories
X is the income level type

Due to the lack of information regarding the waste diversion rate, it is presumed that all collected waste is sent to landfills. Equation 3.3 calculates the total waste disposal quantity.

$$W_{DI} = W_G * C_R \tag{3.3}$$

Where:

W_{DI} is the total Waste disposal quantity (Tonnes/Year)
W_G is the Total waste generation (Tonnes/Year)
C_R is the Waste collection rate (percentage)

3.4.3 Carbon Emissions/Reduction Assessment

Using the waste fractions calculated above, the carbon emissions production or reduction potentials were calculated in $MTCO_2eq$ using emission factors from the IPCC (2006) as quoted in U.S.EPA (2016). The tier 1 approach was adopted, as this is the methodology for countries where national data and statistics are not available. The emissions factor for the biological treatment of biogenic MSW as listed by the guidelines is 1 g CH_4/kg of wet waste. Nitrous oxide emissions are assumed to be negligible, and an assumed 95% of methane is recovered for energy generation. GHG impacts are considered from the point at which the waste is discarded by the waste generator, to the point at which it is disposed, treated, or recycled into new products (U.S.EPA 2016). The emissions factors for the anaerobic digestion of biogenic MSW were developed using the same streamlined LCA approach as per the IPCC (2006) as detailed in Trois and Jagath (2011).

The equation below was used to determine the methane emissions or emission reduction potential in $MTCO_2eq$ for all municipalities:

$$\text{Waste quantity in tons} \times \text{emission factor} = \text{MTCO2eq} \tag{3.4}$$

The emissions produced/reduced were calculated for a 50-year period for each of the defined scenarios selected, using the appropriate emission factors.

3.4.4 Landfill Space Saving and Waste Diversion Rate

The estimation of landfill space savings from waste diversion is largely an empirical calculation, as the unique conditions and operational activities on site, specifically compaction of waste into landfill cells, influence the actual airspace saved. Actual landfill space savings (LSS) depend on the degree of compaction employed and the efficiency to which it is conducted.

$$\mathrm{LSS} = \frac{tw}{C_{\mathrm{ave}}} \tag{3.5}$$

where LSS = total landfill space savings, *tw* = total waste in tons, Cave = average compacted of MSW. The value for the compacted density of MSW was assumed to be 1200 kg/m^3 (1.2 tons/m^3).

The waste diversion rate refers to the total quantity of waste that is diverted from the landfill.

$$\mathrm{WDR} = \frac{\text{total quatity of waste diverted}\left(\text{tons}\right)}{\text{total quantity ofwaste entering waste stream}\left(\text{tons}\right)} \tag{3.6}$$

3.5 Case Study: South African Metropolitan Municipalities

There are eight metropolitan areas in South Africa as detailed in Fig. 3.3 (Abera, 2022b). This chapter presents a closer look at the eThekwini Municipality as one of the most populous municipalities in the country.

The total national population in 2020 is estimated around 60 million (Statistics South Africa 2021). 57% of the population is concentrated in three provinces, of which 26% of the population resides in Gauteng, 19% in KwaZulu-Natal, and 12% in Western Cape. The remaining 43% is distributed in the rest of the provinces, having Northern Cape the lowest population (2% of the total national). National urbanization rate is estimated at 67% (UNDESA 2019). Gauteng is the most urbanized province (99%), followed by Western Cape (87%). KwaZulu Natal, North West, and Free State have an urbanization rate of 60% (Kamalie 2017). Limpopo is the less urbanized province with 20% of the population living in urban areas. Future estimates suggest that urbanization in South Africa will reach 79.8% by 2050 (UNDESA 2019). At a metropolitan level, Johannesburg is the most populated metro with 5,874,882 people, followed by Cape Town and eThekwini (Stats-SA 2021). Figures 3.4 and 3.5 show the MSW generation and composition in the metropolitan areas, respectively.

Figure 3.4 illustrates that MSW generation in the metropolitan areas is expected to grow to 9671 kt by 2050, which is 42% higher than the current amount. The

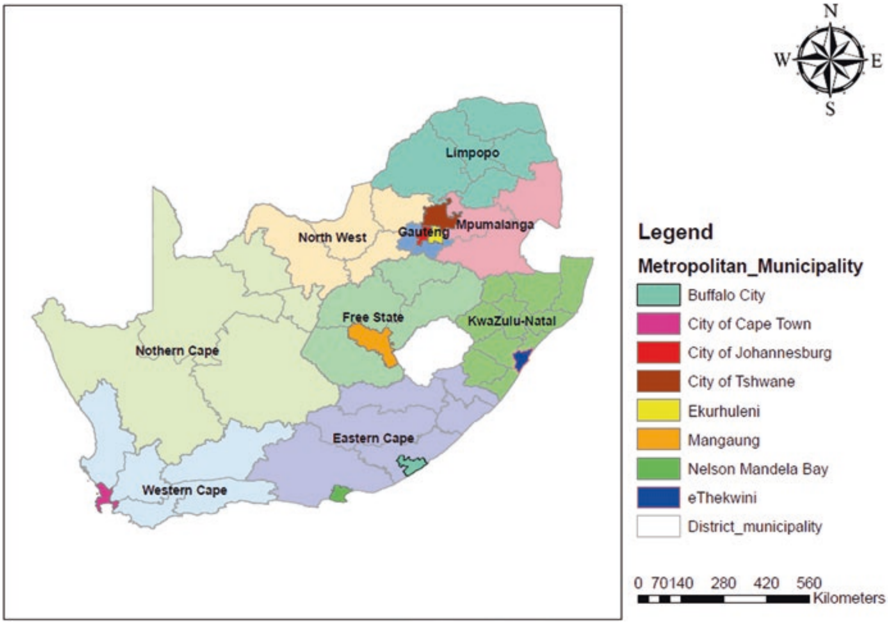

Fig. 3.3 Map of South Africa provinces and metropolitan municipalities. (Abera, 2022b)

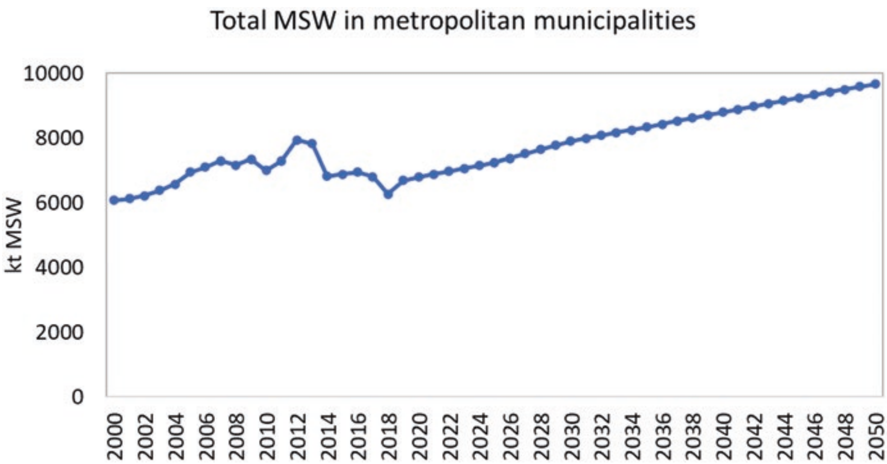

Fig. 3.4 Total MSW generation in metropolitan areas. (Source: IIASA 2022)

estimates in Fig. 3.5 suggest that the average estimated MSW composition of the metropolitan municipalities in 2020 is 42% food, 14% plastic, 13% paper, 6% glass, 3% metal, and 22% other waste (including textile, wood, diapers, some e-waste, among others). By 2050, shares are expected to be the same; however, as total MSW is increasing over time, it is likely that food waste will increase by 39% and other fractions between 42% and 45% compared to current levels.

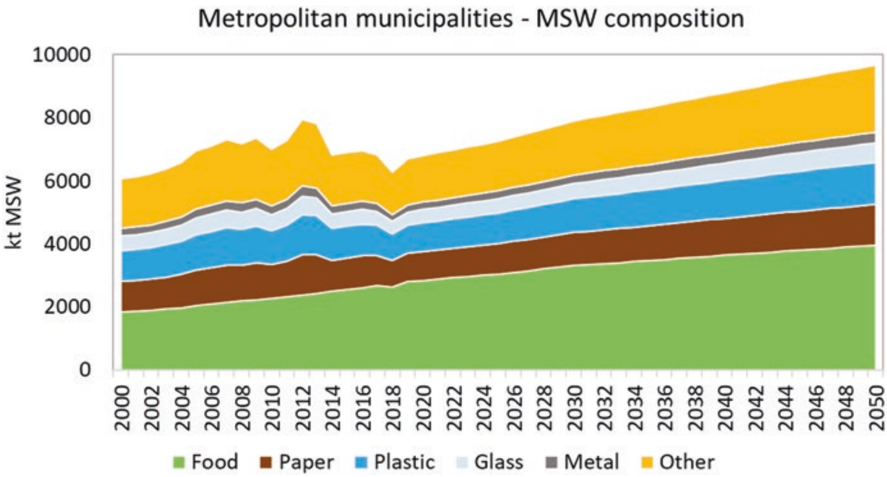

Fig. 3.5 MSW composition metropolitan areas. (Source: IIASA 2022)

3.5.1 Focus on the eThekwini Municipality – KwaZulu-Natal Province

The eThekwini municipality is located on the KwaZulu-Natal Province's southern, eastern coastline, with an approximate area of 2297 km^2. eThekwini has an approximate population of 3,158,000 million, consisting of 45% rural, 30% peri-urban, and 25% urban areas. eThekwini Municipality currently has two active general waste (MSW) landfill sites (i.e., Illovu and Buffelsdraai landfill sites) as well as two closed facilities (Bisasar Rd. and Marianhill landfills) that accept construction and demolition waste and garden refuse. The Buffelsdraai Landfill was commissioned in 2006. It has an estimated lifespan of 60 years. The landfill is surrounded by sugarcane farms and low-income housing (eThekwini 2016). The landfill covers 100 hectares of land and has a total capacity of 45 m^3. The Illovu landfill site is located south of Durban. The landfill is surrounded by sugarcane plantations and has an estimated lifespan of approximately 18 years. The landfill covers around 52 hectares of land.

In addition to the seven transfer stations within the municipality, there are a further fourteen garden waste transfer stations (DSW 2016). The transfer sites are open for public use, and some of the sites double as drop off centers for other recycling material (DSW 2016). The municipality also has two additional garden refuse landfill sites, Wyebank and Shallcross (DSW 2016). According to the Cleansing and Solid Waste Unit (CSW), the garden landfill site Wyebank reached capacity in 2016.

In the eThekwini Municipality, collection of waste is done by either DSW (Durban Solid Waste) or CBCs (Community Based Contractors) for collection of household waste at low-income and high-density settlements. The integrated waste management plan of the eThekwini Municipality (eThekwini 2016) shows that DSW provides households with a once per week waste collection service. Waste is collected from households, commercial areas, and industrial areas. Household

Table 3.3 Features of major sanitary landfill facilities in the eThekwini Municipality

Features	Bisasar Rd	Mariannhill	Buffelsdraai	Illovu
Status	Closed (2015)	Closed (2019)	Open	Open
Years to closure	0	0	50+	50+
Type of waste accepted	Since 2015 accepts only garden refuse, sand, C&D waste	Since 2019 accepts only garden refuse, sand, and C&D waste	MSW Garden refuse C&D waste	MSW Garden refuse C&D waste
Type of facility/ baseline scenario	Sanitary landfill with gas recovery and LFGTE facility for the generation of electricity (6 MW)	Sanitary landfill with gas recovery and LFGTE facility for the generation of electricity (1 MW)	Sanitary landfill with gas recovery and flaring	Sanitary landfill with gas recovery and flaring
Average received waste (t/day)	1000	300	2135	770
Area (m^2) for landfilling	0	0	25,020	0
Design airspace availability (m^3)	25,000,000	4,400,000	43,026,691	9,660,000
Approximate remaining airspace availability (m^3)	330,000	102,500	40,185,392	8,786,615
Remaining landfill years	0.9	0.9	52	31.7
Remaining design life (year)	1	1	52	32
Rehabilitated areas (m^2)	360,000	193,000	232,350	8500

waste is collected in DSW supplied black plastic bags, placed on kerbs on the required collection day. The use of orange and clear plastic bags is adopted for certain recyclable waste. In commercial and industrial areas, waste is collected either by CSW or by private waste collection companies. Table 3.3 presents the main facilities present in the eThekwini Municipalities and indicate the baseline scenarios adopted in the WROSE simulations.

The eThekwini metropolitan municipality shows an increasing trend of MSW per capita throughout the study period. MSW per capita is assessed at 196 kt/cap/year (0.54 kg/cap/day) in 2000, showing an increase of 12% in 2020 compared to 2000. By 2050, per capita MSW rate is expected to be 239 kg/cap/year (0.65 kg/cap/day) (Fig. 3.6). In Fig. 3.6, it can be observed that MSW per capita grew relatively faster than GDP per capita between 2006 and 2018. Projections show that after 2025, GDP per capita is expected to grow at faster pace compared to MSW per capita.

Figure 3.7 presents the total MSW generation in eThekwini. The total MSW generation in 2000 is assessed at 593 kt per year. In 2020, it is estimated that the MSW generation reached 873 kt which represents an increase of 46% compared to

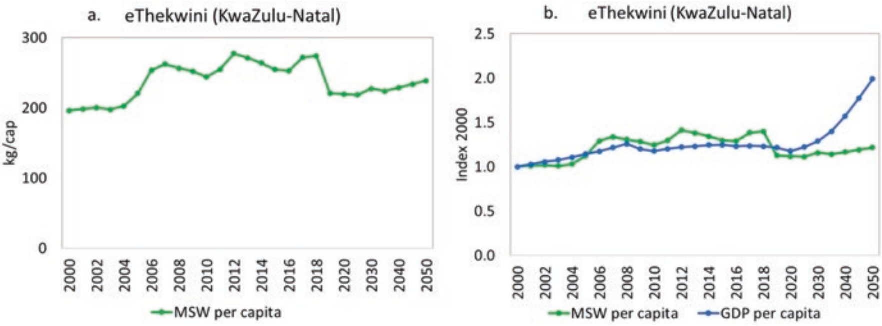

Fig. 3.6 (**a**) MSW per capita and (**b**) MSW per capita and GDP capita index 2000. (Source: IIASA 2022)

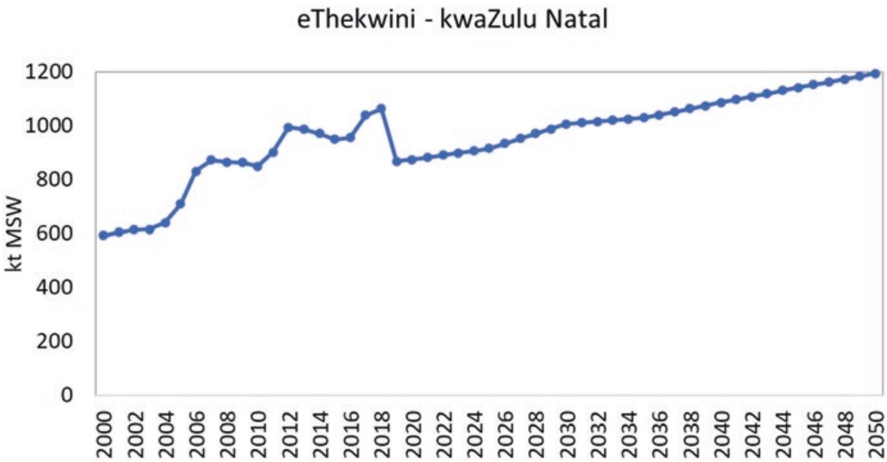

Fig. 3.7 Total MSW generation eThekwini. (Source: IIASA 2022)

2000. By 2050, it is estimated that MSW quantities will rise up to around 1193 kt. The annual growth rate between 2020 and 2050 is assessed at 1.05%.

Figure 3.8 shows the MSW composition in the eThekwini metropolitan area.

Figure 3.8 shows that food waste is the biggest fraction of the MSW stream, with 57% back to 2000 and estimated to be around 53% towards 2050 or 637 kt per year. Paper, plastic, and other mixed waste made up 34% of the MSW in 2000 and 36% in 2020. By 2050, it is estimated that these fractions will make up 37% of the total MSW generated, of which 10% is plastic, paper 14%, and mixed waste 13%. Figure 3.9 presents the total waste entering eThekwini landfills since 2001.

Figure 3.9 shows that prior to the commissioning of the Lovu landfill site and the Buffelsdraai landfill, that majority of the waste went to the Bisasar Road landfill site. When Bisasar reached the final stages of capacity, the amount of waste per annum reduced.

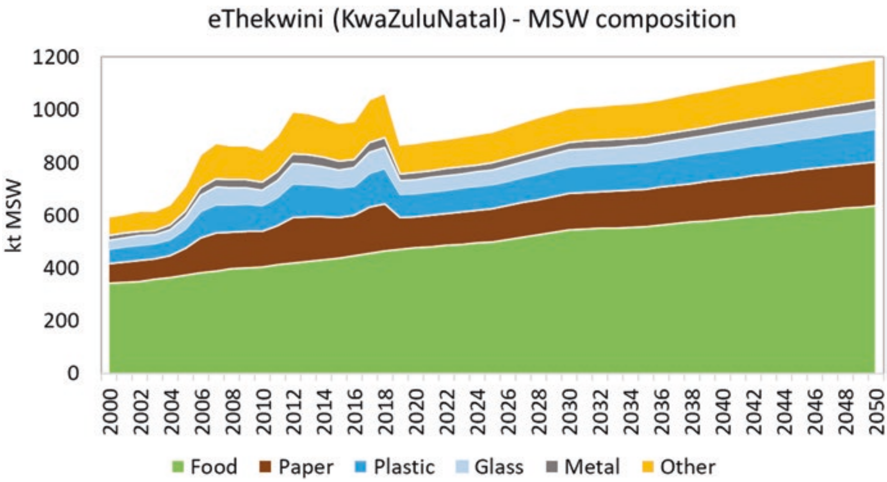

Fig. 3.8 MSW composition in eThekwini. (Source: IIASA 2022)

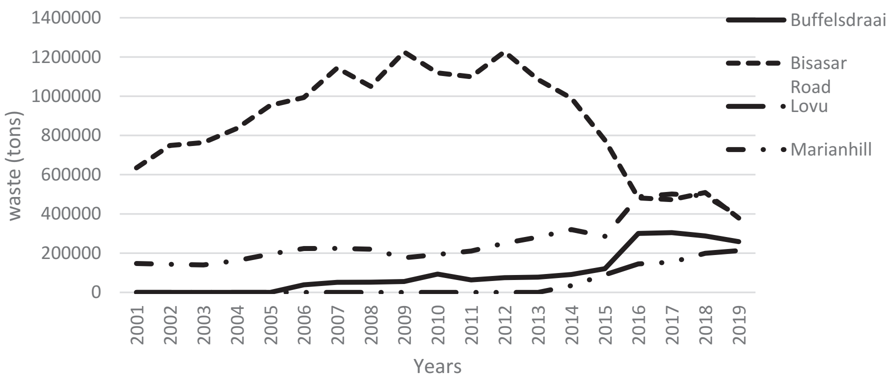

Fig. 3.9 Total waste entering eThekwini landfills in the past 19 years. (UKZN 2022)

3.6 Results and Discussions

From Fig. 3.2, the scenarios chosen for the eThekwini Municipality simulations in WROSE are as follows:

– Scenario 2B (BAU – baseline)
– Scenario 4B – Anaerobic digestion
– Scenario 5 – Aerobic composting

The simulation was run for Buffelsdraai and Lovu only, due to the other existing landfills having reached maximum capacity. The analysis was run using a projection until 2081, for both landfill sites. Although the Lovu landfill site has a lower life expectancy than the Buffelsdraai landfill site, the projection until 2081 is justified as

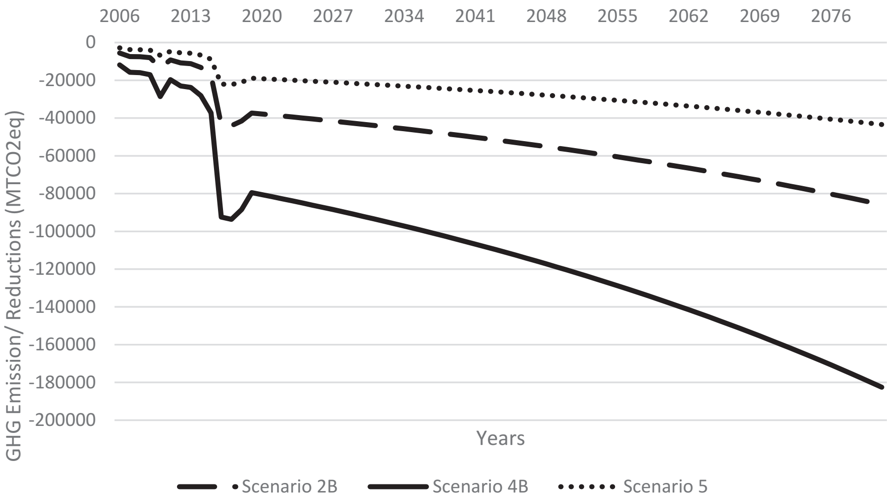

Fig. 3.10 GHG emissions reductions for the Buffelsdraai landfill

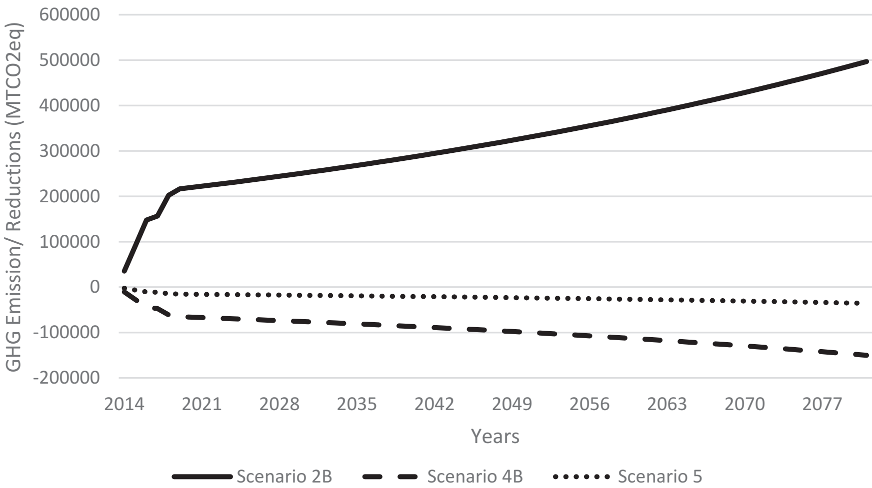

Fig. 3.11 GHG emissions reductions for Illovu landfill

adopting a sustainable waste management strategy will help divert waste and preserve the life expectancy. The carbon emissions/reductions for each landfill and their respective scenarios are shown and discussed below.

Figures 3.10 and 3.11 display the estimated future GHG reductions for each of the scenarios selected.

From Figs. 3.10 and 3.11, it is evident that scenario 5 (landfill gas recovery, recycling, and composting) is the least favorable waste management strategy as it

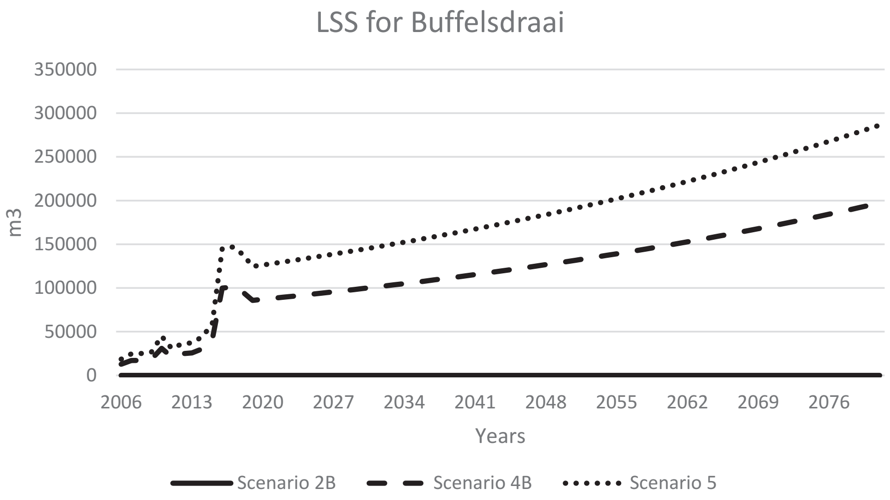

Fig. 3.12 Landfill Airspace Savings (LSS) for the Buffelsdraai Landfill

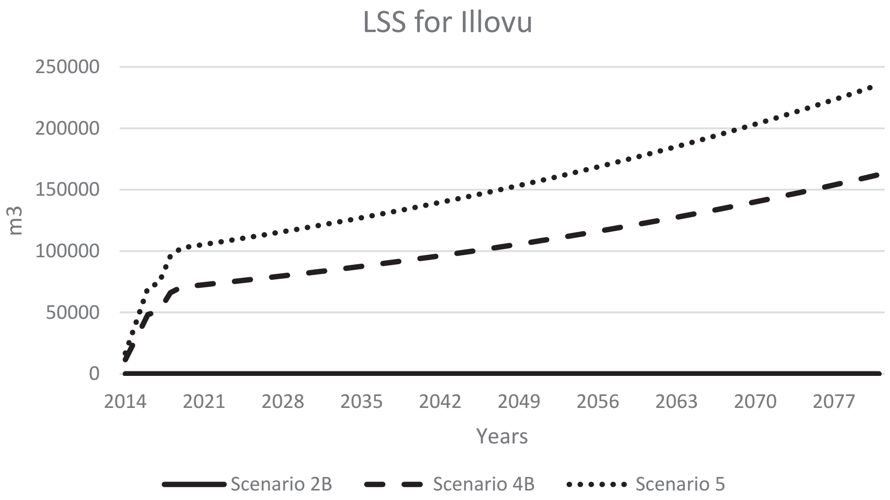

Fig. 3.13 LSS for the Illovu landfill

reduces the least amount of carbon emissions, while scenario 4B (landfill gas recovery, recycling, and anaerobic digestion) produces the most favorable results as it reduces the most amount of carbon emissions.

The landfill space savings are summarized below for the respective landfills and scenarios in Figs. 3.12 and 3.13.

From Fig. 3.12, scenario 2B offers no landfill space savings as no waste is diverted. Scenario 5 offers the highest LSS over the projection period due to waste

Table 3.4 Waste diversion rates

	Scenario 2B	Scenario 4B	Scenario 5
Buffelsdraai landfill	0	39.85%	57.85%
Lovu landfill	NA	39.85%	57.85%

Table 3.5 Waste diversion rates for food waste, biogenic waste, and garden refuse streams only

	Scenario 2B	Scenario 4B	Scenario 5
Buffelsdraai landfill	0	28.22	46.22
Lovu landfill	NA	28.22	46.22

streams like garden refuse and biogenic food waste being diverted. On average, scenario 5 saves up to 45% more landfill space than scenario 4B. This makes scenario 5 the most viable option in terms of promoting longevity to landfills. Figure 3.13 presents the projected landfill airspace savings for the Illovu landfill.

From Fig. 3.13, it is evident that scenario 5 is again the preferred scenario as it produces the most landfill airspace saved during the projection. The waste diversion rates (%) are summarized in Tables 3.4 and 3.5 for both landfills.

Both landfills have the same diversion rates for scenarios 4B and 5 as the same waste composition ratio was used for the simulations. From Tables 3.4 and 3.5, it is evident that scenario 5 offers the highest diversion rate as it diverts recyclables, biogenic food waste, as well as garden refuse.

3.7 Conclusions and Recommendations

The aims of this study were to find the most appropriate waste management scenario, which can be adopted by South African municipalities to reduce future GHG emissions while achieving a high waste diversion rate as well as determine how to optimize the conversion of biogenic food waste to a resource and thus improving environmental sustainability. The GHG emission/reduction results, simulated by the WROSE model, showed that scenario 4B (land fill gas recovery with electricity generation, recycling, and anaerobic digestion) was the most appropriate scenario as it provided the greatest GHG emission reductions for both landfills. The landfill space savings simulated by the WROSE model showed that scenario 5 (landfill gas recovery with electricity generation, recycling, and composting) offered the highest landfill space savings as well as the best diversion rates. Scenario 5 offered the highest waste diversion rates and landfill space savings. The main limitations of the study are related to the absence of a standardize outlining and reporting of MSW and the lack of available and reliable data. This limitation combined with the lack of available and reliable data sources forces the adoption of approaches to construct MSW datasets at metropolitan municipality level that somehow reflect past and current MSW generation and composition. As projections build on current MSW information, the assumptions will increase the uncertainty of the resulting future estimates. It is also important to note that the backcast and projections of waste generation and composition are just indicative as they build on only GDP per capita and do not consider any cultural traditions or latest technological developments that can influence the composition of MSW in the future.

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