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# Waste-to-energy: Exploring the roadmap for energy generation from commercial waste in South Africa.

**Article Highlights:**

Research Problem and Questions: The study addresses the barriers to adopting waste-to-energy (WtE) technologies in South Africa, focusing on commercial integration. It seeks to understand the technological, economic, and regulatory challenges hindering WtE adoption.

Methodology: A systematic literature review (SLR) from 2020 to 2023 was conducted to develop the conceptual framework, which was tested using a case study method. The materials for the case study were obtained through qualitative interviews with 15 participants from various sectors across four South African regions.

Findings: The research identifies significant technological, economic, and regulatory obstacles, along with a lack of awareness and social acceptance of WtE. It shows that businesses control waste feedstock but struggle with inadequate legislative support.

Contribution to Practice and Theory: The study proposes an implementation framework to facilitate WtE adoption, with policy recommendations such as taxation and subsidies. It contributes to theory by exploring the complex interactions between technology, economics, regulation, and social acceptance in WtE adoption.

**Article Abstract:**

**Purpose:**
This study aims to investigate the adoption of waste-to-energy (WtE) technologies in South Africa, focusing on identifying the key drivers, barriers, and potential solutions for commercial uptake. The ultimate aim is to propose an implementation framework that promotes renewable energy while reducing landfill reliance.

**Design/methodology/approach**
A systematic literature review (SLR) of papers published between 2020 and 2023 was conducted to identify factors impacting WtE adoption in South Africa. The conceptual model developed from the SLR was tested using a qualitative case study approach. Data was collected through 15 semi-structured interviews with commercial entities and WtE experts from four regions of South Africa.

**Findings**
Anaerobic digestion and pyrolysis are identified as the most suitable waste-to-energy technologies in the South African context. Among the financial challenges of WtE in South Africa, the availability of cheap coal, low landfill tariffs, high capital costs, funding constraints, and regressive economic incentives are critical. The lack of government support, insufficient incentives, regulatory burdens, weak policies and limited innovation capacity are considerable non-financial barriers hindering WtE technologies' growth.

The successful adoption of renewable energy also requires adequate infrastructure, increased sustainability awareness, and technical expertise.

**Research limitations /implications**
While the sample size is diverse and consists of a range of organisations, it may not capture the thoughts and experiences of other SA businesses in their entirety. It is important to note that the lack of existing research on the implementation, benefits, and impacts of WtE technologies limits the authors' ability to interpret and benchmark our findings. Yet, this study contributes by developing an implementation framework to encourage WtE adoption, recommending policy actions such as regressive taxation on fossil fuels and landfills, and promoting renewable energy through subsidies, awareness, and energy credits.

**Practical implications**
This study provides a practical framework for businesses and policymakers to adopt WtE technologies by addressing key barriers. The research suggests that businesses could reduce waste management costs and generate new revenue streams by adopting anaerobic digestion and pyrolysis. Policymakers are encouraged to disincentivize landfills and promote WtE through financial incentives such as subsidies and energy credits. The implementation framework offers clear recommendations for integrating WtE into South Africa's energy and waste management strategies, supporting both sustainability and economic goals.

**Social implications**
The main social contribution is the potential for WtE adoption to improve waste management practices and generate new job opportunities within the renewable energy and waste sectors.

**Originality/value**
This study provides a novel contribution by developing an implementation framework tailored to South Africa's unique regulatory, economic, and social contexts. The research highlights the importance of aligning WtE adoption with sustainability goals, reducing reliance on fossil fuels, and promoting renewable energy. The framework serves as a practical guide for policymakers, businesses, and industry leaders seeking to implement sustainable waste management solutions in South Africa.

**Keywords:** West to Energy (WtE), Landfills, Renewable Energy, Waste Management, Africa.

**Abbreviations**

| | | | |
|---|---|---|---|
| Waste-to-energy | WtE | Systematic literature review | SLR |
| municipal solid waste | MSW | anaerobic digestion | AD |
| South Africa | SA | Renewable Energy Independent Power Producer Procurement Programme | REIPPPP |
| renewable energy | RE | Illustrative quote | IQ |
| Environmental, Social, and Corporate Governance | ESG | independent power purchasers | IPPs |

**Waste-to-energy: Exploring the roadmap for energy generation from commercial waste in South Africa**.

## 1. Introduction

Waste-to-energy (WtE) technologies represent a critical solution in modern waste management strategies (Adeleke et al., 2021). As urban populations continue to grow and the generation of waste increases, the challenge of managing municipal solid waste (MSW) becomes more acute. WtE offers dual benefits: it helps significantly reduce the volume of waste that would otherwise occupy landfills while simultaneously generating energy (Amsterdam & Thopil, 2017; Moodley & Trois, 2022). Similar to other developing economies (Ahmed et al., 2024), South Africa (SA) faces significant waste management and energy supply challenges (Muthambi, 2022), exacerbated by a rapidly growing population and urbanisation. Annually, the country generates approximately 122 million tons of waste, of which only 10% is recycled or recovered, while the vast majority, about 90%, ends up in landfill sites (Stubbs, 2022). SAWIC (2023) states that SA operates over 1200 licensed landfill sites. This situation is compounded by inadequate resources and limited land availability for waste disposal (Chagunda et al., 2023).
Concurrently, SA is grappling with substantial energy deficits. According to the World Bank (2023), 11% of the population lacks access to electricity. Frequent electricity disruptions, known locally as load-shedding, are primarily due to inadequate generation capacity, ageing infrastructure, and ongoing maintenance challenges (Szewczuk, 2015). WtE technologies can provide the generation capacity (estimated as 50,000 megawatts of renewable energy [RE] to the electricity) needed to curb load-shedding (Daw & Gibbs, 2017). Ozonoh et al. (2018) suggested that SA has an abundant source of MSW for WtE, while Govender et al. (2019) indicated that a WtE technology like biogas could generate 2.5 GW of clean electricity. Combustible waste classes (i.e., plastic, paper, cardboard, wood, organic waste) contain properties and compositions that are ideal waste substrates for WtE technologies (Zeeshan et al., 2021).

South African businesses are targeting zero waste-to-landfill by 2030, driven by Environmental, Social, and Corporate Governance (ESG) goals to reduce their environmental impact and carbon footprint (ABinBev, 2024). WtE technologies can play an important role in this initiative as they address environmental and health issues by capturing methane from waste (Alao, 2022). The energy produced through WtE not only provides additional income by enabling businesses to sell back to the national grid but also creates employment opportunities (Andreoni et al., 2022; Daw & Gibbs, 2017). Additionally, WtE can reduce reliance on traditional energy sources, leading to cost savings and enhancing a business's green credentials to attract both customers and investors (Mbazima et al., 2022).

Despite the potential of WtE technologies to significantly contribute to sustainable waste management and energy generation in SA, commercial adoption of WtE is negligible. WtE is the lowest form of energy generation, accounting for only 0.2 % of renewable energy (RE) in SA, as fossil fuels (i.e., coal) dominate the market (Andreoni et al., 2022) despite the presence of necessary conditions (Govender et al., 2019). Our systematic literature review (SLR) indicates that more extensive research on the causes of the slow adoption of WtE is needed. While existing studies (e.g., Amsterdam & Thopil, 2017; Ozonoh et al.,2018) have highlighted the environmental and economic benefits of WtE, there is a notable lack of detailed analysis on the integration of WtE technologies with SA's unique regulatory, economic, and social contexts (Daw & Gibbs, 2017). Specifically, the long-term impacts of WtE on national energy policies (Mbazima et al., 2022), the practical challenges related to commercial adoption (Lutge & Standish, 2013), lack of government support (Cai et al., 2023), policy incentive (Becker & Fischer, 2013) and limited awareness of the potential benefits (Ozonoh et al., 2017) among local businesses. Furthermore, there is insufficient exploration into the financial models (Chagunda et al.,2023) that could make WtE ventures more viable and attractive to potential investors.

This research aims to address a few of these gaps (i.e., drivers and barriers, government's role and policy incentives, availability and accessibility of waste feedstock and financial models) by providing insights into the current state of WtE technologies available in SA and understanding the sustainability drivers of SA Businesses. The main objective is to develop a framework for WtE adoption in SA. Therefore, we address the following research questions (RQ's):

RQ1. How do South African business's sustainability goals drive the decision-making process for WtE technologies?

RQ2. What are the challenges experienced by South African businesses in adopting WtE technologies?

RQ3. How could South African businesses overcome these challenges?

We assess SA businesses' appetite for WtE technologies and identify and understand the barriers, challenges, and opportunities for WtE adoption. It contributes to the academic discourse on WtE by integrating a multidimensional analysis encompassing SA's unique regulatory, economic, and social landscapes. Moreover, the conceptual model (Figure 1) derived from the SLR and a WtE framework developed from empirical analysis (Figure 2) provides a structured approach to understanding the interplay between regulatory, economic, and technological dimensions of WtE adoption. The conceptual model will support future research in these areas, while the proposed adoption framework offers a practical guide to optimise WtE systems in SA.

This research informs policymakers and business leaders on strategic directions for WtE adoption by assessing businesses' readiness and appetite for WtE solutions, identifying barriers, and highlighting opportunities. Furthermore, it investigates various waste feedstocks and their potential for energy generation, providing a pragmatic approach to enhancing WtE viability.

This paper conducts an SLR to identify factors influencing WtE adoption in section 2. Section 3 presents the rationale for our methodology. The analysis of qualitative data is presented in section 4. Section 5 presents the broader meanings of our findings, while section 6 concludes the paper.

## 2. WtE in South Africa: A systematic review of literature

An SLR is conducted to explore the factors affecting the adoption of WtE technologies among SA businesses. We captured studies published between 2003 and 2023. The time frame of publication is critical since, during these two decades, WtE captured wider attention and acceptance as a sustainable way of waste management and energy generation in Africa (Amo-Asamoah et al., 2020; Kwakwa, 2021) and the developing world (Ahmed et al., 2024; Elmassah, 2024). Using a PRISMA method, we searched the Scopus database and applied a rigorous screening process (e.g., literature published in the Chartered Association of Business Schools [CABS] and Australian Business Deans Council [ABDC] Journal quality list) to identify 30 relevant literatures (Saha et al., 2024 a). The details of the SLR methods are available in Appendix A. A summary of the findings is listed below (Table 1).

Table 1: WtE research focusing on South Africa

| | **Author(s)** | **Key Focus Area** | **Scope** | **Methodology** | **Main findings** |
|---|---|---|---|---|---|
| **1** | Adeleke et al. (2021) | Sustainable utilisation of energy from waste | SA | Literature Review | The potential of energy from waste as a resource and its energy potential. |
| **2** | Andreoni et al. (2022) | Challenges and opportunities for a green economy | SA | Case Study | Policy instruments driving energy transition and support for new green energy paradigm. |
| **3** | Becker & Fischer (2013) | Incentive schemes for RE generation | China, India, SA | Case Study | Promoting RE electricity generation and assessment of the effectiveness of policy instruments. |
| **4** | Cai et al. (2023) | CO2 emissions in BRICS countries | BRICS countries | Quantitative Literature Review | Need for policy change to reduce CO2 emissions. |
| **5** | Chitaka & Schenck (2022) | Organic waste value chain in SA | SA | Case Study | Understanding of SA's organic waste value chain |
| **6** | Daw & Gibbs (2017) | Impact of IPPs in SA | Electricity crisis in SA | Literature Review | IPPs' role in addressing electricity shortage |
| **7** | Dippenaar (2018) | Examining tax incentives for SA businesses | SA businesses | Literature Review - Mixed Methods | Role of tax incentives in RE decision-making. |

| | Author(s) | Key Focus Area | Scope | Methodology | Main findings |
|---|---|---|---|---|---|
| **8** | Godfrey & Oelofse (2017) | Shifts in waste management in SA | SA | Review Article | Circular economy transition, economic, and environmental benefits of WtE. |
| **9** | Govender et al. (2019) | Biogas to Electricity | SA | Quantitative Literature Review | Investment limitations in biogas projects. |
| **10** | Khan et al. (2015) | Fruit waste as a feedstock for RE in SA | SA | Review Article | Utilising fruit waste for RE and potential use of organic waste. |
| **11** | Lutge & Standish (2013) | Pig and dairy manure for electricity generation | Pig and dairy farms in SA | Quantitative Literature Review | Financial viability of manure for energy generation. |
| **12** | Mashoko et al. (2013) | Utilizing byproduct bagasse for electricity | SA sugar industry | Case Study | Potential to generate 960MW of energy per annum from bagasse. |
| **13** | Matsuo & Schmidt (2019) | Green environmental policies | Mexico and SA | Case Study | Designing green policies for local RE value chains. |
| **14** | Moodley & Trois (2022) | Using organic waste for electricity generation | SA | Literature Review | Organic waste in bio-refineries has the potential to produce three products for energy. |
| **15** | Mugido et al. (2014) | Using alien plant species for energy generation | SA | Quantitative Literature Review | Biomass energy plant's financial viability. |
| **16** | Naicker & Thopil (2019) | Suitable RE technologies for SA | SA | Literature Review | Feasibility of different RETs and identification of key barriers to technology adoption. |
| **17** | Ozonoh et al. (2018) | Determining attractive feedstock for RE | SA | Case Study | Producing clean energy with reduced emissions. |
| **18** | Pegels (2010) | Barriers to RE investments in SA | SA economy | Literature Review | Factors supporting RE deployment policies. |
| **19** | Rennkamp (2019) | SA climate policy | SA | Case Study | Addressing public policy problems and policy innovation elements. |
| **20** | Russo & Blottnitz (2017) | Potential of biogas for electricity generation | SA beef and pork value chain | Literature Review | AD to produce biogas for energy self-sufficiency. |
| **21** | Schmidt et al. (2017) | Barriers of Fossil Fuel Subsidies | SA and Tunisia | Case Study | Policy designs to strengthen RE and reduce fossil fuel subsidies. |
| **22** | Sebitosi & Pillay (2008 a) | RE and environmental policy in SA | SA | Discussion Paper | Energy planning for RE and environmental sustainability implementation. |

| | Author(s) | Key Focus Area | Scope | Methodology | Main findings |
|---|---|---|---|---|---|
| **23** | Sebitosi & Pillay (2008 b) | Barriers to RE industry development | SA | Literature Review | Viable RE industry options and barriers to the sustainable RE industry. |
| **24** | Taghizadeh-Hesary (2022) | Driving energy efficiency in Africa | Africa | Case Study | Policy reform and public-private partnerships for energy efficiency. |
| **25** | Todd & McCauley (2021) | Policy barriers to RE transition | SA | Case Study | Policy reform for climate change policy adjustments for RE transition. |
| **26** | Tsikata & Sebitosi (2010) | Challenges of moving away from coal | SA | Case Study | RE, as an alternative to coal, addresses electricity supply challenges. |
| **27** | Udeagha & Muchapondwa (2023) | Green innovation for environmental sustainability | SA | Case Study | Economic policy uncertainty and green innovation for economic growth. |
| **28** | Ugwu & Enweremadu (2019) | Utilizing okra waste for biogas | N/A | Experimental Study | Viable feedstock for biogas production. |
| **29** | Winkler (2005) | Policy options for RE. | SA | Policy analysis | Several policy reforms created a market for green electricity. Investment in RE could reduce negative economic, social, and environmental impacts. |
| **30** | Winkler et al. (2009) | RE technology learning. | SA | Case study | Scenario-based modelling using. |

Source(s): Authors' elaboration of reviewed literature

The focus ranged from the availability of waste feedstock to legislative policies (Table 2). Economic viability and the cost of WtE remain the primary focus (25) of the literature, while technology, social awareness, and regulatory issues consistently appear as critical factors of WtE adoption in SA.

Table 2: Primary focus of reviewed articles

| Focus area | Technology factors | Economic factors | Regulatory factors | Social factors |
|---|---|---|---|---|
| Waste raw materials (9) | 4 | 8 | 2 | 6 |
| Funding/financing of WTE technologies (3) | 3 | 3 | 2 | 2 |
| Barriers to SA businesses (5) | 5 | 5 | 3 | 3 |
| SA legislative policies (13) | 9 | 9 | 8 | 9 |
| Total (30) | 21 | 25 | 15 | 20 |

Source(s): Authors' elaboration of reviewed literature

**Available technologies and feedstock for WtE**

WtE technologies include anaerobic digestion (AD), incineration, pyrolysis, gasification, and biofuels. Each technology has unique advantages for waste management and energy generation in SA but must overcome significant economic and operational barriers to be effectively implemented (Govender et al., 2019; Zeeshan et al., 2021). AD can use diverse organic waste streams and produce clean energy, but it requires a high volume of feedstock and continuous monitoring (Russon & Blottnitz, 2017). Incineration handles most MSW and generates revenue, but it is costly and can pose environmental risks if emissions are not controlled (Ozonoh et al., 2018). On the other hand, pyrolysis adapts to different feedstocks and integrates into other power systems, yet it demands significant energy, capital, and skilled personnel (Mabalane et al., 2021). Gasification uses invasive plants and enhances energy security by capturing carbon dioxide, but it is expensive to implement and needs specific feedstocks and skilled operators. However, biofuels offer a lower carbon footprint and utilise various biological materials. Obtaining and combining the correct feedstock ratio is crucial for WtE conversion to improve efficiency and reduce emissions. Schmidt et al. (2017) explained that plant efficiency influences the feasibility and cost-effectiveness of WtE technologies.

**Accessibility and availability of waste feedstock**

The accessibility and availability of waste feedstock are critical for these WtE technologies. For WtE generation, the moisture content of waste feedstock needs to be minimal, and waste needs to be constantly fed into the plants (Govender et al., 2019). The volume of waste feedstock affects not only the energy generation capacity but also the plant's economic viability. Laboratory tests revealed organic waste streams, such as plant waste (Mugido et al., 2014) and fruit waste (Khan et al., 2015), as potential feedstock; their scalability is yet to be proven (Ugwu & Enweremadu, 2019). Botha and Blotnitz (2006) and Khan et al. (2015) indicate that fruit and plant waste (i.e., bagasse) can be converted into biofuel due to their high sugar concentrations. Mashoko et al. (2013) estimated that 27.9 tons of bagasse can produce 150 kWh of electricity.

Manure is a suitable substrate for biogas due to its high energy conversion (Russo & Blottnitz, 2017). Lutge and Standish (2013) reported that using pig manure to generate energy for farms reduces 1.56 metric tons of carbon emissions per annum. The gross energy produced from biogas utilising abattoir waste and manure is about 725 GWh/year.

Other waste streams, e.g., packaging waste, the second-highest waste stream in SA, can be used as a substrate in a biorefinery (Moodley & Trois, 2022). Although plastic is not organic, the oil extracted during pyrolysis or gasification can be turned into biofuel, chemicals, or alternate fuel supplements

(Nkosi et al., 2020). However, a primary drawback is that plastic needs combustion to be broken down, which could result in using some form of fossil fuel, albeit at lower volumes.

Chagunda et al. (2023) suggest that competition can arise for waste feedstock between WtE, recycling, composting, animal feed, and landfilling sites, affecting volume and availability. In the following sections, we discuss the financial and non-financial causes of the slow and negligible adoption of WtEs in SA (Table 3).

**Funding constraints and public-private partnership for WtE**

WtE plants and projects require high investments (Winkler et al., 2009). WtE plants work on different conversion processes, such as combustion, bacteria, and gas-to-heat. Installing these plants with the correct environmental and safety requirements requires high expenditure (Taghizadeh-Hesary et al., 2022). Owing to the amount of capital needed, the WtE industry in SA is in its infancy, as funding and financing options are limited (Cai et al., 2023).

Table 3. Factors affecting the WtE adoption in SA

| **Waste feedstock** | **Financial Challenges** | | **Regulatory** |
|---|---|---|---|
| Composition | Cost-effectiveness | Access to financing | Policies |
| Calorific values | Return on investment | Lack of awareness and expertise | Availability and reliability of WtE technologies |
| Availability | Government grants and subsidies | Regulations | Tax credits, subsidies, grants |
| Access | Limited access to capital | Available technology | Carbon credits and power purchase agreements |
| Technology | Long-term cost savings | Government influence | Environmental impact |
| Competition for feedstock between WtE, recycling, composting, animal feed and landfilling | Revenue generation | Partnerships | Legislation and regulations |

Source(s): Authors' elaboration of reviewed literature

To deal with financial constraints, Andreoni et al. (2022), Govender et al. (2019), and Taghizadeh-Hesary et al. (2022) recommend public-private partnerships and eliminating regulatory red tape, while Todd and

McCauley (2021) argued in favour for foreign investments. The cost of implementing and running plants, the potential for revenue generation, and the decreased reliance on the country's electricity grid need to be benchmarked against WtE plants operating in developed countries (Elmassah, 2024; Naicker & Thopil, 2019).

The authors (e.g., Sebitosi & Pillay, 2008 a, b; Udeagha & Muchapondwa, 2023) cited here speculate that the lack of rigour in energy policies hinders SA's transition to renewable energy. They also suggest that revenue generated from selling energy from WtE plants could offset some of the initial investment. Energy can also be fed back into the electricity grid to provide additional power and reduce the ongoing power cuts in SA (Naicker & Thopil, 2019).

**Non-financial Barriers to WtE adoption**

Lack of government support, incentives, regulatory burdens, and policies are some of the barriers that hinder WtE adoption (Adeleke et al., 2021; Matsuo & Schmidt, 2019). In addition, the availability of cheap coal, low landfill tariffs (Adeleke et al., 2018), and lack of innovation capacity (Ozonoh et al., 2018) in SA hinder WtE technologies growth. Adopting renewable energy also depends on adequate infrastructure, sustainability awareness, and technical expertise (Daw & Gibbs, 2017; Wasserman, 2023).

Russo and Blottnitz (2017) and Ugwu and Enweremadu (2019) highlight that regulatory frameworks and policies are critical for developing these plants. The 'Waste Act' (Creecy, 2020) promoted WtE recovery programs and encouraged waste diversion from landfills. These policies regulate the types of feedstocks permitted, control the levels of air emissions allowed, and ensure the appropriate handling and disposal of by-products. Nonetheless, the current political environment in SA is not conducive to deploying a sustainable RE industry (Becker & Fischer, 2013), as the implementation of climate policies has been constrained by opposing coalitions and unequal power relations among various political factions.

The weak environmental policy and traditional planning approaches delayed the establishment of climate budgets and a carbon tax (Rennkamp, 2019) and exacerbated environmental degradation. In a similar fashion, Daw and Gibbs (2017) discussed that potential competition and reservations by existing traditional energy suppliers (i.e., ESKOM) and other industries (e.g., mining) hinder the economic benefits associated with these technologies. For example, the current regulatory structure only allows independent power producers to sell to ESKOM directly for their use in the form of a monopoly (Daw & Gibbs, 2017). The current model of exclusive engagement by the government and ESKOM in the electric power sector needs to be revised (Naicker & Thopil, 2019). Therefore, Rennkamp (2019) explains the importance of the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) in SA in facilitating the integration of WtE power producers. Public awareness of the benefits of renewable energy can help increase the acceptance and support of policies (Tsikata & Sebitosi, 2010).

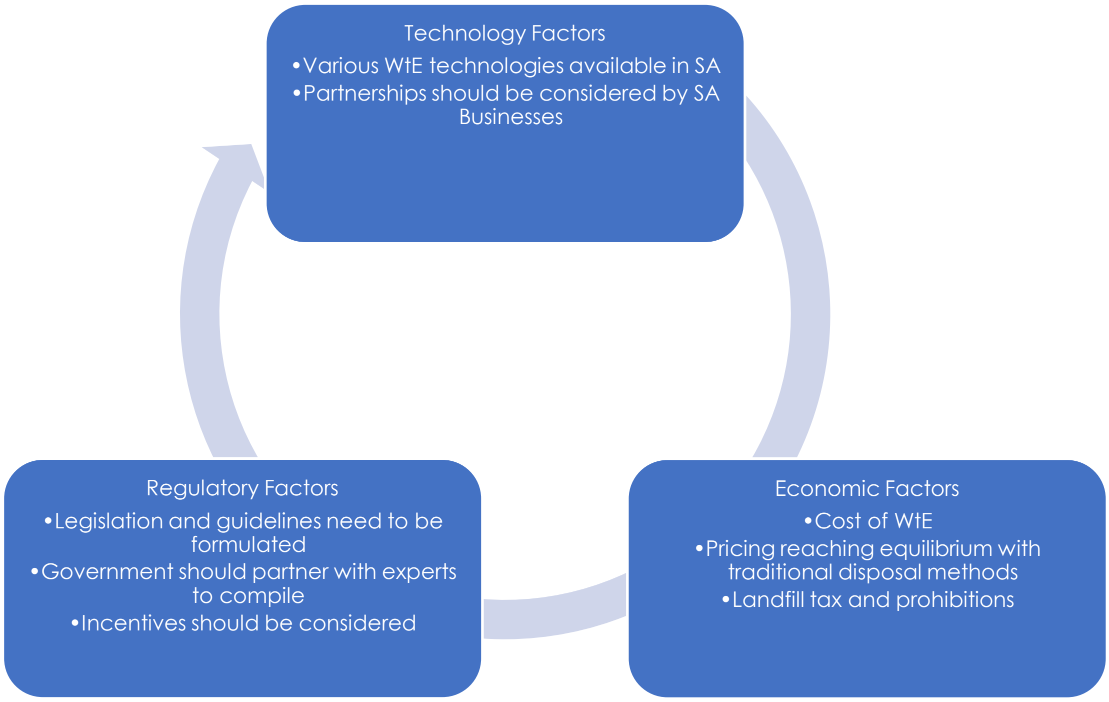


Figure 1. Conceptual model for adoption of WtE technologies
Source(s): Authors' elaboration of critical factors identified from reviewed literature

While presenting the factors influencing SA businesses' adoption of WtE technologies in Table 3, we notice intrinsic links among these factors. For example, waste characteristics, such as composition, moisture content and calorific values, can impact the performance of WtE technologies (Naicker & Thopil, 2019). High set-up costs, a lack of funding and subsidies, awareness of renewable energy and low prices for competing fossil fuels (Becker & Fischer, 2013) make adoption negligible. With that, the role of energy policies, the supply structure of energy and the political will for energy market reform took the centre stage of academic debate (Naicker & Thopil, 2019). Figure 1 presents the interlink between the factors and how they influence WtE adoption in SA in the form of a conceptual model. This conceptual model is tested by using primary data to examine if these factors are pertinent to SA business's decision-making process for WtE adoption.

## 3. Methodological approach

This research adopted a case study research design, the preferred methodological approach in 13 of 30 papers reviewed here (Table 1), and qualitative research is the methodological approach (Saha et al., 2024 b) suitable for a better understanding of context, personal awareness, and interpretations of participants. WtE is a trending topic in SA, and larger SA businesses with global footprints are experiencing intense pressure from their counterparts in developed countries to mirror and employ these technologies to achieve their sustainable goals (Elmassah, 2024). The case study methodology is appropriate to investigate a real-life phenomenon such as this (Yin, 2018). This design allowed us to examine multiple SA businesses from various industries.

**Data Sample**

Our unit of analysis is South African firms, and the sample contains 15 businesses (Table 4). As for the selection criteria and to ensure purposeful and rich data, interviewees must have sufficient experience and knowledge of the WtE industry. In addition to demographic fit, our sample ensures appropriate geographical coverage by including firms from KwaZulu Natal, Gauteng, and Western Cape, as most WtE plants in SA have been initiated in these areas (Mbazima et al., 2022). We followed a purposive sampling process, as the interviewed participants were selected because of their relevance to our research questions and access to relevant data required for our research (Amsterdam & Thopil, 2017; Bell et al., 2019).

Table 4. Sample demography

| Industry Sector (6) | No. of participants | Region (4) | No. of participants | Age Group (3) | No. of participants | Gender (2) | No. of participants |
|---|---|---|---|---|---|---|---|
| Food & Beverage | 5 | Gauteng | 11 | 20 - 30 | 3 | Male | 9 |
| Paint | 2 | Western Cape | 2 | 30 - 40 | 3 | Female | 6 |
| Chemical Manufacture | 1 | KwaZulu Natal | 1 | 40 - 50 | 9 | | |
| Waste/Environmental | 3 | Limpopo | 1 | | | | |
| WtE | 3 | | | | | | |
| Environmental Consultancy | 1 | | | | | | |
| **Total** | **15** | | **15** | | **15** | | **15** |

Source(s): Authors' elaboration of the interview sample

**Data protocol and coding**

The semi-structured interview questions were derived from the SLR for theoretical embeddedness and to capture relevant insights necessary to address the research questions. Two sets of questions were used for data collection. Appendix B includes two sets of interview questions: Set 1 for commercial businesses and Set 2 for SA Waste Industry stakeholders. Set 1 explores the benefits and challenges businesses face when adopting WtE. In contrast, Set 2 evaluates various WtE technologies, focusing on those that effectively balance environmental sustainability and income generation. This allowed participants to share their viewpoints and experiences with WtE and provide insights into the benefits and challenges experienced (Saha et al., 2023). For example, Appendix B, set 1, Q14 'If you could receive the energy back, will your organisation pursue WtE?' –relates to the government factor (Todd & McCauley, 2021) in the conceptual model and how the reinforcement policy (regulatory factor) will determine the adoption of WtE. Q22 from set 2, 'Does the composition of waste-feedstock matter for generating energy? –relates to technology factors and highlights whether waste feedstock composition matters for WtE generation (Russo & Blottnitz, 2017). This allowed participants to share their viewpoints and experiences with WtE and provide insights into the benefits and challenges experienced (Saha et al., 2023).

Interviews were conducted during November and December 2023 through Microsoft Teams on the respondents' chosen date and time to minimise disruption to their daily commercial activities. They were transcribed verbatim using the MS Teams recording and transcription option. The average interview duration is 60 minutes. Transcripts were imported into the QSR NVivo data management software tool (version 14) for data organisation and coding. We followed Braune and Clarke's (2021) thematic analysis framework to analyse the interview data. This six-step process allowed us to familiarise ourselves with the data, select keywords, generate codes, compile themes, combine concepts, and develop a conceptual model.

We coded the data using Saldana's (2013) guide, following an inductive approach in which codes emerged from the collected data. These working codes were refined utilising Corbin & Strauss's (1990) axial coding technique through an exhaustive approach by identifying similarities and patterns, summarising, and removing the working codes to generate axial codes. For example, several participants cited 'renewable energy' and 'zero-waste-to-landfill' as drivers towards adopting WtE, categorised under the SLR's technology factors. Through this method, the initial open codes of 'renewable energy' and 'landfill' categorised under 'technology factors' were refined to the axial codes of 'waste disposal methods' and 'alternate disposal methods'. These axial codes were then grouped under the theme 'sustainability'. This methodology was used to refine all open coding into axial coding. The axial codes were then critically evaluated until saturation was reached, and no further themes emerged. The themes and codes are aligned with the RQs and presented in Appendix C.

## 4. Analysis and findings

Our analysis generated 113 working codes, which were refined into 41 open codes. These were then transformed into six axial codes (waste disposal methods, alternate disposal methods and rets, waste, goals and targets, challenges and opportunities, and political will) and five themes (sustainability, waste feedstock, strategic goals, adoption factors, and political landscape) emerging. The theme of sustainability had sub-themes of ‘waste disposal methods’ and ‘alternate disposal methods and RETs’, understanding the traditional vs. new methods available. The complete list of codes is shown in Appendix C.

**Influence of ESGs on WtE adoption in South African Businesses (RQ 1)**

We analysed three commercial industries’ (food & beverage, paint, chemicals) WtE potentials through our data collection. Our data identified a significant potential for WtE in SA using commercial waste. Table 5 presents the potential of commercial business WtE.

Table 5 commercial business WtE potentials.

| Industry | Type of Waste | Energy Potential | WtE Technologies Available |
|---|---|---|---|
| **Food & Beverage** | Organic waste – generated from food waste, wood chips, plant and fruit waste etc. | Organic waste decomposes to form gasses. These gasses can be captured and converted to clean energy. | Biogas<br>Anaerobic Digestion |
| **Paint** | Mixed hazardous and general waste – chemicals, solvents and packaging waste. | Due to their complex composition, not all waste streams have the potential for energy generation. Proper analysis is needed to understand which chemicals can be mixed together to generate energy. | Incineration<br>Pyrolysis |
| **Chemicals** | Mixed hazardous and general waste. | Only advanced WtE systems can be used for these waste streams, due to the high variability and unpredictability of chemicals. | Incineration |

Source(s): Authors’ elaboration of the interview data

Our findings strongly suggest that SA businesses are driving sustainability. Most interviewees (e.g., SM, Environmental Controller) are exploring different ways of dealing with waste. There is consensus among participants from all locations that WtE is a solution they are probing to drive their ESG goals. Interview data suggests that anaerobic digestion (AD) and pyrolysis are the most suitable technologies for South African businesses. AD is particularly eco-friendly, as it converts organic waste into biogas, reducing methane emissions and producing renewable energy while offering businesses opportunities to generate revenue by selling surplus energy. Similarly, pyrolysis offers flexibility in processing mixed waste, particularly plastics, which are abundant in commercial waste streams and can be converted into valuable biofuels or chemicals. This dual benefit of environmental sustainability and economic viability makes these technologies favourable to waste practitioners in SA. Table 6 illustrates the sustainability drivers for WtE.

Table 6. Illustrative quotes on organisational goals as drivers for WtE in SA

| Organisational Goals | Illustrative quote (IQ) | Source |
|---|---|---|
| **Sustainability Goals** | 1. So, by 2025, Zero waste to landfill. That is the mandate that we have been given by our executive team. | BM |
| **Value Chain of Sustainability** | 2. Sustainability is a value chain, and it's about looking at everything around the value chain and ensuring whatever you do, you do it in the least impactful way. | NR |
| **Sustainability Goals** | 3. The biggest drive for the business at this point is to comply with 2050 net zero global goals, which is looking at reducing the amount of energy consumption, reduced amount of water usage and perhaps recycling the water for reuse, through various systems also looking at reducing carbon emissions and improve recycling rates and reducing waste to landfill. | SM |
| **Circular Economy and Recycling** | 4. Aligning with the circular economy goals... we have quite a large recycling issue to divert all of the recycled lightens from landfill. | WJR |
| **Cost and Sustainability** | 5. Well, and I'm going to be very open and honest with our break away from the parent company. However, there's always a cost implication. | AN |

Source(s): Authors' illustration of interview quotes.

Ten participants (BM, SM, MR, NR, SK, FD, ALB, GT, MVT, and JVR) agreed that WtE is of interest to their businesses, while two (AN and WJVR) agreed with caveats, i.e., cost consideration and offtake agreements for the energy. However, ST was undecided as it depends on the business's short—and long-term goals, and SS and LM confirmed they are not interested in WtE now due to cost pressure (IQ. 1-5, Table 6).

Five participants (i.e., SK, SM, ST, MR & BM) from the food and beverage industry agreed that partnerships with WtE plants and their waste services providers are vital to reaching their ESG targets (e.g., IQ. 1 and 3, Table 6). Their MSW comprises organic and packaging waste suitable for biogas, pyrolysis, and incineration (ranked from better to worst). A portion of their waste, comprising packaging, organics, and wood waste, goes to MSW. Biogas technology is the cheapest and most widely used technology for organic waste. However, incineration is the only WtE technology solution for mixed MSW, which costs ten times more than landfills. Many of these businesses (e.g. ABinBev from the beverage industry and Shoprite from the food industry) either recycle, compost or provide their waste for animal feed. Partnerships are needed, as the set-up costs for businesses (e.g., IQ. 5, Table 6) to procure their own WtE plants are expensive.

Decision making in competing industries, e.g., supply to WtE vs. composting or recycling, is challenging. However, participants relayed the importance of reducing their environmental impact and the potential savings on energy costs. As a WtE consultant in our sample expressed:

We have given a lot of thought to biogas, gasification, pyrolysis, and hydrothermal liquefaction WtE technologies. The demand for waste-to-energy is growing. Two reasons - One is we don't have energy in SA and two is we have a lot of waste in SA. [source: JVR ]

WtE plants highlighted that off-take agreements for energy buyers are crucial for success. These participants (i.e. WVJR, ALB and GT) indicate that WtE is not the only initiative being discussed, as composting, waste for animal feed, and product reuse are also being considered. Two participants (i.e., SK and ST) from the beverage industry have their biogas facilities on their premises, which process a small percentage of organic waste for their own energy needs; other participants (e.g., BM, SM, MR from food retail and beverage industry) compost their waste or supply it to animal feed. However, these participants are still exploring using part/all of the waste for animal feed. The remaining two participants (SS from the chemical industry and LM from the paint industry) do not intend to divert their waste from landfills; however, they will justify switching if landfill taxes and high tariffs are introduced.

Table 7 summarises the amount of waste generated by participating commercial firm (8) organisations, the various technologies employed for energy generation, and their potential waste contribution to WtE.

Table 7: Participants organisations' waste volumes and energy generation methods

| | **Other Sources of Energy Generation and Waste Diversion** | | | | **Waste diverted from landfill** | | | **Potential Waste Contribution to WtE** |
|---|---|---|---|---|---|---|---|---|
| **Participant** | Solar | Biogas | Diesel Generators | Waste-to-Landfill per Month (tons) | Waste to Animal Feed per Month (tons) | Waste to Compost per Month (tons) | Waste to WtE per Month (tons) | |
| **BM** | Yes | - | Yes | 192 | 122 | 140 | 0 | 99% |
| **SM** | - | - | Yes | 10 | 1000 | 136 | 0 | 65% |
| **AN** | - | - | Yes | 20 | 0 | 0 | 0 | 50% |
| **MR** | - | - | Yes | 43 | 7100 | 13 | 0 | 60% |
| **LM** | - | - | Yes | 10 | 0 | 0 | 0 | 0% |
| **SS** | Yes | - | Yes | 63 | 0 | 0 | 0 | 0% |
| **SK** | Yes | Yes | Yes | 400 | 7300 | 120 | 3250 | 83% |
| **ST** | Yes | Yes | Yes | 300 | 7200 | 6 | 2340 | 77% |

Source(s): Authors' elaboration of the interview data

Landfill is currently the preferred and cheapest method of disposal for businesses. However, the need for SA businesses to reduce waste-to-landfill is growing in the WtE industry. Therefore, the sustainability theme consisted of three axial sub-themes: 1) waste disposal methods, 2) alternate disposal methods and RETs, and 3) Goals and Targets. Table 8 shows the number of related codes, references in the transcript, and insights derived from the interview data.

Table 8: Key Sub-Themes and Their Impact on Waste-to-Energy (WtE) Adoption in South African Businesses.

| Sub-Theme | Number of Codes | Number of References | Insight |
|---|---|---|---|
| **Waste Disposal Methods** | 4 | 52 | Businesses' awareness of traditional disposal methods, including landfill, recycling, composting, and waste to animal feed. |
| **Alternate Disposal Methods and RETs** | 12 | 819 | Focus on other renewable energy technologies like solar and wind, with less interest in WtE technologies like biogas and incineration. |
| **Goals and Targets** | 6 | 817 | Businesses' ESG goals to drive the adoption of WtE technologies. |

Source(s): Authors' elaboration of the coded data

All five participants (i.e. BM, SM, MR, SK and ST) consistently mandate zero waste-to-landfill by 2030; therefore, initiatives need to be established now to reach the target. Air emissions were highlighted by participants (e.g., NR – WtE Consultant) as a drawback for WtE technologies due to the different compositions of waste feedstock. However, participants agreed that close monitoring and scrubbing of gases[1] can alleviate this problem. The byproducts from these technologies (ash/sludge from biogas) can be used as a fertiliser, and (oils and chemicals from pyrolysis) can be used as alternate fuel replacements (Nkosi et al., 2020).

Four participants (i.e. SM, MR, SK and ST) agreed that although WtE technologies are expensive to use, the reduction in their environmental footprint and potential energy savings outweigh the cost of these technologies, and they will go ahead and pursue partnerships with providers of these technologies. All interviewees argued that although they support their WtE initiatives, some of their waste goes towards animal feed for sale. They will need to weigh the pros and cons of using this waste for WtE and losing the revenue generated from waste to animal feed. Their deciding factor is to obtain the energy back to their plants from the WtE providers to power their facilities during load shedding. They can reduce the

[1] Biogas is produced from organic matter, representing a mix of gases +- 70% methane, 27% carbon dioxide and 3% hydrogen sulphide. The organic waste is broken down through anaerobic digestion, which uses bacteria to eat through the waste and generate biogas. Scrubbing of the biogas means removing the 3% of hydrogen sulphide by injecting atmospheric air into a scrubber tank. The biogas then goes through a dehumidifier, removing any moisture and resulting in clean-burning quality gas (Eneraque, 2024).

high electricity costs on their priority list by receiving the energy back. In relation to this, A WtE firm explained how the process works:

> Waste Management Companies ensure a consistent supply of feedstock for our operations. Testing is done by an external lab via certain parameters required by the operational team for gas production. Then, waste is delivered with a manifest and weighbridge slip. Approved Feedstock is delivered on the solid slab and or liquid receiving area. We have a power purchase agreement with a famous German automotive brand operation in SA, which provides a steady revenue stream. [source: ALB, Feedstock Specialist]

This process exemplifies a successful partnership between the WtE facility, and a multinational corporation committed to sustainable energy solutions. Such collaboration features the potential of WtE technology to contribute to environmental sustainability and economic benefits.

Our findings highlight traditional and alternate disposal methods, ESG goals, legislation, WtE costs, partnerships, government support, legislation, and waste-feedstock as the determinants of SA businesses' adoption of WtE.

**Challenges facing SA businesses in adopting WtE technologies (RQ2)**

Data attributed SA's limited recycling and waste recovery to economic and regulatory factors. However, representatives (e.g., JVR, MVT, FD, and NR) from the waste industry particularly highlighted social factors and offered a holistic view of the current WtE landscape. WtE plant representatives in our sample shed light on the technological aspects and the specific requirements for waste feedstock. Together, these perspectives provided a comprehensive understanding of all the factors influencing the adoption of WtE technologies.

The transcript on adoption challenges is dominated by two themes: (i) adoption factors and (ii) the political landscape. Table 9 highlights the number of codes and references associated with each theme and the critical points emphasised by participants. This detailed analysis provides insights into the challenges, opportunities, and political factors that impact the growth and implementation of WtE initiatives in the region.

Table 9 Key Themes and Sub-Themes Influencing the Adoption of Waste-to-Energy (WtE) Technologies in South Africa.

| Theme | Axial Sub-Theme | Number of Codes | Number of References | Insights |
|---|---|---|---|---|
| **Adoption Factors** | Challenges and Opportunities | 9 | 1247 | Legislation, cost of WtE, and partnerships are key for adopting WtE. |
| **Political Landscape** | Political Will | 7 | 1462 | Government support, regulations, incentives, and awareness drive the growth of WtE. |

Source(s): Authors’ elaboration of the coded data.

All participants cited government intervention as a cornerstone of making WtE a success (Table 10). The driving factors were appropriate legislation and guidelines (IQ 3, Table 10). Participants highlighted that landfill tariffs are still low, averaging at ZAR350 per ton, compared to biogas at ZAR400 per ton, pyrolysis at ZAR500 per ton, and incineration at ZARR4000 per ton. However, biogas is reaching price equilibrium with landfills through economies of scale. Our finding here concurs with Ugwu and Enweremadu (2019), as they found biogas to be the only WtE technology that can compete with landfills for price-sensitive customers. Sustainable goals for alternate waste disposal driven by SA businesses are providing a platform and financial income for these plants to evolve and compete with traditional landfill sites. WtE participants highlight that restrictions on buyers need to be lifted, as ESKOM is only allowed to purchase the energy back from IPPs.

Table 10. Illustrative quotes on awareness and engagement issues

| Government incentives and regulations | Illustrative quote (IQ) | Source |
|---|---|---|
| **Grants and Subsidies for Renewable Energy** | 1. There are a lot of grants and subsidies available through the Development Bank of South Africa, the IDC, the DTI... I initially used to think we had a funding problem until I started looking and researching. | NR |
| **Government's Role in Renewable Energy** | 2.Currently, there is no roadmap on how we move forward with waste to energy. The view is another 20 years for waste-to-energy to be optimally running in SA. | MR |
| **Legislation and Regulations** | 3. The majority of these issues that we face... boils down to the government legislation, regulations and guidelines and how we move forward. | ALB |
| **Stakeholder engagement for policy formulation** | 4.... if people came together and said those things that’s impactful. But I don't think all stakeholders would sit around the table and say that because it's still a benefit to companies that own landfills. | NR |

Source(s): Authors’ illustration of interview quotes.

Landfill sites are still receiving organic and packaging waste, so the government needs to enforce the prohibition of these waste streams from landfills. All participants agreed that increasing landfill site tariffs and prohibitions will force businesses to comply and look at alternate waste disposal methods. Participants also suggest that legislation needs to change to address the government's over-reliance on coal for energy, which could pave the way for WtE to substitute or replace coal for energy generation. Participants (i.e. LM, SM, AN and MR) critiqued politicians' vested interest in fossil fuels as a hindrance to the process of WtE. If WtE adoption increases, many coal mines may face closure:

> The government is making the process slow for waste-to-energy. So, with energy because it is state-owned, the government has interest in mines, to provide coal for energy generation. [source: LM – Quality and Environmental Manager]

**Policy incentives, Awareness building and private-public partnership**

A consensus amongst all participants is that the lack of governmental engagement, awareness, incentives, and legislation does not make WtE popular. The government is not educating and providing awareness about recycling, Zero Waste-to-Landfill, or WtE initiatives. WtE plant participants have taken the onus on themselves to educate local communities about sustainability and create awareness for WtE. However, all 15 participants agree that more engagement needs to be done between the government, private, and public sectors to advance WtE. Some of their statements are listed in Table 11.

Table 11. Illustrative quotes on awareness and engagement issues

| Awareness and engagement issues | Illustrative quote (IQ) | Source |
|---|---|---|
| **Community Engagement** | 1. I would not say that we engage with the community, our customers are our vertically integrated retail stores that we distribute the products to. So, our engagement is directly with the stores and not with the community. - Brandon Moodley | BM |
| **Education and Awareness** | 2. For me, you know, to change individual mindset, it starts with the basic things like training. If people don't understand what they're doing, and why they are doing it then it's difficult to change the culture. - Sabelo Mthetwa | SM |
| **Key Partnerships for Success** | 3. Partnerships are key to advancing the WtE industry. Partnerships and engagement by government, industry players and bodies, commercial customers and the community is critical to make waste-to-energy a success and a viable renewable energy alternative. | WJVR |

Source(s): Authors' illustration of interview quotes.

Sustainability education and awareness development at the grassroots level (IQ 2, Table 11) were discovered as a stepping stone to moving the country forward sustainably. SM highlighted that environmental programs should be introduced from pre-primary to universities so that future leaders have environmental consciousness ingrained in them. These future leaders will have the necessary foundation, insights, and future thinking to drive sustainability forward and address any forthcoming challenges.

The SA government is blinded (suggested by MR and ST) by its focus on RETs like solar, wind, and hydro, which require high capital investments and occupy large amounts of land that cannot be used for anything else. If the government partners with local organisations and experts in this field, it will understand the benefits, opportunities, and impacts of employing and driving WtE.

There is agreement in the literature highlighting these challenges that SA businesses face. Tsikata & Sebitosi (2010) indicate that the government is focused on expanding their coal-based generation plants and RETs for solar, wind and hydro, with no interest in WtE. Although current partnerships with ESKOM involve purchasing renewable energy from IPPs (Radebe, 2019), WtE producers in our sample (e.g., WJVR and GT) desire a change that will allow them to sell their energy directly to businesses. This will promote fair trade in the market and break ESKOM's monopoly on energy supply. Participants express dissent over the need for policy reforms (Naicker & Thopil, 2019) and tax incentives (Udeagha, 2023).

**Impact of the accessibility and availability of waste feedstock on WtE**

The theme ‘waste feedstock’ consisted of the axial sub-theme ‘Waste’, with six codes referenced 817 times. This sub-theme highlighted waste-feedstock products, composition, and availability as determinants of stable supply for WtE generation. Participants from the waste-to-energy plants highlighted the importance of receiving regular, consistent volumes of waste feedstock to service their plants and meet their energy generation targets. WtE consultants (i.e. GT, ALB, JVR and MVT) added to this discussion by stating that the composition of waste feedstock needs to be ideal to make these waste-to-energy plants work:

> Our biogas plants range from 4 megawatts to 10 megawatts down and require a waste feedstock supply of 12-24 tons per day. Organics provide high gas yields to generate energy. [source: ALB – WtE Plant – Feedstock Specialist]

SA businesses have large volumes of waste to supply WtE plants, which primarily consist of organic waste that is used for biogas (e.g., Table 5, 7). Two participants (ST and SK) have their small biogas plants at their facilities and supply their surplus stock to WtE plants. They are charged a gate fee to supply their waste and have no benefit from the energy generated. However, it is a diversion from the landfill strategy for them. Two other participants (SM and BM) supplied their organic waste to animal feed farmers, for which they got a rebate. To encourage a shift to WtE and generate revenue from waste, critical decisions must focus on receiving free power supply from WtE energy or providing incentives such as carbon credits to lower emissions.

A participant, WJVR, from the incineration plant who owns landfills across the country is now focusing on reclaiming MSW from these landfill sites to supply feedstock for their incineration plants. This increases the lifespan of their landfill sites and reduces their need for fossil fuels to power their incinerators. He also indicated that with the new landfill tax being promulgated, SA businesses will have no choice but to find alternative methods for waste disposal or pay high premiums for traditional landfill disposal. He noted that if SA businesses divert 70 per cent of their MSW to WtE plants, this will provide ample feedstock for these plants.

> Our incinerator requires about 500 tons a day. Our landfills generate 10 to 15 000 tons per month at each site. We are currently reclaiming MSW to feed our incinerator. I mean, if everyone, like the private and public sector, decides to divert 70% of their landfill waste, that's already providing 70% of the feedstock that WtE plants need to generate energy. [source: WJVR – Senior Commercial and Innovations Manager]

Two participants (GT and ALB) from the WtE plant advised that they are procuring enough stock from some SA businesses to generate 4MW of power at their plant. They only take organic waste in the solid and liquid composition. Waste streams are assessed on calorific value using a scientific formula, which provides the amount of megajoules of energy they can generate. Although biogas technology is cost-effective for organic waste from landfills, pyrolysis is a more practical technology as it can handle mixed waste feedstocks like the MSW.

**Building a WtE Framework for SA Businesses (RQ3)**

Our findings added additional layers to the conceptual model (Figure 1) and refined it as a WtE adoption framework for SA. The technological aspect focuses on the types of waste feedstock used in WtE processes, including energy production, animal feed, and MSW reclamation. Effective and efficient use of these feedstocks is essential for the viability of WtE technologies. Industry experts indicated that businesses need to balance the use of waste for energy and animal feed, ensuring the feedstock meets the necessary quality and quantity requirements for optimal energy production. Furthermore, although governments are interested in using WtE, its long-term use needs to be aligned with their policies and regulations. Offtake agreements for the energy produced and incentives like carbon credits and reduced taxes are needed to create the true benefit of WtE.


Figure 2. WtE implementation model for South Africa
Source(s): Authors' elaboration of critical factors identified from reviewed literature and empirical data

The costs associated with WtE can be significant barriers for businesses. Interviewees manifested cost issues concerning the financial constraints due to the COVID-19 pandemic, financial expectations from waste to energy, the absence of a valid financial model, and price sensitivity (Table 12). Industry interviews highlighted the importance of partnerships and independent power purchasers (IPPs) in providing financial stability and incentives for investment in WtE. Managing high initial costs and ongoing expenses is essential to ensure WtE remains a cost-effective solution.

Table 12. Illustrative quotes on cost issues

| Cost of WtE and funding models | Illustrative quote (IQ) | Source |
|---|---|---|
| Financial Constraints Post-Pandemic | 1..... And I think cost has become more of a major factor post the pandemic. And I think that that is affected a lot of organizations. You know that are still trying to get business up and running and get to the profits and market share pre pandemic. - | AN |
| Financial Expectations from Waste to Energy | 2. Don't expect to make massive amounts of money from this... These plants are not going to be money spinners. They're going to sit at lower margins. | NR |
| Financial Models | 3. We are trying to give our clients a highly effective process with a financial model that makes sense. | MT |
| Price Sensitivity | 4. It's incredibly price sensitive and until the technology gets cheaper, you would get more adoption... or if more regulations are enforced, then companies are forced to look at these alternatives. | NR |

Source(s): Authors' illustration of interview quotes.

Effective legislation can drive businesses to transition from traditional waste disposal methods to WtE technologies. Participants emphasised the necessity of regulatory support, noting the need for clear and supportive legislation. Government incentives and stringent regulations significantly enhance the attractiveness of WtE technologies.

While social factors were not highlighted in the literature, they were continuously raised in the fieldwork evidence. Environmental, Social, and Governance (ESG) goals, sustainability education, and public awareness are prominent. ESG goals motivate businesses to adopt sustainable practices, including WtE technologies. Sustainability education is essential for developing a workforce that supports the transition to WtE. Raising public awareness about the benefits of WtE fosters community support and acceptance, which is vital for the long-term success of these technologies.

## 5. Discussion

Our analysis suggests that waste is a viable alternative to generating energy. This was the view and consensus amongst all participants who expressed enthusiasm for reducing environmental impact. The data analysis developed a framework (Figure 2) relating to technology, regulations, social awareness and economics using the overarching sentiments throughout the data. The costs of WtE technologies were highlighted as a concern; however, in most cases, sustainability goals, e.g., zero waste-to-landfill, outweigh the costs for WtE. The availability and composition of feedstock for the different WtE technologies were also a concern, as some technologies only use certain waste products.

Identifying WtE costs, technological barriers, waste and energy tax reform, uncertainties of regulations, and lack of incentives aligns with existing literature (e.g., Daw & Gibbs, 2017; Godfrey & Oelofse, 2017; Russo & Blottnitz, 2017; Todd & McCauley, 2021). It is also striking that our findings correspond to literature published a while ago (e.g., Pegels, 2010; Tsikata & Sebitosi, 2010; Winkler et al., 2009), suggesting painfully slow progress in the WtE adoption in SA. Therefore, we suggest developing policies and strategies to promote WtE technologies and building the necessary skills, expertise, and knowledge in SA, which are critical. The focus should be on WtE plants' cost-effectiveness and their potential for job creation.

To this end, the political landscape plays a pivotal role in WtE initiatives and shapes the barriers identified by participants. The SA Government's failure to draft necessary legislation, fast-track the industry, and provide proper guidelines and implementation processes is seen as a regulatory factor that negatively impacts the industry. Firms in our sample are often unaware of various government initiatives in this space (IQ 1, Table 10), which contributes to a lack of confidence in government assistance and leads businesses to investigate and employ these solutions independently. Despite the blame placed on the government and its legislation, industry experts are lagging in their initiative. If these experts do not drive legislation with their expertise in WtE and instead wait for government action, the industry and its technologies will stagnate. Therefore, stakeholder engagement and communication are essential to move forward.

Based on our findings, we propose three policies to enhance the adoption of WtE technologies and promote green energy among South African businesses. First, the future of green energy for South African businesses necessitates shifting away from coal-based fuels. The country has abundant waste feedstock that can be utilised for energy generation through WtE, reducing reliance on the traditional electricity grid. Implementing WtE technologies can significantly lower dependence on coal, contributing to a more sustainable energy landscape.

Second, the cost of WtE needs to decrease for wider adoption. Due to the current high costs in South Africa, there remains uncertainty about the long-term benefits of WtE. The SA government should employ a rewards-based system for clean energy generation to attract price-sensitive customers. Incentives for green and clean energy need to be promulgated and provided to businesses to encourage adoption. We predict that the unit cost for business use will decrease as WtE technologies improve and scale.

Third, regulations should disincentivise different waste streams from going to landfills through higher landfill disposal taxes and fees to discourage disposal. The prohibitions on MSW, such as tyres and electronic waste, should be expanded. These measures will deter businesses from landfilling waste and encourage them to seek environmental solutions, including WtE technologies.

For WtE plants, outsourcing the feedstock procurement to micro-enterprises can be more efficient. These micro-enterprises can source, collect, consolidate, and deliver the feedstock to the plants. This will generate new industries and create much-needed employment. We propose that larger SA businesses conduct a feasibility study to identify whether they require WtE plants on their premises. While smaller businesses should look at partnering with WtE plants that are already set up and have the proven technology to generate energy from waste.

We discovered that SA businesses are also investigating how their waste products can be used as raw materials to manufacture other products, e.g., plastic waste used in manufacturing bricks. Retailers are also considering donating food near expiration (but still suitable for consumption) to charities and food banks, providing food to the poorer population instead of landfilling food waste. This approach not only helps tackle food insecurity but also significantly cuts down on the quantity of organic waste that would otherwise end up in landfills. However, these practices directly affect WtE technologies as the feedstock for WtE processes might diminish if more materials are reused and recycled,

It is essential to acknowledge that the sample size, while diverse and consisting of a range of organisations, may not capture the thoughts and experiences of other SA businesses in their entirety. It is important to note that while sufficient research has been done on waste feedstocks and policies for WtE technologies, there is a lack of research on the implementation, benefits, and impacts of WtE technologies. Such a lack of existing research limits our ability to interpret and benchmark our findings yet provides an opportunity for future exploration of this topic.

Nonetheless, the reliability of our findings and recommendations is supported by several factors. First, the data collection process included businesses from diverse industries and regions, ensuring a representative sample of South Africa's commercial waste landscape. The purposive sampling method, combined with in-depth interviews, allowed for detailed and context-rich insights, reducing the likelihood of bias and improving the reliability of the results. Moreover, the repeated emphasis by participants on key factors such as sustainability goals, regulatory challenges, and economic incentives reinforces the reliability of the findings. The consistency of these themes across various sectors demonstrates that the conclusions drawn are not isolated or anecdotal but are supported by multiple data points and broader literature reviewed here. Additionally, the methodology—specifically the use of the conceptual framework developed from SLR and the adoption framework from primary data—ensures that the recommendations for WtE adoption are grounded in both WtE theory and real-world practices.

Research should also be conducted on capturing methane gasses with WtE technologies at end-of-life landfill sites. Several landfill sites around SA have reached the end of their lifecycles, and harnessing the methane gasses still expelled from the soil could provide a further option for generating energy. The literature also provides insight into funding mechanisms available for businesses considering WtE technologies. However, there is misalignment, as this information is not marketed or provided publicly, providing a lack of awareness to businesses that have decided to fund these projects on their own.

The social impact in terms of job creation is still unclear for WtE. Further research needs to be done to understand the impacts of jobs in other waste-related industries vs the new WtE industries. While workers are still needed for WtE, these plants are driven by technology and mechanised processes rather than the need for manual labour, which is required in other waste-related industries. The waste industry is also not unionised in SA, which means job losses cannot be challenged if WtE increases and other players in the waste value chain are removed.

## 6. Conclusion

The SLR and case study shed light on the complex nature of WtE technologies. WtE is a new concept in SA and should be viewed as a journey rather than a short-term solution. The conceptual model developed on the factors affecting WtE was further enriched as participants highlighted technology, economic, regulatory, and social factors as barriers to adopting WtE.

For South African Businesses, adopting WtE technologies, such as anaerobic digestion and pyrolysis, presents clear economic benefits. Businesses can reduce waste disposal costs, generate additional income by selling surplus energy, and enhance their environmental credentials, which is increasingly important for attracting environmentally conscious consumers and investors. The integration of WtE technologies also aligns with corporate sustainability goals, such as achieving zero waste-to-landfill targets while simultaneously addressing energy security.

In the proposed adoption framework (Figure 2), the identified barriers align with those previously found including the availability of WtE technologies, the costs involved, and the sustainability goals of businesses aiming for zero waste-to-landfill. Therefore, it is essential for both government and industry to actively support and promote the adoption of WtE technologies in South Africa. WtE offers South African policymakers a practical solution to waste management and energy challenges. By providing financial incentives such as tax breaks or energy credits and by implementing stricter regulations to reduce landfill usage, SA government can encourage businesses to adopt these technologies. These measures would not only support national sustainability goals but also alleviate the strain on the national electricity grid by diversifying energy sources with clean, renewable alternatives.

The insights from this study transcend national boundaries as a model for other developing economies with similar challenges in waste management and sustainable energy. This research not only promotes sustainable development within South Africa but also contributes to global efforts in environmental protection and energy security.

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