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Final Report

A comprehensive model for promoting effective decision-making and sustained climate change stabilization for South Africa

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Abbreviations

BAU	Business-as-Usual
CH_4	Methane
CO_2e	Equivalent Carbon Dioxide
CSIR	Council for Scientific and Industrial Research
EPR	Extended Producer Responsibility
GAINS	Greenhouse Gas -Air Pollution Interaction and Synergies model
GDP	Gross Domestic Product
GHG	Greenhouse gas
IIASA	International Institute of Applied Systems Analysis
IWMP	Integrated Waste Management Plans
MACC	Marginal Abatement Cost Curve
MFR	Maximum Technically Feasible Reduction
MSW	Municipal Solid Waste
Mt	Million tons
NDC	Nationally Determined Contributions
NIR	National Inventory Report
POL	Policy
SDG	Sustainable Development Goals
UPLF	Upgrade Landfills
UKZN	University of KwaZulu Natal

Executive Summary

This assessment provides a quantification of the methane reduction potential from the organic (municipal) solid waste in South Africa. It quantifies the potential methane emission reductions by contrasting a Business-as-Usual scenario to three alternative future scenarios. One in which the focus is given to upgrade landfills, an additional one in which no further measures beyond current policy are taken and a third one in which all technical measures currently available to adopt circular waste management systems are implemented. The assessment is carried out at provincial level up to 2050 (5-years-step). The key findings are presented below:

The waste sector in South Africa is estimated to emit 312 kt of CH_4, which corresponds to 8.7 Mt CO2eq when using a global warming potential (GWP) over 100 years. Although some provinces in South Africa have shown an improvement, if current waste management conditions are maintained into the future, it is expected that CH_4 emissions will increase by 68% in 2050. Despite recent progress in the waste related political framework, there is a lack of implementation of existing policies.

Although upgrading landfills is an important measure to significantly reduce methane emissions in the provinces, without additional measures to divert organic waste from landfills, methane emissions are expected to increase. Landfill measures alone are not enough to bend the curve. If implemented, current waste policies will succeed in reducing methane emissions, however, further action could offer additional reductions in the waste sector.

Gauteng and Western Cape have been identified as the provinces with the highest contribution to methane emissions from waste. Interventions in these two provinces account for 50% of the methane reduction potential from waste in South Africa. Therefore, Western Cape and Gauteng could be prioritized as the main provinces to abate CH_4 from waste in the country.

The cost associated with emission reductions depends on the level of ambition. Only upgrading the landfills (UPLF scenario) will result in the lowest methane abatement potential at low cost compared to the other scenarios. The Policy (POL) and the Maximum Technical Emission Reduction (MFR) scenarios offer higher methane abatement potentials but come at a higher marginal abatement cost. By 2050, the adoption of the UPLF scenario results in a reduction of 3.3 MtCO2e at a cost of 51 Euro/tonCO2e. POL and MFR scenarios have the potential to reduce 8.6MtCO2e and 12 MtCO2e at a marginal abatement cost of 105 Euro/tonCO2e and 359 Euro/tonCO2e, respectively.

1. Introduction

This final report presents the development of a project collaboration between the University of Kwazulu-Natal (UKZN) and the International Institute of Applied Systems Analysis (IIASA) on "**A comprehensive model for promoting effective decision-making and sustained climate change stabilization for South Africa".** Within this project**,** IIASA assessed the methane emissions mitigation potential from the organic waste sector in South Africa at provincial level. The provinces included in the analysis are Eastern Cape, Free State, Gauteng, KwaZulu Natal, Limpopo, Mpumalanga, North West, Northern Cape, and Western Cape.

This final report exposes relevant aspects in the waste sector at provincial level in South Africa. The results revels that, there is a big gap with respect to waste data availability and consistency in terms of generation, composition, and management. High uncertainty in methane emission estimates is due to the lack of characterization of landfills as well as the amounts of landfilled waste overtime. This fact has also been highlighted in the South Africa's National GHG Inventory Report 2000-2020 (Department of Forestry, Fisheries and the Environment House, 2022a).

There is not a standardize system to report waste generation and composition and, in many cases, the reported quantities represent only the amount of waste disposed of to landfills, a situation that can lead to under-estimation of the total quantities of municipal solid waste generated. In addition, the lack of a consistent definition of what is municipal solid waste makes it difficult to carry out the analysis. In some cases, the reported value includes hazardous and construction and demolition waste while in other the main composition is household waste. The aforementioned aspects combined with the lack of historical information (i.e., time-series) results in the adoption of various assumptions that increase the uncertainty of the results.

Despite these gaps and based on our previous work submitted to the World Bank (The World Bank, 2023), a consistent starting point to project municipal solid waste generation amounts at the provincial level was found based on estimates of metropolitan areas. In general, back-casting and projections of MSW use the most consistent reported years. A similar approach was undertaken regarding waste composition.

The following chapters present the assessed methane mitigation potentials from the organic waste sector in South Africa at provincial level, including a comparison to the estimates reported in the South Africa's National GHG Inventory Report 2000-2020 (Department of Forestry, Fisheries and the Environment House, 2022a) .

2. Project background

The adoption and improvement of sustainable waste management systems go beyond sanitation as the waste sector plays an important role in the reduction of greenhouse gases (GHG) as well as in sustainability. Estimates in South Africa suggest that the waste sector accounts for about 4 % of total national GHG emissions (Department of Forestry, Fisheries and the Environment House, 2021). However, the connection between waste and climate change is not fully understood, causing a potential retarding effect on the achievement of the Nationally Determined Contributions (NDCs) and sustainability. 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. Therefore, this project aims to propose sets of scenarios that integrate suitable waste management systems at provincial and national level using the IIASA-GAINS[1] model that can support the South African Government, through The SARCHI Chair in Waste and Climate Change, in the implementation of the NDC 2030, SDGs and NDCs to stabilize the impact of waste on climate change.

3. Setting the scene

The 8th National Greenhouse Gas Inventory Report of South Africa (Department of Forestry, Fisheries and the Environment House, 2022) estimates that the waste sector accounts for 4.1 % of the total GHG in South Africa. 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. Methane emissions from solid waste disposal have increased 34.1% since 2000. The total GHG emissions from the sector, including wastewater have increased 26.3% since 2000. Emissions are reported for waste from households, commercial businesses, institutions, and industry and include only GHG's generated from managed landfills. It is assumed that 76% (managed landfill sites) of the MSW at national level is sent to landfills (Department of Forestry, Fisheries and the Environment House, 2022b). Emissions from unmanaged sites (generally shallow) are not accounted for due to the lack of information (Department of Forestry, Fisheries and the Environment House, 2022b). In 2019, South Africa approved a Carbon Tax Act and now prices GHG emissions in all sectors except waste and AFOLU (Republic of South Africa, 2021).

Waste policies at national level shaping MSW management include the National Environmental Management Waste Act 2008 and the Waste Amendment Act 26 of 2014 which establishes waste classification and management regulations. In addition, The National Environmental Management Act 1998, and the amendment in 2021 which determines that plastic carrier bags must contain a minimum of 50% recyclate from 1st January 2023, 75% from 1st January 2025 and 100% from 1st January 2027. Another important aspect is the regulation of Extended Producer Responsibility (EPR) (Consultation on the amendments to the regulations and notices regarding extended producer responsibility, 2020 amending Waste Act 2008) which establishes specific targets regarding recycled content in products, reuse, collection target and recycling target for identified waste streams that are applicable for a period of 5 years from the date of implementation. Furthermore, 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 (Figure 1) have to develop integrated waste management plans (IWMP) that integrate and optimize waste management services that support the achievement of national objectives.

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[1] https://iiasa.ac.at/models-tools-data/gains

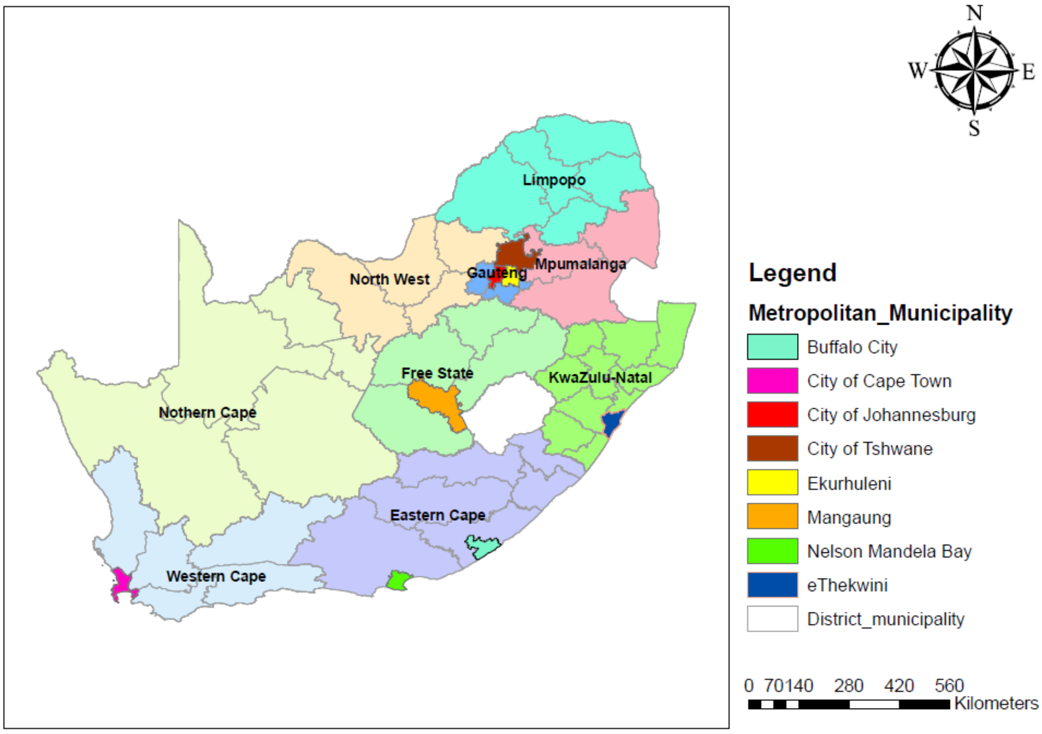

Figure 1. Map of South Africa provinces and metropolitan municipalities

Courtesy: Abera Yared (2022)

4. Methodology

This assessment applies the GHG-Air pollution Interactions and Synergies (GAINS)[2] model (Amann et al., 2011), especially the waste sector module (Gómez-Sanabria et al., 2022; Lena Höglund-Isaksson, 2012) developed at the International Institute for Applied Systems Analysis (IIASA)[3]. The model estimates emissions of air pollutants and GHGs based on international emission inventories, national and regional statistics, expert consultations and adopted policies. The GAINS model allows to contrast different plausible future scenarios (e.g., baseline and mitigation scenarios) to find the most cost-beneficial strategy to simultaneously reduce emissions of air pollutants and GHGs. The model combines socio-economic variables (exogenous), technologies and cost of emission sources, the formation and dispersion of pollutants in the atmosphere and an assessment of environmental impacts of air pollution (Figure 2).

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[2] https://gains.iiasa.ac.at/models

[3] https://iiasa.ac.at/

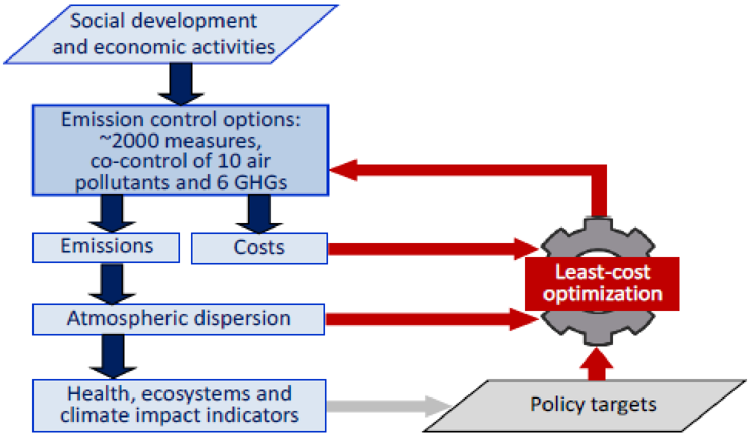


Figure 2. GAINS model structure. Source: Amann et al., 2011.

4.1 Municipal solid waste module

The municipal solid waste (MSW) module in GAINS was first developed by Höglund-Isaksson (2012) and has been further advanced by Gómez-Sanabria et al., (2022, 2018). The module integrates socio-economy variables (exogenous), waste generation quantities, waste management technologies and emission factors. The model allows to assess GHG and air pollutants emissions and indicators such as landfill diversion rates, recycling rates by stream (including anaerobic digestion and composting), carbon flows and energy generation (Figure 3).

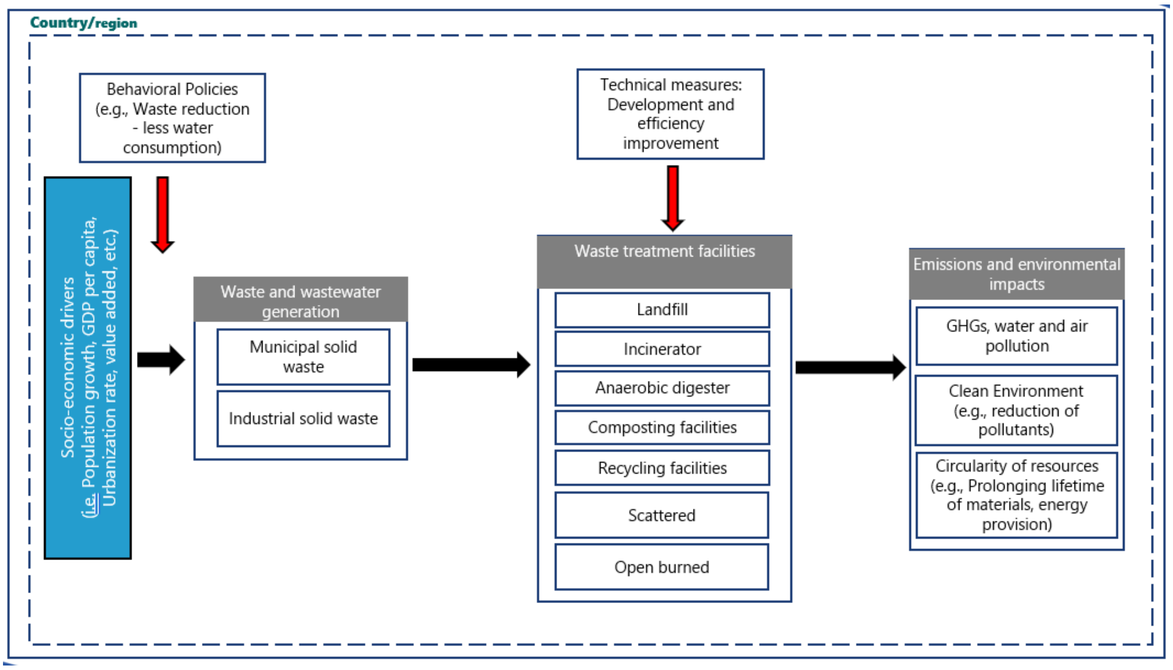


Figure 3. GAINS – MSW module structure.

The MSW module includes a consistent representation of MSW flows by stream based on the material flow accounting concept. Estimation of MSW flows is done at urban and rural areas for each of the 184 regions included in the GAINS model in a 5-year step up to 2050. MSW projections are based on MSW per capita elasticity to GDP per capita (first developed in GAINS by Höglund-Isaksson, 2012) by income group (Gomez Sanabria et al., 2021; Gómez-Sanabria et al., 2018). MSW composition is estimated based on the elasticity of food waste generation per capita to GDP per capita (Gómez-Sanabria et al., 2022; Gómez-Sanabria et al., 2018). Table 1 presents the MSW matrix in GAINS.

Table 1. GAINS MSW matrix: MSW streams and technologies

Solid waste management technology	**Municipal solid waste**							
	Food	**Glass**	**Metal**	**Other**	**Paper**	**Plastic**	**Textile**	**Wood**
Open burned	X			X	X	X	X	X
Scattered and/or disposed to water-courses	X	X	X	X	X	X	X	X
Unmanaged solid waste disposal site - low humidity - < 5m deep	X			X	X		X	X
Unmanaged solid waste disposal site - high humidity - > 5m deep	X			X	X		X	X
Compacted landfill	X	X	X	X	X	X	X	X
Covered landfill	X			X	X		X	X
Landfill gas recovery and flaring	X			X	X		X	X
Landfill gas recovery and used	X			X	X		X	X
Incineration (poor air quality controls)	X			X	X	X	X	X
Incineration (high quality air pollution controls - energy recovery)	X			X	X	X	X	X
Anaerobic digestion	X							
Composting	X							
Recycling		X	X		X	X	X	X

Source: Gómez-Sanabria et al., 2018

4.2 Marginal Abatement Cost Curve (MACC)

The marginal abatement cost curve follows the methodology presented in Höglund-Isaksson et al., (2020) and Höglund-Isaksson et al., (2012). Costs for mitigation methane per unit of waste are calculated as the sum of investment costs, labour costs, non-labour operation and maintenance costs, cost-savings due to recovery or saving of electricity, heat or gas, and non-energy cost savings. Unit costs are expressed in constant 2015 Euros per unit of activity and assume a market interest rate of 10 percent. The average cost per unit of reduced emissions is first calculated at technology level by dividing the unit cost with the difference between the technology emission factor and the no control emission factor. For more details refer to Höglund-Isaksson et al., (2020) and Höglund-Isaksson et al., (2012). South African specific costs were not available. Therefore, estimations are carried out based on international information. Detailed input cost parameters are presented in Table 19 in Höglund-Isaksson et al., 2023 (In review).

5. Scenarios

This project looks more closely at the IWMP of provinces in order to understand the current waste management situation and to identify strategies aimed at improving waste management systems, thereby reducing GHG emissions from this sector. The **Business-as-Usual (BAU)** scenario builds on information about current waste generation, waste collection rates and management (disposal, recycling and recovering facilities) by province and by urban and rural areas presented in the South Africa state of waste report (Department of Environmental Affairs 2018). In general, waste collection rates in rural areas are significantly lower compared to urban areas. Therefore, it is assumed that rural areas disposed of part of their waste in unregulated dumpsites. Assumptions on recycling rates by province built upon the statistics presented in Statistics South Africa (2018). The **Upgrade-Landfills (UPLF)** scenario assumes increases in collection rates in urban and rural areas following the mandate "All South Africans live in clean communities with waste services that are well managed and financially sustainable and mainstreaming of waste awareness and a culture of compliance resulting in zero tolerance of pollution, litters and illegal dumping". It assumes that the waste collected is not diverted from landfills, but it integrates the upgrade of landfills to sanitary landfills with energy recovery and use as follows: 10% of all landfills will be upgraded by 2025, 20% by 2030, 30% by 2040, and 40% by 2050. The **Policy (POL)** scenario assumes on top of the Upgrade-Landfills scenario, the targets presented in the National Waste Management Strategy (2020) (Department of Environment, Forestry and Fisheries, 2020). Those include 40% of waste diverted from landfills within 5 years; 55% within 10 years and at least 70% within 15 years, with some years of delay based on past implementation trends. It adopts the same mandate as the UPLF scenario regarding collection rates. The **Maximum Technically Feasible Reduction (MFR)** scenario includes the maximum implementation of a bundle of measures to improve waste management and to curb GHG emissions. The solutions are not independent actions, but rather simultaneous actions that deliver various environmental co-benefits. These solutions include faster increases in waste collection rates, faster diversion of waste from landfills and quicker action to upgrade landfills and close dumpsites.

6. Results

This section presents the projections of waste generation by province and the quantification of methane emissions in the BAU, UPLF, POL and MFR scenarios at provincial level. It is important to notice that the estimates integrate urban and rural areas .

6.1 Waste generation and composition

Estimates of current waste generation, composition and projections up to 2050 (Figure 4) follow the GAINS methodology presented in Gomez Sanabria et al., (2021). Estimates for waste generation in 2020 show that South Africa generated 13.2 Mt (million tons) /year of municipal solid waste. This estimate is comparable to the 12.7 Mt of waste assessed by Polasi et al., (2020). Gauteng, Eastern Cape, and Western Cape account for most of the waste generation driven by population and income growth. By 2050, South Africa is expected to generate 42% more waste than in 2020.

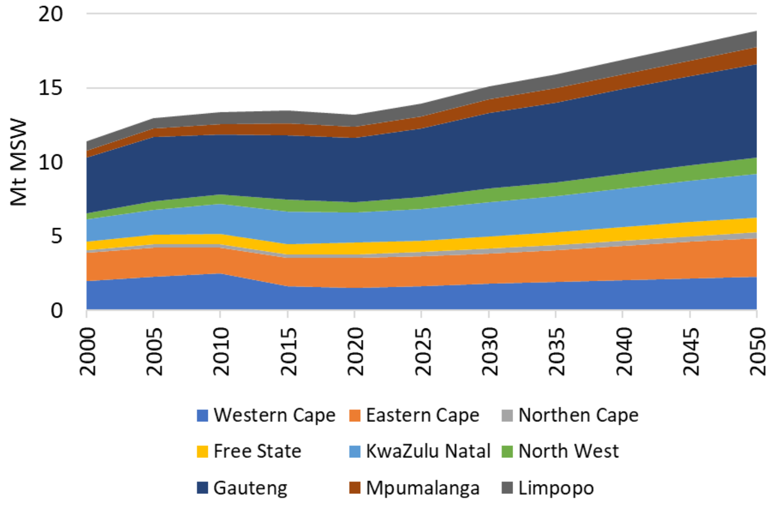
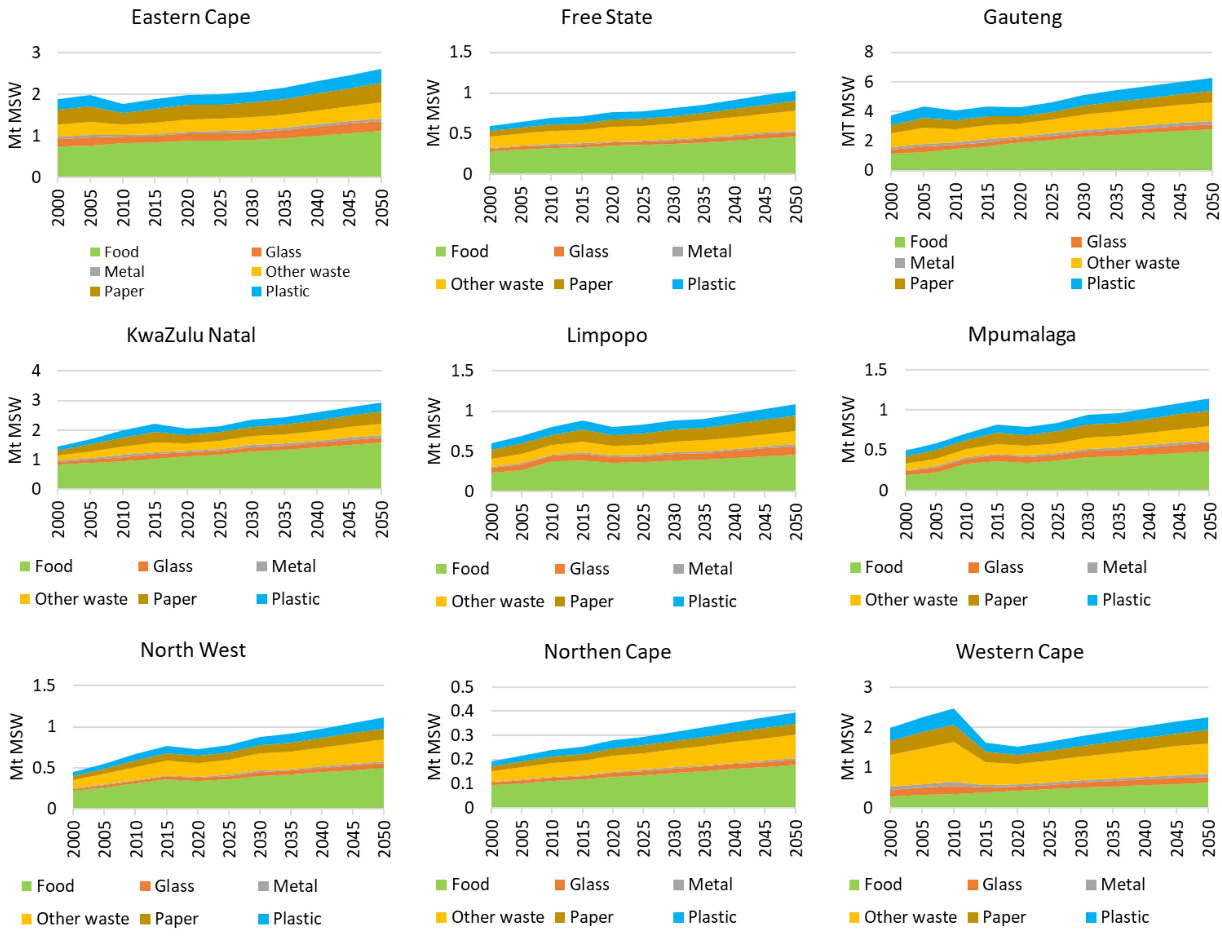


Figure 4. Trends in waste generation in South Africa by province

Waste composition by province assumes similar composition as their corresponding metropolitan cities. This assumption was adopted due to the lack of consistent information at provincial level.



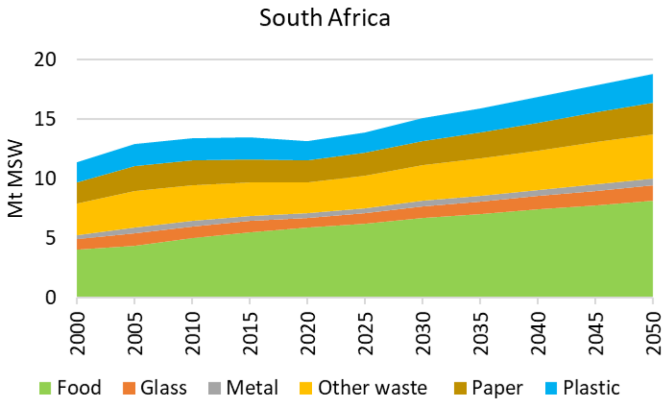


Figure 5. Trends in waste composition at provincial and national level

6.2 Business-as-Usual Scenario

The Business-as-Usual (BAU) scenario estimates MSW collection rates for urban and rural areas (Figure 6) based on the information presented at household level in the in the South Africa state of waste report (Department of Environmental Affairs 2018). It is assumed under this scenario that not additional actions are taken to increase collection rates into the future. Gauteng, Western Cape and KwaZulu Natal show the highest MSW collection rates in both urban and rural areas.

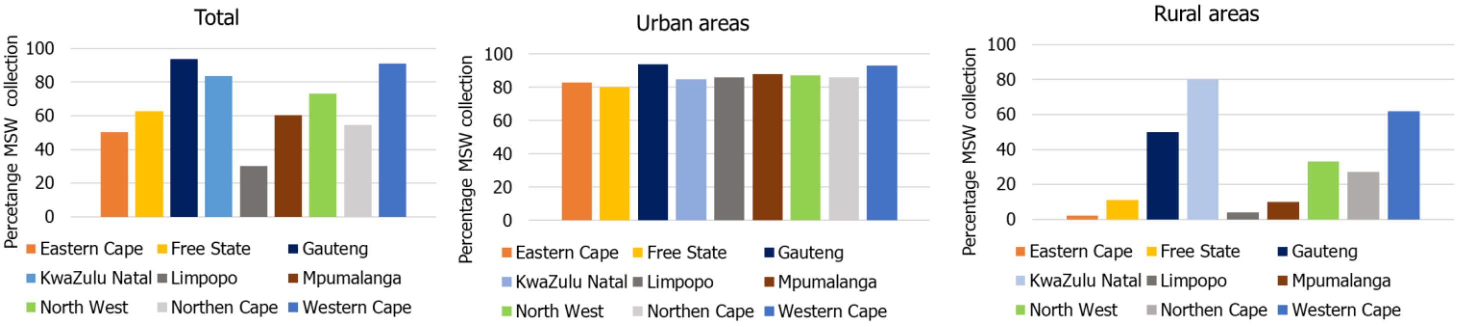


Figure 6. MSW collection rates by province assumed for 2020

In general, the current MSW management shows that the implementation of existing policy is delayed and therefore there is barely any progress towards diverting waste from landfills and closing or upgrading unmanaged/non-sanitary dumpsites (Figure 8). In the BAU scenario, it is estimated that 75% of the organic waste generated ends up in dumpsites/landfills while 25% is uncollected. The uncollected fraction is assumed to open burned or scattered waste. Estimates show that 90% of the landfills are covered and/or compacted and the rest are purely dumpsites. Most of the dumpsites are assumed to be located in rural areas as a consequence of the absence of waste collection services.

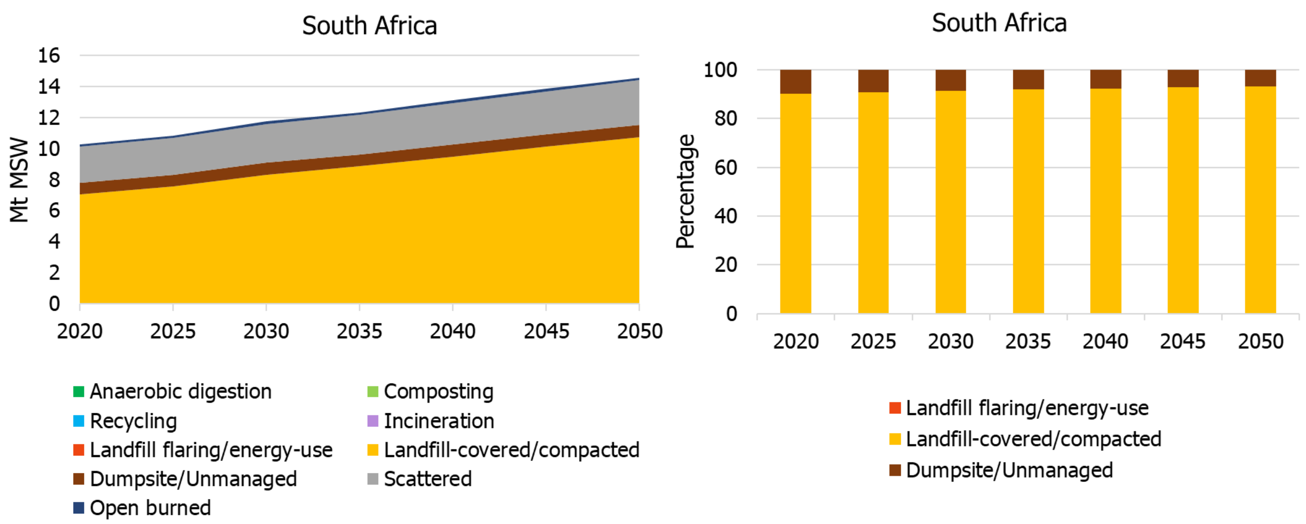


Figure 7. National MSW management (organic fraction) and distribution of solid waste disposal sites in the BAU scenario

If these conditions prevail into the future, methane (CH_4) emissions are expected to increase from 311 kt in 2020 to 524 kt in 2050 (Figure 8) driven by increases in MSW generation. The estimate presented in this study for the year 2020 is 64% times lower than the 870 kt CH_4 reported in the latest South Africa's National GHG Inventory Report - NIR (2022). The differences are related to the waste generation and composition and the type of waste management (i.e., type of landfills assumed). While the NIR (2022) assumes one national waste generation and composition and considers a national generalized trend in terms of waste disposal, the estimates here presented build on more detailed information at metropolitan and provincial level. In both cases, the uncertainty is very high due to the lack of information.

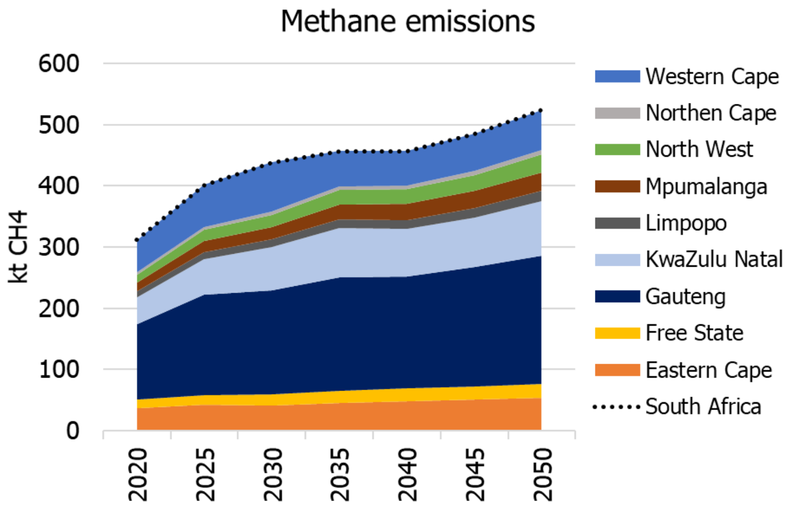


Figure 8. Methane emissions by province in the BAU scenario.

Provincial methane emission estimates show that Gauteng contributes about 40% of the national emissions, followed by Western Cape, KwaZulu Natal and Eastern Cape. It is important to note that even though collection rates are high in these provinces, the collected waste is not handled in the most beneficial way. This finding highlights these provinces as a priority when taken action to mitigate CH_4 emissions from the MSW sector in South Africa.

6.3 Upgrade Landfills Scenario

The Upgrade-Landfills (UPLF) scenario shows that if the waste collection policy mandate is met, MSW collection rates can considerably increase in both, urban and rural areas. Urban areas start from a better baseline (2020) compared to rural areas, therefore towards 2050 collection rates can potentially increase up to 95% - 97%. In rural areas, the expansion of collection service is assumed to be slower due to the fact that the development of infrastructure (e.g., roads) is also required. Provinces already with more than 50% collection in 2020 can potentially collect more than 65% of the MSW by weight in 2050. For other provinces will be more challenging to expand the service (Figure 9).

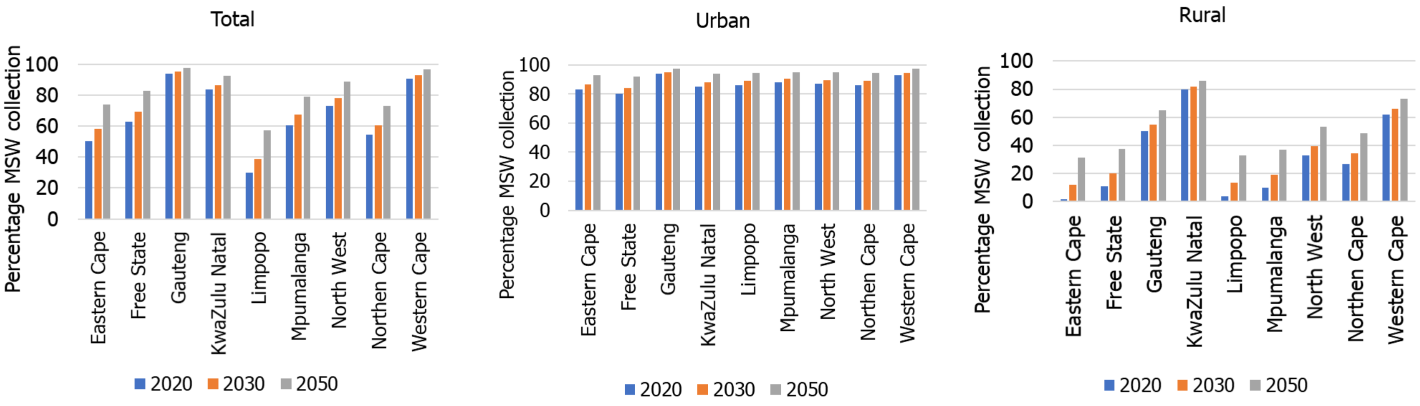


Figure 9. MSW collection rates by province in the UPLF scenario

The increase of waste collection without any waste diversion from landfills results in a rise of 4% and 11% of organic waste ending up in landfills in 2030 and 2050 respectively, compared to the corresponding baseline (BAU). This scenario projects that from the total organic waste ending up in solid waste disposal sites 2% (2Mt) in 2030 and (4%) 5 Mt in 2050 will be landfilled in sites with installed gas recovery and energy use systems. By 2050, the distribution of landfills shows that 40% of the landfills will have installed gas collection and energy recovery systems, however, 50 % will still be covered/compacted and 10% uncontrolled disposal sites (Figure 10).

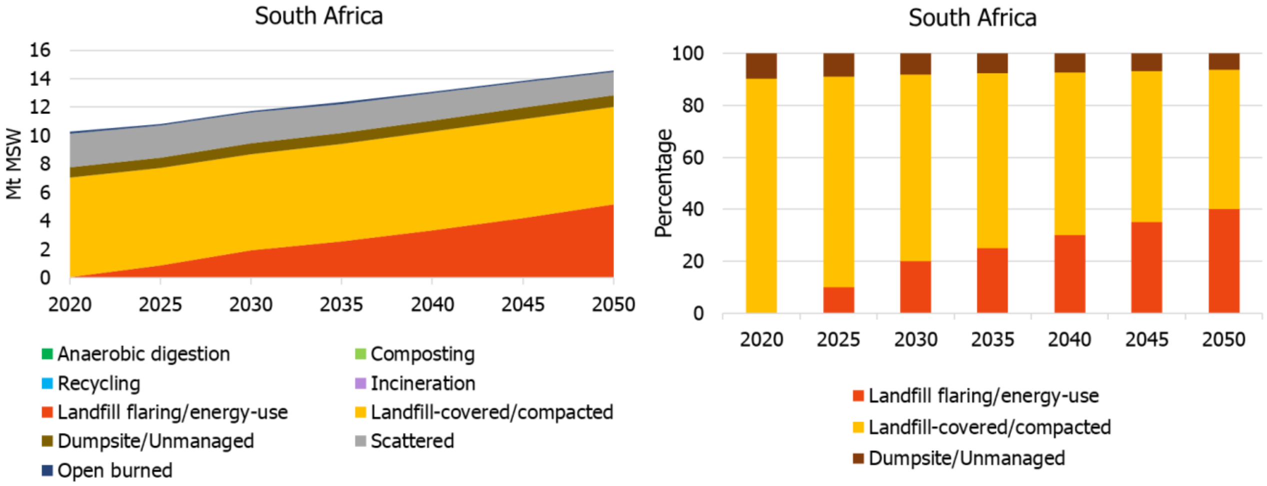


Figure 10. National MSW management (organic fraction) and distribution of solid waste disposal sites in the UPLF scenario

The UPLF scenario shows that just by upgrading landfills and dumpsites (or closing dumpsites) to landfill sites with installations for gas recovery and use, it will be possible to reduce national methane emissions from MSW by 12% in 2030, 17% in 2040 and 22% in 2050 compared to the expected emissions in BAU for the same years (Figure 11). This scenario indicates that although there are reductions in methane emissions compared to BAU, the trend in the future is towards increase. The adoption of the single strategy of upgrading landfills translates into the emission of 10.8 MtCO2e[4] in 2030 from the MSW sector, representing between 3% and 2.5% of the NDC fixed target emission range for 2030 of 350 – 420 MtCO2e (Republic of South Africa, 2021). In 2050, methane emissions from the MSW sector are expected to be 11.42 MtCO2e. At provincial level, Gauteng, KwaZulu Natal and Western Cape will continue emitting the majority of the CH_4 from MSW. These three provinces account for ~70% of the total emissions in the country.

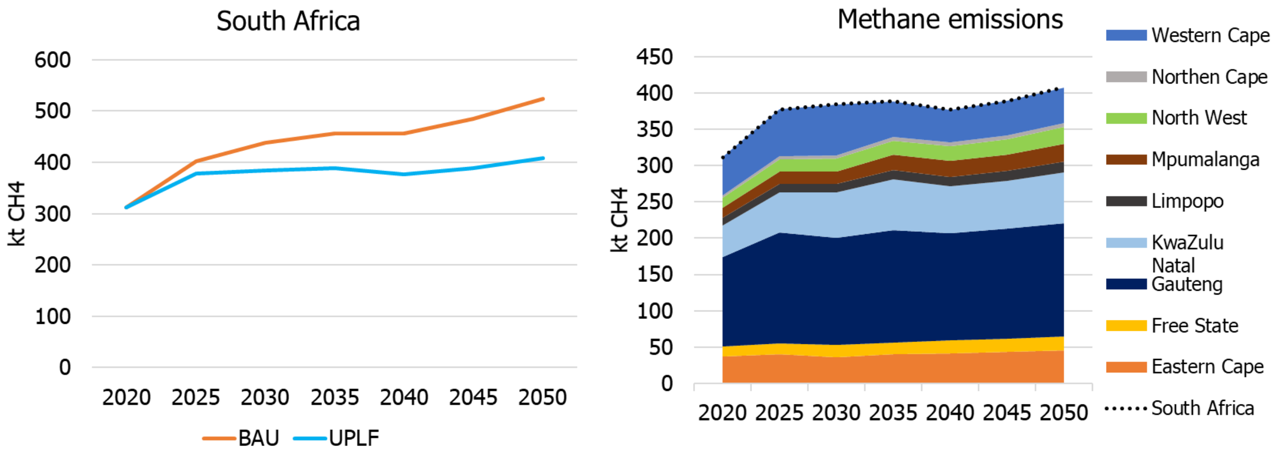


Figure 11. National methane emissions and methane emissions by province in the UPLF scenario

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[4] Using AR5 GWP of CH_4 – $28CO_2e$ (IPCC, 2014)

6.4 Policy Scenario

The Policy (POL) scenario assumes that the waste collection policy mandate is met and adopts the upgrade of landfills in a similar same way as in the UPLF scenario. On top of that, this scenario includes the diversion targets presented in the National Waste Management Strategy (2020) which are 40% of waste diverted from landfills within 5 years; 55% within 10 years and at least 70% within 15 years. This scenario assumes that the adoption of the targets is delayed based on past trends regarding implementation of the strategy. Therefore, South Africa is expected to meet the target of 55% waste diversion from landfills by 2050.

The POL scenario shows that it will be possible to avoid the landfilling of 2.8 Mt of organic waste by 2030, which is 30% less organic waste compared to the UPLF scenario in the same year. By 2050, it will be feasible to divert 6.6 Mt of organic waste from landfills which is about 50% of the total organic waste collected and 52% less compared to organic waste landfilled in the UPLF scenario in the same year. The diversion of organic waste is the result of increases in composting of food and garden waste and recycling of other organic materials (e.g., paper waste). The POL scenario shows that it will be possible to transition from unmanaged sites to managed sites, first into controlled landfills and towards 2050 more engineered sites with gas flaring or with installations for gas recovery and use as source of energy. By 2050, it is expected that 60% of the fraction of organic waste that is not yet diverted from landfills will be disposed of in landfills with gas flaring/recovery and use and the rest (40%) will end up in controlled covered/compacted landfills (Figure 12).

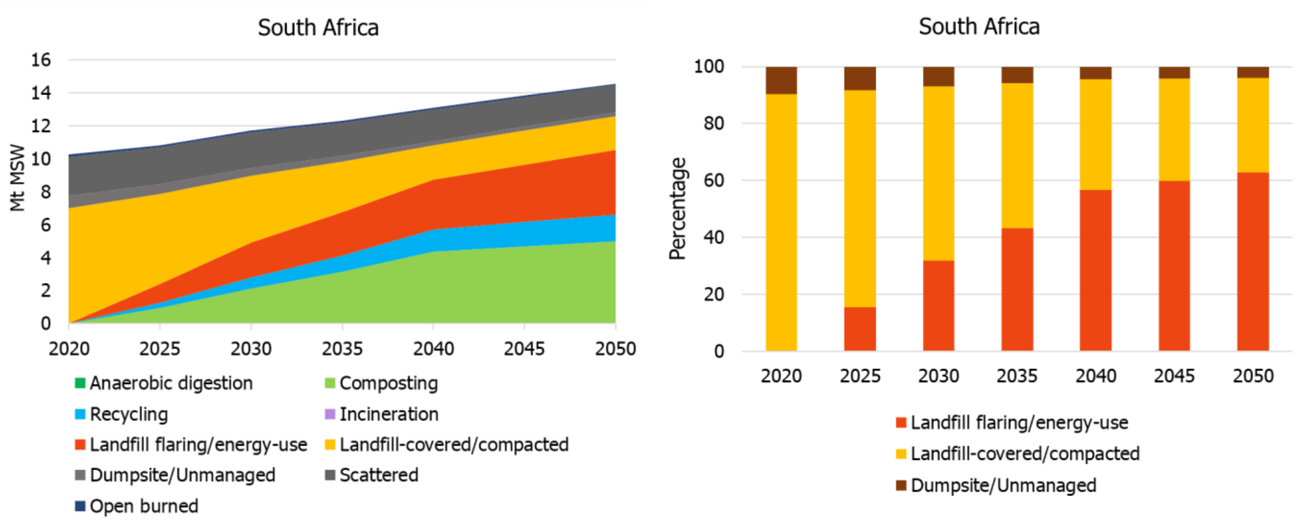

Figure 12. National MSW management (organic fraction) and distribution of solid waste disposal sites in the POL scenario

The POL scenario shows that the adoption of the strategies transitioning from unmanaged/uncontrolled solid waste disposal sites to more engineered sites with installations for gas recovery and use as source of energy in combination with targets aiming at diverting organic waste from landfills will result in a reduction of 11%, 31% and 58% of CH_4 emissions in 2030, 2040 and 2050 compared to BAU, respectively. Compared to the UPLF scenario, no additional emissions reduction is expected in the POL scenario in 2030, 17% in emissions reduction is expected in 2040 and 47% in 2050 (Figure 13). This translates into the emission of 10.8 $MtCO2e$[5] in 2030 from the MSW sector (which is similar to the UPLF), representing between 3% and 2% of the NDC fixed target emission range for 2030 of 350 – 420 MtCO2e (Republic of South Africa, 2021). The MSW sector is expected to emit 6.1 Mt CO2e in 2050 in the POL scenario.

At provincial level, the majority of the CH_4 emission reductions in 2030 are expected in Gauteng and Western Cape, with 12% and 10% compared to the corresponding BAU. Towards 2050, Gauteng, Western cape and KwaZulu Natal will reduce their emissions by about 50% compared to the BAU scenario. All other provinces will reduce their emission by about 35%. However, Gauteng and KwaZulu Natal will still account for 50% of the expected CH_4 emissions from MSW in 2050 in this scenario.

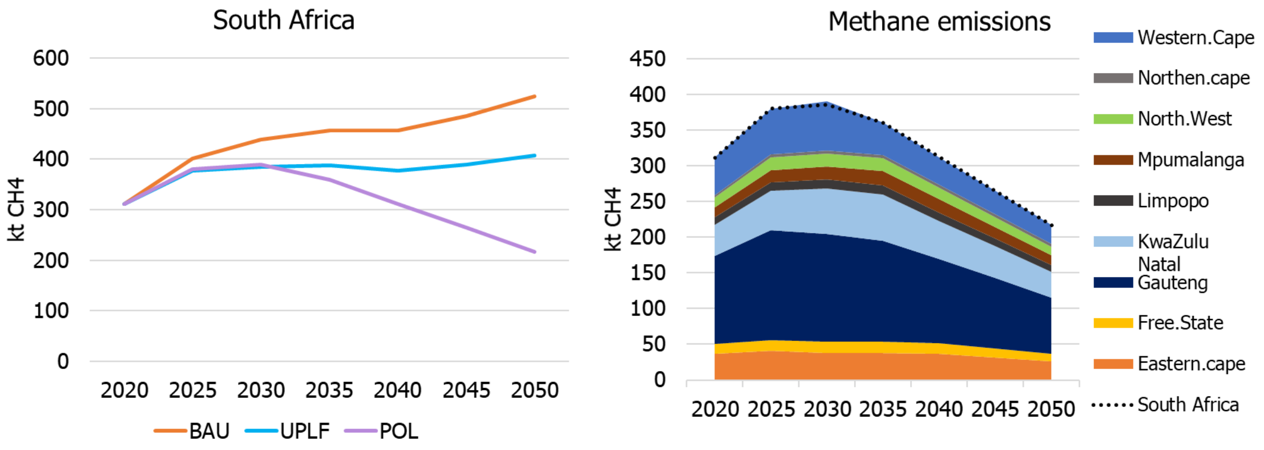

Figure 13. National methane emissions by scenario and methane emissions by province in the POL scenario

6.5 Maximum Technically Feasible Reduction (MFR)

The MFR scenario shows that there are actions that can be additionally taken to reach the fully implementation of a national circular MSW management system. This means that a first priority is given to technologies that circulate materials, thereafter to technologies that recover energy, and only as a last resort to well managed landfills. The following maximum recycling potentials of waste streams are applied: 90% of municipal paper and 100% of food waste can be source separated and treated in composting/anaerobic digesters with biogas recovery. In addition, it assumes maximum recycling rates for inorganic materials such as 80% of plastic and glass and 90% for metal waste (Gómez-Sanabria et al., 2022).

Under this scenario it will be possible to reach ~100% MSW collection (source-separated) rates already by 2030, in both urban and rural areas. Figure 14 shows that to move from the POL scenario to the MFR scenario in urban areas requires an average increase in collection of 15%. However, in rural areas a substantial effort

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[5] Using AR5 GWP of CH_4 – $28CO_2e$ (IPCC, 2014)

will be needed to reach the 100% collection in 2030. It is important to note that most of the MSW generation happens in urban areas and therefore is relevant to capture the maximum MSW in cities.

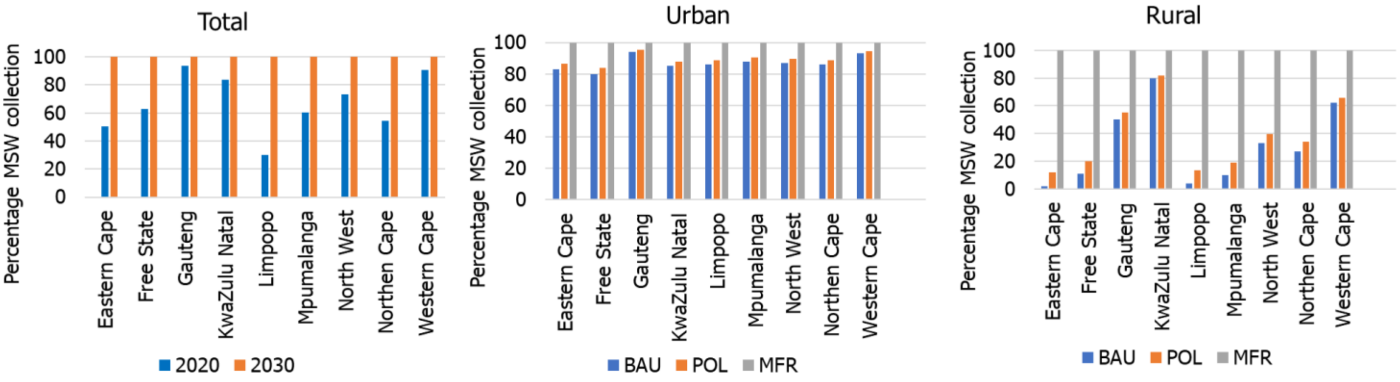

Figure 14. MSW collection rates by province in 2030

Under the MFR scenario will be possible to avoid the landfilling of 7 Mt in 2030 and 14.5 Mt of organic waste in 2050. This translates into the diversion of organic waste from landfills of additional 2 Mt compared to POL and 2.7 Mt compared to BAU in 2030. It is expected that the landfilling of MSW will be faced out by 2045. However, existing landfills will need to be appropriate managed for at least 30 years after its closure. It is expected that all unmanaged or uncontrolled disposal sites are upgraded with gas recovery and energy use installations by 2045. The MFR assumes that food and garden waste will be managed by combining composting and/or anaerobic digestion and faster increases of recycling of other organic materials compared to POL (e.g., paper waste) (Figure 15).

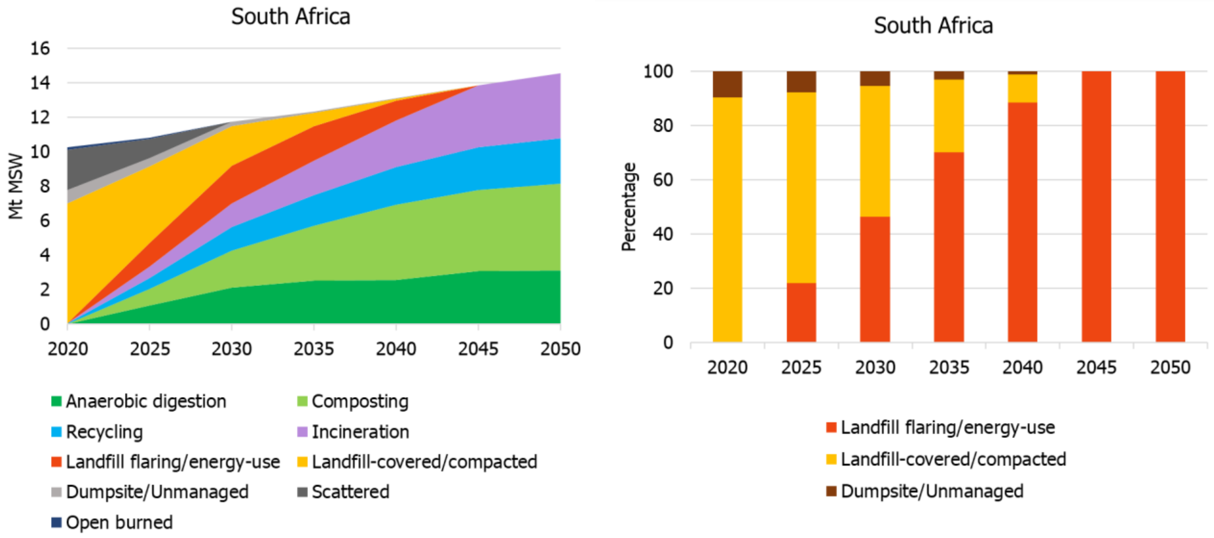

Figure 15. National MSW management (organic fraction) and distribution of solid waste disposal sites in the MFR scenario

The adoption of these strategies will result in a reduction of 20% and 73% of CH_4 emissions in 2030 and 2050 compared to BAU, respectively. Compared to UPLF, these strategies will reduce 9% and 67% of CH_4 emissions in 2030 and 2050, correspondingly and compared to POL, these strategies will reduce 9% and 56% of CH$_4$ emissions in 2030 and 2050. In the NDC context, this translates into similar emissions (10 MtCO2e[6]) compared to UPLF and POL in 2030 from the MSW sector, representing between 3% and 2% of the NDC fixed target emission range for 2030 of 350 – 420 MtCO2e (Republic of South Africa, 2021). In 2050, the MSW sector is expected to emit 2.7 MtCO2e in the MFR scenario, which is 3.5 MtCO2e less than in POL, 8.8 MtCO2e less than UPLF and 9.5 MtCO2e less than BAU (Figure 16). The comparison of CH$_4$ emissions between scenarios highlights that just by upgrading landfills without any waste diversion is not enough to bend the curve. The combination of various strategies is required to reach significant CH$_4$ reductions over time. If implemented, the policies related to waste management will have some success in reducing CH$_4$, however, there is a further reduction potential by implementing more ambitious policies in the waste sector.

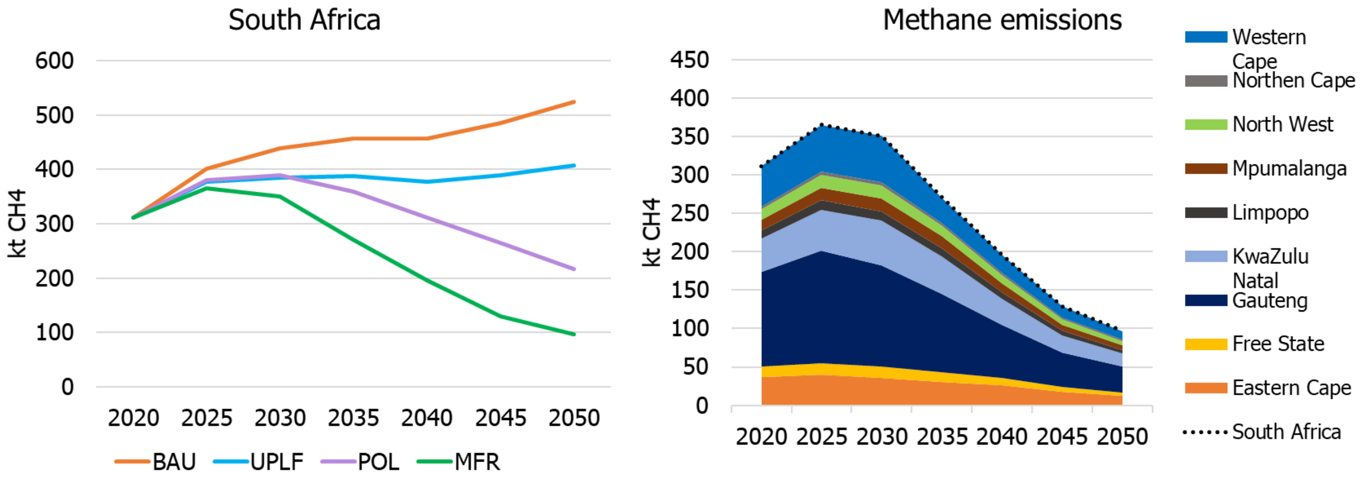

Figure 16. National methane emissions by scenario and methane emissions by province in the MFR scenario

At provincial level, the MFR shows that by the implementation of more ambitious policies, provinces will managed to achieve faster CH$_4$ emission reductions between 2030 and 2050. Through the implementation of these actions, Western Cape and Gauteng will be able to reduce 80% the emissions in 2050 compred to BAU, respectevely.

6.6 Marginal abatement cost curve (MACC)

The key assumptions used to assess the abatement potential of each mitigation option is given Section 4.2. South African specific costs were not available. Therefore, estimations are carried out based on international information. The Marginal abatement cost curve (MACC) links the additional cost of abating an extra unit of methane to a related abatement potential in a given year. An opportunity cost approach is used, where the additional cost of moving to a higher policy ambition level is estimated in comparison to the baseline (BAU). Most of the waste in South Africa is assumed to be disposed of in unmanaged solid waste disposal sites. The

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[6] Using AR5 GWP of CH$_4$ – 28CO$_2$e (IPCC, 2014)

MACC is calculated for each one of the scenarios (BAU, UPLD, POL and MFR) for the years 2030, 2040 and 2050. Unit costs are expressed in constant 2015 Euros per unit of activity and a market interest rate of 10 percent is assumed for fixed investments. The value of electricity generation, biogas generation, marketing of compost and recyclables is included in the accounting as savings (Höglund-Isaksson, 2012; Höglund-Isaksson et al., 2020). The maximum feasible reduction of CH_4 emissions in the waste sector is modelled as an "optimal" waste treatment path as defined by the EU waste hierarchy (European Parliament and European Council, 2008; The European Parliament and of the Council, 2023). In an "optimal" case, all waste is source separated and treated for recycling or energy recovery. Treatment of biodegradable waste for energy recovery is preferred to landfill disposal with gas recovery (Höglund-Isaksson, 2012; Höglund-Isaksson et al., 2020).

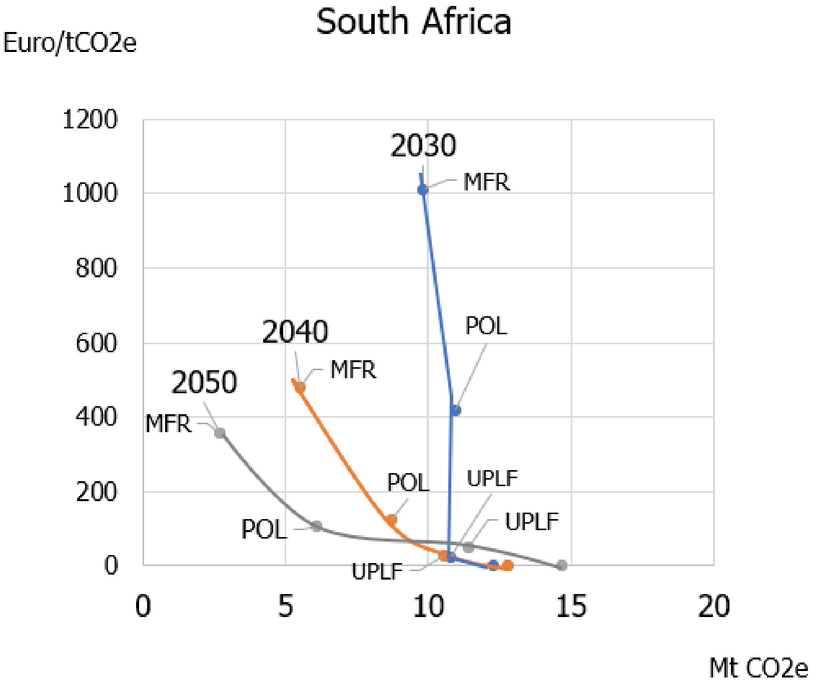

Figure 17. Marginal Abatement Cost Curve (MACC) for the waste sector in South Africa

Figure 17 shows that the MACC in 2030 the methane reduction potential from implementing the UPLF scenario results is rather limited with a reduction of 1.5 MtCO2e at an associated cost of 23 Euro/tonCO2e. The adoption of the POL scenario results in an abatement of 1.4 MtCO2e with associated cost of 420 Euro/tonCO2e. This relatively high cost compared to UPLF is associated to the cost of installing new capacity to treat source-separated waste in order to meet the required political targets of landfill waste diversion. The MFR has the potential to reduce 2.5 MtCO2e with associated cost of 1010 Euro/tonCO2e. This scenario assumes that the adoption of technology to divert waste from landfills is faster compared to POL and therefore the associated cost is higher. The limitation of the abatement potential in 2030 comes from the fact that CH_4 emissions are released from waste landfilled in the past.

By 2040, the reduction potential of the UPLF scenario is 2.2 MtCO2e with associated cost of 30 Euro/tonCO2e. The POL scenario reduces 4.1 MtCO2e at a cost of 124 Euro/tonCO2e. The MFR has the potential to reduce 7.3 MtCO2e with associated cost of 478 Euro/tonCO2e. By 2050, the adoption of the UPLF scenario results in a reduction of 3.2 MtCO2e at a cost of 51 Euro/tonCO2e. POL and MFR scenarios have the potential to reduce

8.6 MtCO2e and 12 MtCO2e at a marginal abatement cost of 105 Euro/tonCO2e and 359 Euro/tonCO2e, respectively.

In comparison to the other scenarios, the UPLF shows an increase in the marginal cost throughout the years due to the fact that there are increases in waste generation and collection resulting in increases of quantities of waste disposed of in landfills, but not additional savings (i.e., earnings) from alternative treatments (i.e., selling of compost or recyclables). The POL and MFR marginal cost decreases over the years due to the opportunity of selling materials from alternative treatments, namely, recyclables (i.e., paper, plastic, glass, etc.) and biogas from anaerobic digestion, in addition to energy from landfill gas.

7. Key messages

The waste sector in South Africa is estimated to emit 312 kt of CH_4. If current waste management conditions are maintained into the future, it is expected that CH_4 emissions will increase by 68% in 2050 as a result of increased waste generation. This study finds Western Cape and Gauteng provinces to be responsible for about 50% of total methane emissions from the waste sector (MSW) in South Africa.

The comparison of CH_4 emissions between scenarios highlights that just by upgrading landfills (UPLF) without any waste diversion is not enough to bend the curve. The combination of various strategies is required to reach significant CH_4 reductions over time. If implemented, the policies related to waste management are expected to succeed in reducing CH_4 (by 307 kt CH_4 or 8.6 Mt CO_2e in 2050), however, there is a further reduction potential by implementing more ambitious policies in the waste sector (reaching a maximum reduction of 428 kt CH_4 or 12 MtCO_2e in 2050).

The implementation of actions to divert organic waste from landfills through adoption of alternative treatments such as recycling, anaerobic treatment and/or composting, Western Cape and Gauteng are expected able to reduce 80% of the emissions in 2050 compared to BAU, respectively. Because Western Cape and Gauteng provinces account for 50% of the methane reduction potential from waste in South Africa, these two provinces could be prioritized as the main target provinces to abate CH_4 from waste in the country.

The cost associated with emission reductions depends on the level of ambition. The UPLF scenario brings the lowest abatement potential at low cost compared to the Policy (POL) and Maximum technically feasible reduction (MFR) scenarios in which abatement potentials are higher, but marginal abatement costs increase significantly. By 2050, the adoption of the UPLF scenario results in a reduction of 3.2 MtCO2e at a cost of 51 Euro/tonCO2e. POL and MFR scenarios have the potential to reduce 8.6 MtCO2e and 12 MtCO2e at a marginal abatement cost of 105 and 359 Euro/tonCO2e, respectively.

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