POTENTIAL FOR COMBINED BIO-HYDROGEN AND BIO-METHANE PRODUCTION IN SOUTH AFRICAN MUNICIPALITIES

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ABSTRACT

South Africa is experiencing a waste management problem, with sanitary landfills rapidly filling up. Current population growth and rising urbanisation are bound to exacerbate this issue. It is paramount to find alternatives to landfilling to extend the lifespans and reduce the carbon emissions of the waste sector. The national and local governments are setting targets and implementing bans to encourage the diversion of biodegradable waste from landfills, but South Africa lacks alternatives that can fully valorise the economic potential of organic waste, especially at the municipal level. This study aims to identify the gaps and suggest a pathway for implementing a novel technique, double-stage anaerobic digestion (2S-AD), and the potential scaling up to full scale. The WROSE™ model is utilised to assess the viability of 2S-AD in South African municipalities using a series of environmental, techno-economic, social and institutional factors. Several scenarios based on source-separated organic fractions are proposed to prepare the insertion into an Integrated Waste Management Plan and will be further developed in future research.

KEYWORDS

2-stage AD, bio-hydrogen, organic waste, Integrated Waste Management System, WROSE™ model

INTRODUCTION

South Africa has been experiencing steady population growth and a significant internal migration from rural areas to major metropolitan areas (Statistics South Africa, 2022). Municipal Solid Waste (MSW) production is expected to rise by 30% in the 2012-2025 period and even out after 2100 (Oelofse & Nahman, 2019). The improved municipal collection rates in African countries, estimated at 66-75% in 2025, will put municipal waste systems under additional constraints (Gebremedhin et al., 2018).

In South Africa, 76% of the yearly waste production is landfilled (DFFE, 2022). While the most recent State of Waste Report (DEA, 2018) records a national 100% landfilling rate for MSW, such a number is incorrect and needs to be rectified, as confirmed by the 8% diversion rate in the Western Cape Province (DEA&DP, 2021). Moreover, the waste sector accounts for 3.8% of the national greenhouse gas (GHG) emissions (DFFE, 2021), mainly originating from the decomposition of the biodegradable fractions (food and garden waste), which make up 30-60% of MSW (DEA, 2018). The country is experiencing a steady decrease in available landfill airspace and a simultaneous increase in waste-related GHG emissions. Between 2015 and 2017, carbon emissions from waste increased by 4.4%, while the total national GHG emissions lowered by 2.8% in the same timeframe (DFFE, 2021).

Consequently, it is essential to reduce the impact of organic waste management by promoting the circularity of the by-products. South Africa has recently implemented alternative waste treatment methods for putrescible fractions. Composting focuses on stabilising and diverting organic waste to save landfill airspace and prevent leachate production (du Plessis, 2018). A well-known process such as anaerobic digestion, which does not promote circularity when implemented in rural areas using manure and agricultural waste (Trois, 2021), has been successfully producing biogas in South Africa thanks to several industrial-scale plants, allowing the recovery of valuable by-products such as methane and digestate (Dell'Orto & Trois, 2022). In a double-stage anaerobic digestion (2S-AD) system, the possibility of extracting intermediate products such as volatile fatty acids, which can be used to produce bio-plastics (Moodley & Trois, 2022), and hydrogen from the first stage of 2S-AD further enhances the material and energy recovery as an embodiment of the concept of circular economy, given the potential use of hydrogen in industry and transportation (Sharma et al., 2015).

Nonetheless, several gaps must be addressed before implementing double-stage AD in South Africa at a small- and, potentially, full-scale. This paper lays the foundation for assessing the suitability of 2-stage AD in South African municipalities, identifying the drivers and barriers and defining a methodology for the analysis of the new technology using a life cycle assessment tool such as the Waste Resource Optimization and Scenario Evaluation (WROSE) model developed by the SARChI Chair in Waste and Climate Change at UKZN (Trois & Jagath, 2011). This study also proposes new scenarios to be implemented in Integrated Waste Management Plans (IWMPs) at the municipal level by using the case study of the eThekwini Municipality in Durban, South Africa (Dell'Orto & Trois, 2022).

RESEARCH QUESTIONS

This research aims to investigate the following:

- Feasibility of 2-stage AD in South African municipalities
- Suitability of available feedstocks;
- Potential for full-scale implementation of 2S-AD;

- Pathways for insertion into the portfolio of available waste management methods at the municipal level.

METHODOLOGICAL APPROACH

The first steps in assessing the potential for the implementation of 2S-AD in South Africa are the selection of a case study and the identification of the boundary conditions. The eThekwini Metropolitan Municipality in Durban, South Africa, extends for 2,297 km^2, with 68% of the area considered rural, while 32% is urban (eThekwini Municipality, 2016, 2022). The population is estimated at 4,050,968 (eThekwini Municipality, 2022).

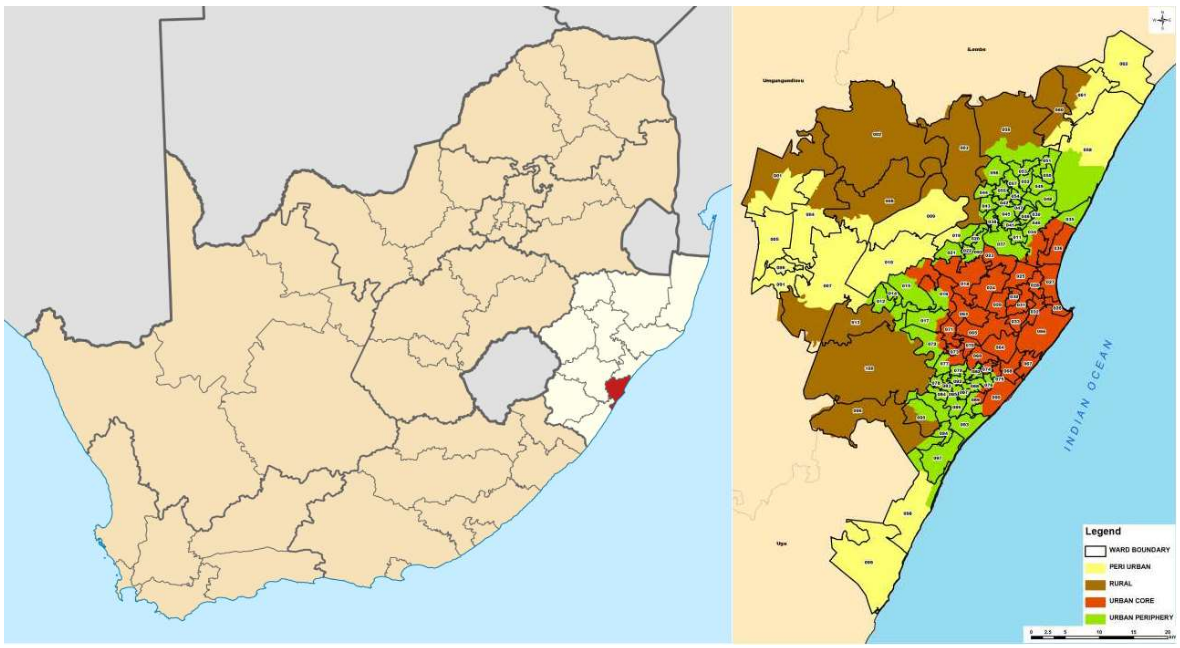

Figure 1: Location and settlement characteristics of wards in eThekwini Metro Municipality. Red (●): urban core; green (●): urban periphery; yellow (●): peri-urban areas; brown (●): rural areas. (Source: elaboration from Wikipedia and eThekwini Municipality Integrated Waste Management Plan 2016-2021)

This research focuses exclusively on the source-separated lignocellulosic fractions from the municipal waste streams in eThekwini. The quantity and quality of the identified organic waste will be checked to define the suitability as feedstocks and used as input, along with the preliminary determination of context-appropriate strategies, for the Waste to Resource Optimization and Scenario Evaluation (WROSE™) model, developed by the SARChI Chair in Waste and Climate Change at UKZN (Trois & Jagath, 2011).

WROSE™ is a powerful tool to assess the impact of implementing alternative treatment methods compared to the current baseline situation. Figure 2 represents the scenarios currently available in the model. Since the separate collection of waste is not fully implemented in any South African municipality, all the scenarios start from unsorted and untreated municipal solid waste.

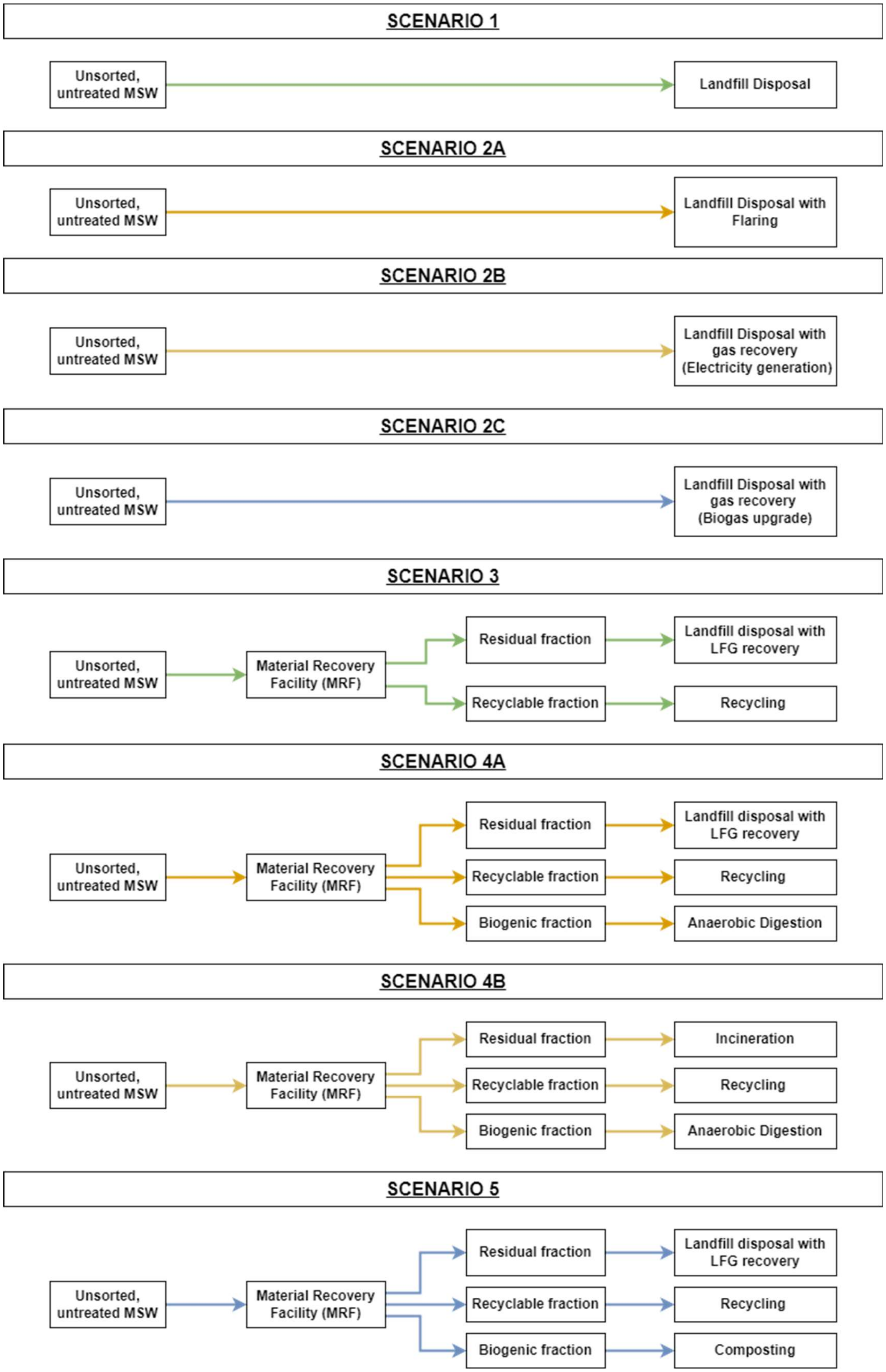

Figure 2: WROSE™ waste management scenarios (source: Dell'Orto & Trois, 2022, adapted and modified from Trois & Jagath, 2011)

The following step is the definition of the baseline scenarios depending on the current waste management practices. Then WROSE™ analyses how the situation would change if alternative treatment methods were implemented, according to a specific set of indicators (Dell'Orto & Trois, 2022; Kissoon & Trois, 2017; Trois & Jagath, 2011):

- Environmental indicators

The reduction in greenhouse gas emissions is assessed by applying IPCC emission factors, per the South African nationally determined contributions, and more peculiar emission factors determined using the WROSE™ model and tailored to the South African context (Friedrich & Trois, 2011, 2013a, 2013b). The diversion of waste from landfills will translate into a reduction in airspace usage and the consequent broadening of the landfill lifespan and monetary savings.

- Techno-economic indicators:

From a technical standpoint, the feasibility of the process is analysed based on the availability of appropriate feedstocks and, in the case of double-stage anaerobic digestion, the bio-hydrogen and bio-methane potentials (BHP and BMP, respectively), the pre-treatments needed by each lignocellulosic feedstock to increase BHP and BMP, and the scaling-up of 2S-AD. The economic feasibility depends on the localisation of the plant, the initial costs of investment, the profitability of by-products in the circular economy markets, and the prospective savings in the short- and long-term.

- Social indicators:

An innovation of WROSE™ is the inclusion of social aspects in the evaluation through the analysis of the job creation potential, represented as tonnes of waste or MW of electricity per job created. Direct and indirect risk factors for public and individual health are also considered in the decisional process, as well as the social perception and involvement in environmental impact assessment processes (including taking part in the source separation of waste).

- Institutional indicators

WROSE™ examines the policy framework to determine if the environmental and energy legislation or the financial and administrative regulation can influence the implementation of a particular scenario.

Based on the priority given to each set of indicators, the model can predict the best waste management strategy or pathway for the introduction into an Integrated Waste Management Plan.

Nevertheless, 2S-AD is not included in the model, and the current scenarios cannot be adapted without changing the feedstock. The degree of impurity of organic waste separated in a material recovery facility (MRF) makes it unsuitable for anaerobic digestion (Cesaro et al., 2016). It is necessary to design new scenarios that use the only source-separated putrescible waste in the South African municipal streams: food waste, garden refuse and the organic fraction of municipal solid waste (OFMSW), as represented in Figure 3 (Dell'Orto & Trois, 2022). However, the recalcitrant nature of lignocellulosic compounds makes it necessary to include a pre-treatment step for the feedstock to maximise the biodegradability and, consequently, the biogas production of 2S-AD (Moodley, 2021). These scenarios will be investigated with the same methodology as above to prepare for their insertion into an Integrated Waste Management Plan.

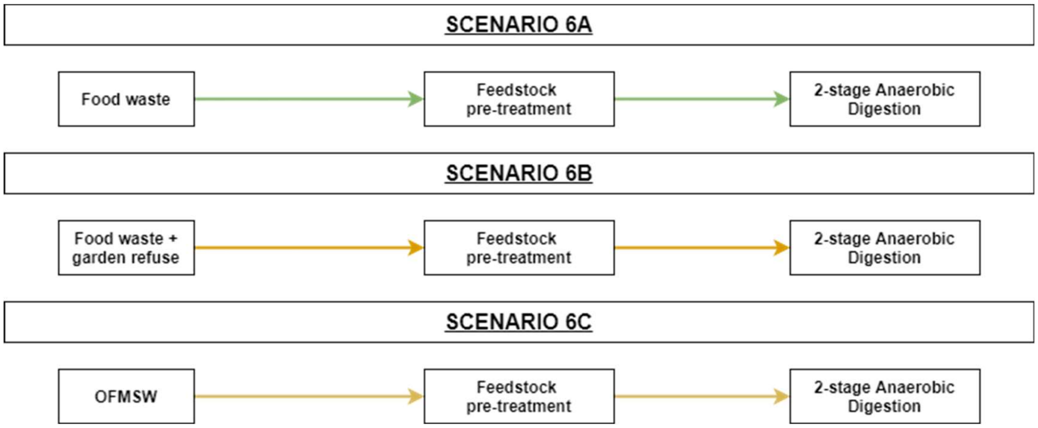

Figure 3: Proposed scenarios for the inclusion in WROSE™ (source: Dell'Orto & Trois, 2022)

PRELIMINARY RESULTS

Waste data analysis suggested that fruit and vegetable waste from fresh produce markets and garden refuse as the only feedstocks suitable for 2S-AD and available in eThekwini. Additionally, energy crops grown on the capping soil of the closed landfills can potentially be valorised through double-stage anaerobic digestion if phytocapping is implemented in the municipal landfill sites. However, the lignocellulosic feedstocks have a recalcitrant nature and a high carbon-to-nitrogen (C/N) ratio, making their mono-digestion more challenging if not preceded by appropriate pre-treatments to reduce the C/N ratio and increase their biodegradability.

A thorough literature review identified the drivers and barriers to the implementation of 2S-AD in South African municipalities. Even though the lack of separate collection systems across the country limits the suitable feedstock to the few clean waste streams, organic waste streams comparable to the ones available in eThekwini have been successfully tested globally in lab-scale 2S-AD (Table 1). Nevertheless, more research needs to be carried out to determine the best conditions and necessary pre-treatments to perform the co-digestion of two solid streams such as food waste and garden refuse, since the majority of the research on double-stage anaerobic co-digestion was conducted using a liquid (e.g., sewage sludge) and a solid waste. Simultaneous treatment of food and lignocellulosic waste would balance the C/N ratio and reduce the total solids percentage of the feedstock, increasing the efficiency of the system and the biogas yields.

Table 1: Municipal-based lignocellulosic waste used as a feedstock in lab-scale 2-stage AD (source: Dell'Orto & Trois, 2022)

Feedstock	Hydrogen Yield	Methane Yield	References
Food waste + garden waste	46.2 ± 0.9 mL H_2 gVS^{-1}	682 mL CH_4 gVS^{-1}	Abreu et al., 2019
Food waste	8.6 ± 4.8 mL H_2 gVS^{-1} d^{-1}	428.3 ± 30.9 mL CH_4 gVS^{-1} d^{-1}	Baldi et al., 2019
Organic fraction municipal solid waste (OFMSW)	29.8 mL H_2 gVS^{-1}	619 mL CH_4 gVS^{-1}	Lavagnolo et al., 2018
Garden waste (grass)	52 mL H_2 $kgVS^{-1}$	517 mL CH_4 $kgVS^{-1}$	Liczbiński & Borowski, 2021
Garden waste (leaves)	23 mL H_2 $kgVS^{-1}$	421 mL CH_4 $kgVS^{-1}$	Liczbiński & Borowski, 2021

On the other hand, the political scenario is currently favourable to implementing alternative treatments for organic waste. The national target for the diversion of organic waste from landfills is 40% by 2025, and the Western Cape province aims to implement a more stringent organics-to-landfill ban by 2027 (Chitaka & Schenck, 2022). Additionally, the Cabinet has extended the Hydrogen Society Roadmap (HSRM) until 2031 to prepare for the transition toward a hydrogen economy. The roadmap should promote new opportunities for secondary materials, which are still limited (Oelofse & Nahman, 2019). Moreover, new technologies are traditionally considered by the public as more expensive than landfilling, thus delaying a more widespread implementation of alternative waste treatment methods.

CONCLUSIONS

Organic waste is commonly disposed into landfills in South Africa. A proper valorisation of biodegradable fractions would reduce the country's carbon footprint and create social and monetary value. Double-stage anaerobic digestion is an alternative treatment method that can potentially lead to the creation of new jobs and the reintroduction of by-products such as bio-hydrogen and bio-methane into a more circular economy. Still, the technology has not yet been applied at full scale and needs to be tuned up before allowing industrial applications. This study explored some of the barriers and presented a pathway toward the insertion of 2S-AD into an Integrated Waste Management System at a municipal level. A series of future scenarios have been proposed and will be investigated using the WROSE™ model to determine the feasibility of 2S-AD in South African municipalities.

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