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RESEARCH ARTICLE

An Analysis of Industrial Symbiosis as a Strategic Tool for Integrated Waste Management Plans (IWMPS) in South Africa – A Case Study of Mpumalanga Province

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Abstract

Waste management is a global environmental crisis that is often overlooked on the environmental agenda. For an emerging country like South Africa, the impacts of poor waste management are more severe when compared to the developed world. A systems-oriented and eco-innovative concept, such as industrial symbiosis, offers environmental, social and economic benefits when waste exchange and recycling are encouraged among industry players. Low levels of uptake of the industrial symbiosis process cripples its success and slows the achievement of overall sustainable waste management. Mpumalanga province offers a complex environment to study the relationship between industrial symbiosis and its role in decision-making tools such as integrated waste management plans (IWMPs). This article explores the integrated waste management planning regulatory environment in South Africa and argues for the inclusion of industrial symbiosis as an integrated waste management implementation instrument. Through content and document analysis, this article seeks to investigate waste legislation, policy and strategy while scrutinising industrial symbiosis literature. The article draws from global literature on industrial symbiosis and encourages heightened participation and buy-in from the government, through its inclusion in integrated waste management plans and finally, integrated development plans.

Keywords Waste · Industrial Symbiosis · Integrated Waste Management Plan (IWMP) · Circular Economy · Mpumalanga

1. Introduction

Global waste volumes consistently rise and threaten to exceed population growth by 2050 (Kaza et al., 2018), with a projected increase to 3.4 billion tons and resultant greenhouse gas emissions up to 2.38 billion tons of CO2-equivalent. (Sharma et al., 2021; Mukwevho et al., 2024). This provokes holistic and research-based investigations into existing waste management practices, legislation and policy, to optimise existing planning mechanisms and tools, especially through advanced circular economy initiatives. Waste management, an underestimated sustainability challenge, has direct links to numerous United Nations Sustainable Development Goals, especially Goal 12, "Responsible Consumption and Production" (Rodic and Wilson, 2017). These links emphasise the importance of planning and addressing global waste management in a structured, holistic and transdisciplinary manner. Sustainable development can be achieved through waste prevention, recycling, reuse and recovery activities, which can support the transformation of waste into a resource or new product (Lombardi et al., 2023). A resource efficiency and cleaner production approach that encapsulates this is

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"industrial symbiosis". Industrial symbiosis is a globally recognised integrated environmental approach that originated from recognising that industries and systems must not operate in isolation but should adopt a holistic systems approach. The term was coined from Denmark's Kalundborg eco-industrial park, where industry players interacted with each other as part of one system, to achieve reduced environmental impact (Frosch and Gallopoulos, 1989).

The globally realised benefits of industrial symbiosis include the reduction of consumption of natural resources and promotion resource efficiency (Lombardi et al., 2023, O'Carroll, 2014), generation of employment, (Godfrey and Oelofse, 2017), upscaling of waste pickers and the informal sector, elongation of landfill space, reduction in carbon footprint and improved health of fauna, flora and aquatic environments (Sharma et al, 2021; Lombardi et al., 2023).

In the context of the developing world, the adoption and implementation of a circular approach, such as industrial symbiosis in policy and legislation, is sluggish. For South Africa, this is amplified when institutional capacity, financial ability and waste management knowledge are weak (Godfrey and Oelofse, 2017). Contrastingly, developed countries have taken quicker and larger strides in including industrial symbiosis in their legislative frameworks and policies. Successful efforts to integrate circular economy approaches into integrated waste management planning have been conducted in Italy (Di Foggia and Beccarello, 2021), Turkey (Tutunchian and Altınbaş, 2023) and the United States of America (Anshassi et al., 2019), proving that circular economy approaches are the cornerstone of efficient and successful waste management systems and plans. In South Africa, the National Waste Management Act (Act 59 of 2008) (NEM:WA, 2008) is the principal legislation that governs waste. The National Waste Management Strategy (NWMS, 2020), a statutory requirement of the NEM:WA (2008), advocates circular economy strategies as part of sustainable waste management. An opportunity to achieve this is through the integration of industrial symbiosis in Integrated Waste Management Plans (IWMPs).

An IWMP is defined as a comprehensive plan, strategy or detailed roadmap that ensures advanced efficiency and effective waste management (Buffalo City IWMP, 2021; Mpumalanga Provincial IWMP, 2019). South African municipalities and provinces are mandated to develop these five-year strategic plans as a mandatory requirement of the NEM:WA (2008) as per Chapter 3, Sections 11 to 13. An IWMP governs how waste is managed, resource efficiency optimisation, roles, responsibilities, finances, key performance indicators, waste infrastructure and facilities, compliance and enforcement, waste diversion targets, data and information reporting, recycling and reuse programmes, stakeholder engagement and various other factors pertaining to waste management service delivery (Mpumalanga Provincial IWMP, 2019).

Even though the "waste as a resource" paradigm shift (which industrial symbiosis is underpinned by) has progressed (Ojeda-Benitez et al., 2000), South Africa is still crippled by the complexities of waste management, such as lack of organisation, financial constraints, illegal dumping, depleting landfill airspace, limited recycling and waste reduction initiatives and importantly, the lack of enforcement and implementation of waste policy and legislation (Nahman and Godfrey, 2010; Godfrey et al., 2020; Mukwevho et al., 2024). The lost connection that may alleviate these challenges is industrial symbiosis as part of mandated IWMPs. The Mpumalanga province, a prototype of coal-dependent economies globally, offers a complex yet unique environment to explore industrial symbiosis and integrated waste management. Mpumalanga plays a critical role in South Africa's energy economy as the "hub" for power generation (GreenCape, 2024), yet it is challenged by striking poverty levels (Mpumalanga Department of Economic Development and Tourism, 2022). Earmarked as the key role player for paving sustainable pathways towards a just transition away from fossil fuels, the province has heightened pressures to restructure environmental protection and justice, as well as climate change, particularly as the "world's most coal-dependent economy" (Ward et al., 2020; Nel et al., 2023; Mpumalanga Climate Change Mitigation Strategy and Implementation Plan, 2022).

Existing literature exposes a prominent research gap, revealing that waste management in coal-dependent economies, particularly Mpumalanga, is severely understudied. The link between the Mpumalanga industrial symbiosis in relation to Mpumalanga IWMPs has not been investigated. Recognising the overlap between IWMPs and industrial symbiosis has been muted in South Africa and global success in doing so encourages such developing areas. This article investigates the interface between industrial symbiosis and IWMPs in Mpumalanga, to address this research gap, using content and document analysis. The status of Mpumalanga IWMPs and the Mpumalanga industrial symbiosis programme are examined, and prominent gaps and shortcomings are identified. This study aims to showcase how the inclusion of industrial symbiosis in IWMPs can advance the regulation and implementation of circular economy approaches, while achieving a multitude of environmental, social and economic benefits. The research questions are:

a) What is the status of the current IWMP legislation?
b) What is the status and prominent gaps of IWMPs in Mpumalanga Province?
c) What are the shortcomings and achievements of industrial symbiosis?
d) How can industrial symbiosis be incorporated into IWMPs as a strategic sustainable waste management tool?

2. Literature Review and Theoretical Framework

2.1. Overview of Integrated Waste Management Planning in South Africa

In the developing global context, such as South Africa, the negative impacts of poor waste management are significant (Fakoya, 2014; Tsheleza et al., 2019) and therefore demand an integrated waste management framework. The systemic barriers to successful waste management on the continent call for the integration of advanced circular models that deviate from a linear economy. IWMPs, as the main planning frameworks for the governance of waste management in South Africa, make them favourable for this integration.

Two focal pieces of legislation and strategy that oversee IWMPs are the National Environmental Management: Waste Act (Act 59 of 2008) (i.e. NEM:WA, 2008) and the National Waste Management Strategy (NWMS, 2020). The NEM:WA (2008) exists to regulate waste management and Chapter 3; Section 11 requires that all municipalities and provinces responsible for waste management must develop an IWMP. The IWMP must explore the jurisdiction's current waste management status quo, address poor waste management and the negative impacts of such, waste minimisation and recycling programmes, waste reduction targets, proposal of improved environmental behaviours and practices, detail available or anticipated financial resources to implement the IWMP, aspects of compliance, as well as annual reporting (NEM: WA, 2008). Further to this, the IWMP must form part of the area's Integrated Development Plan (a strategic master plan that is updated every five years and embodies a municipality's plans for overall social and economic development, which receives allocated budgets and funding for service delivery), as per the Municipal Systems Act (Act 32 of 2000), (NEM:WA, 2008; North West University, 2025; Department of Environmental Affairs, 2012).

In more developed contexts globally, countries that have adopted frameworks such as IWMPs in their policies include Brazil, China and the United States of America (Clarke et al., 1998; Tam, 2007; De Souza, 2021). South African IWMPs are comparable to various waste management plans globally. Some examples include waste management plans, which European Union member states are obligated to develop under the European Union Waste Framework Directive, State Solid Waste Management Plans under Federal Law in the United States of America and Comprehensive National Waste Management Plans under the Waste Control Act (2016) in South Korea. However, compared to waste management plans globally, South African IWMPs lag in the integration and implementation of industrial symbiosis within the plan and as a strategic mechanism to foster circularity.

The role of the NWMS (2020) is to supplement the NEM: WA (2008) by providing strategic approaches and targets to achieve the NEM: WA (2008). The NWMS (2020) is underpinned by the circular economy (Matinise and Oelofse, 2022) and has three main strategic pillars, i.e., Pillar 1: Waste Minimisation, Pillar 2: Effective and Sustainable Waste Services and Pillar 3: Compliance, Enforcement and Awareness. A key intervention under Pillar 1 is "Prevent waste generation through cleaner production, industrial symbiosis and extended producer responsibility" (NWMS, 2020). The NEM: WA (2008) requires that IWMPs are aligned with the NWMS (2020) and its targets. More recently, the IWMP Guidelines (2022) have proposed a "circular waste economy" sub-section within IWMPs, to indicate current circular economy activities, thus suggesting a first stride towards a paradigm shift in IWMP development. However, these guidelines do not operationalise industrial symbiosis and regulate it as a waste management strategy in IWMPs. In Europe, policy has been influenced to integrate industrial symbiosis and circular economy themes (Bonoli et al., 2020) and IWMPs offer a compelling platform for this integration in South Africa.

Figure 1 provides a graphical representation of the hierarchical structure of the legislation and policy referred to in this article.

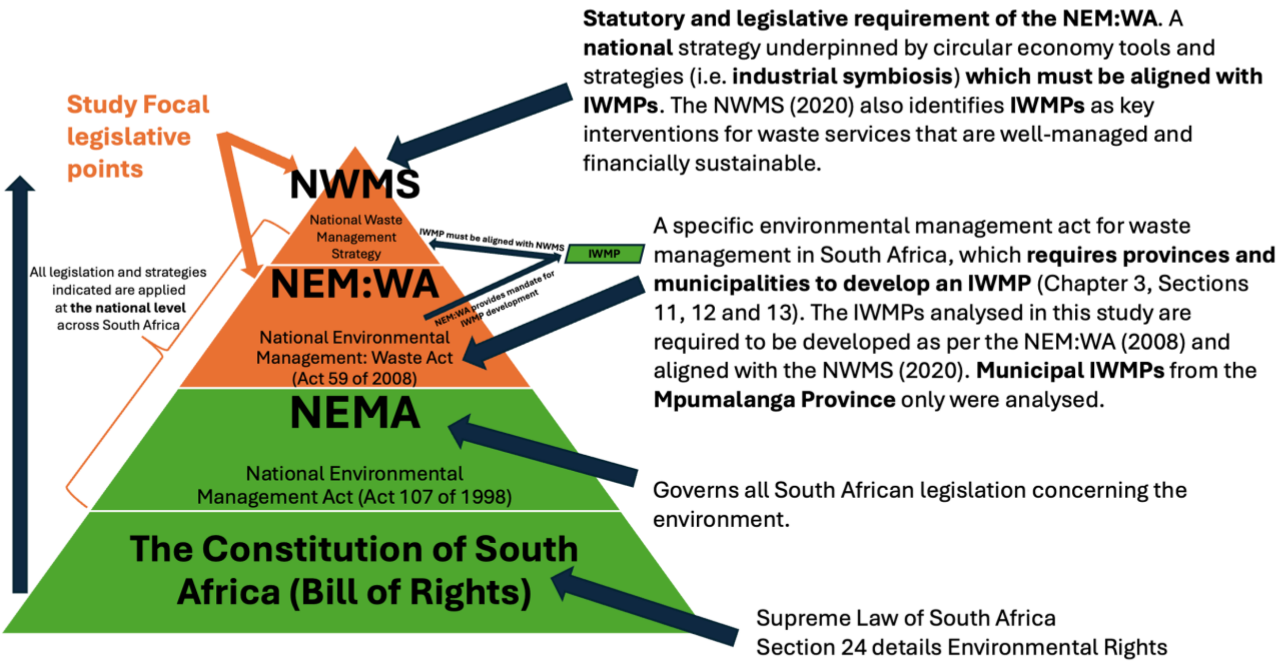

Figure 1. Hierarchical relationship between relevant national waste management legislation and policy (South African Waste Management Legislative Framework) (Dune and Roberts, 2025).

2.2. Mpumalanga Integrated Waste Management Planning

Mpumalanga, a rural region, is primarily responsible for the country's power generation and energy system. Greenhouse gas intensity in South Africa places it in fourteenth place among the G20 countries, demanding the exploration of circular opportunities to pave the way towards a "just transition" (Pai et al., 2021). Mpumalanga serves as a microcosm of other carbon-intensive and coal-reliant regions globally, where a transition away from fossil fuels is pertinent. A just transition aims to reduce carbon intensity while observing environmental, social and economic impacts. Considering a just transition, the synergies between industrial symbiosis and integrated waste management planning may present solutions for recycling and reuse, diversion of waste from landfill, decreased coal waste stockpiling, reduction of greenhouse gas emissions and generation of innovative product and green employment in a coal-dependent economy (National Cleaner Production Centre South Africa, 2025; Ward et al., 2020; UN-Habitat, 2024), striking the three pillars of sustainability.

A noticeable rift between policy and implementation is evident in Mpumalanga, given that its only available provincial IWMP was finalised in 2019, despite NEM:WA (2008)'s requirement for updates and reviews every five years. The Mpumalanga Provincial IWMP (2019) states that the key challenges that hinder successful and efficient waste management include "rural topography; rapid increase in informal settlements due to urbanisation; limited institutional capacity; financial unsustainability; insufficient coordination, participation and stakeholder inclusivity; resource inefficiency; and limited integrated waste management infrastructure". The severity of poor waste management in the province is illustrated in Bethal, where the landfill continues to expand in size, encroaching on a main road (Botha, 2023). Only 55% of households have access to refuse removal services, yet the province generated an estimated 27 615 295.7 tons of general and hazardous waste in 2017, according to the South African Waste Information System (SAWIS, 2019). Moreover, only a small portion of the municipalities have implemented recycling initiatives (Mpumalanga Provincial IWMP, 2019). These findings highlight the challenges tied to a linear economy and the unrealised benefits of a waste management system where industrial symbiosis is not widely implemented in legislated planning tools, such as IWMPs.

2.3. The Journey of Industrial Symbiosis

Industrial parks are prime environments for demonstrating industrial symbiosis, and literature celebrates the Kalundborg, Denmark example, which originated in the 1970s, where various entities have partnered to share resources such as energy, water and materials. This exemplary and magnified industrial symbiosis system allows the participating companies to achieve financial savings and profit while reducing environmental impact and waste (Frosch and Gallopoulos, 1989; Gopalakrishnan and Bakshi, 2017; Valenzuela-Venegas, 2016). Chertow (2000) proposed the following definition for industrial symbiosis: "*Traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity"* (Chertow 2000). An example of a relationship between a wastewater treatment plant and a power plant was explained, where wastewater is provided for cooling at the power station, while excess steam from the power plant is provided to another user. Such a relationship fosters the re-use of residual resources between industries, rather than the use of virgin or raw materials (Chertow, 2007). Another prominent example of industrial symbiosis in literature is by-product synergy in Kansas City, United States of America. Cimren *et al* (2011) applied a tool called Eco-Flow, whereby by-product synergies were explored. The results indicated the implementation of industrial symbiosis, where companies exchanged resources, which could achieve potential savings of up to $15 million annually, cost reduction of approximately 25%, a 30% decrease in greenhouse gas emissions, as well as a 37% diversion of waste from landfills.

The 2018 Amendment to the Waste Framework Directive (2008/98/EC) legislated the requirement for the promotion of sustainable resource management and industrial symbiosis by European Union member states (European Committee for Standardisation, 2018). Some European examples, such as the Council of the European Union, European Parliament and European Commission, exemplify instances where "industrial symbiosis" has been used in various forms of documents, including policy and legislation (European Committee for Standardisation, 2018).

Asia has also been forthcoming and driven industrial symbiosis in legislation and policy. In China, industrial symbiosis implementation has been supported through regulatory amendments such as the Cleaner Production and Promotion Law (2003), the Law on Pollution Prevention and Control of Solid Waste Amendment (2005), as well as the Circular Economy Promotion Law (2008), (Liu *et al*., 2017). The Eco-Industrial Parks initiative influenced the issuance of Decree No.82/2018/ND-CP ("Decree 82") of the Government of Vietnam. This decree includes various standards and requirements for the regulation of industrial parks to transition to more sustainable and resource-efficient hubs, through industrial symbiosis (Stucki *et al*., 2019; United Nations Vietnam, 2019). Buda and Ricz (2023) investigated industrial symbiosis and policy in Uganda. They agreed that African economies are limited by financial constraints, and industrial symbiosis offers an economically sustainable solution that does not have significant financial demand. While this is the case, African literature that promotes industrial symbiosis is limited (Buda and Ricz, 2023). They further argued that these limitations within research support their stance that policy and economic mechanisms to encourage industry symbiosis are unresearched, a similar research gap identified for South Africa.

A Nigerian study on Eco-Industrial Parks by Bilyaminu *et al* (2024) recommended that policies and regulations must be developed by policymakers in government, with a focus on industrial symbiosis and circular economy. They identified a lack of such policies as a significant bottleneck to the implementation of industrial symbiosis in Nigeria and recommended that academic research investigate regulatory change that recognises the numerous benefits of industrial symbiosis and circular economy principles. This article thus extends itself to wider African and global contexts, demonstrating that existing challenges in Mpumalanga, South Africa, echo systematic challenges in broader African and global economies. Equally, Oni *et al* (2022) agree that a regulatory environment that allows for industrial symbiosis-specific regulations can help improve industrial symbiosis in Africa.

2.4. Industrial Symbiosis in South Africa

South Africa has been a leader in implementing industrial symbiosis, compared to other African countries (Oni *et al*., 2022). The adopted definition of industrial symbiosis in South Africa is a "*resource efficiency and cleaner production approach*" that promotes mutually beneficial relationships, where "*unused or residual resources (material, energy, water, waste, assets, logistics, expertise, etc.) of one company are used by another, resulting in mutual economic, social and environmental benefits*" (NWMS, 2020), (Refer to Figure B in

Annexure A). The industrial symbiosis programme was launched by its implementing agent, the National Cleaner Production Centre South Africa, in 2014 in Gauteng. Before this, a pilot study had already commenced in 2013 in the Western Cape. The National Cleaner Production Centre South Africa (2025) further describes industrial symbiosis as a tool for local economic development and waste management service delivery, owing to how industrial symbiosis reduces waste management costs while advancing enterprise development and green employment opportunities.

In South Africa, the industrial symbiosis programme is operational in all nine provinces and offers a host of funded services to alleviate the challenges of a rudimentary linear economy (Refer to Annexure A). The industrial symbiosis methodology adopted by the National Cleaner Production Centre South Africa (Refer to Annexure A), is achieved through facilitating relationships between companies that "have" under-utilised or waste resources, with those that can utilise these resources as raw materials or input into a new process (O'Carroll, 2014). Combined efforts have resulted in the diversion of 518 000 tons of waste away from landfills, mitigation of 1.7 million tons of greenhouse gas emissions and landfill cost avoidance of R129 million (National Cleaner Production Centre South Africa, 2025).

Herath *et al* (2023) found a total of 34 barriers to industrial symbiosis implementation categorised under six themes: a) economic (inadequate budg*et al*locations, cost-benefit analysis challenges and costs associated with fleet and logistics), b) organisational (lack of knowledge of industrial symbiosis, reluctance to participate and adapt to change, lack of integration and low institutional support), c) regulatory (regulatory red-tape, contradictory legislation and lack of industrial symbiosis related legislation, d) technological (poor technological know-how, quality of waste, insufficient infrastructure), e) risk (investment, demand and supply, performance and outcomes risks) and f) information (lack of access to information and training, low awareness of industrial symbiosis). These themes are no different to the barriers experienced in South Africa, equally as a developing country and closely tied to IWMP implementation barriers. Similarly, in Zimbabwe, Nyakudya *et al* (2023) explored industrial symbiosis as a panacea to the challenges posed by industrial waste in Harare. Their study discovered similar parallels to those that plague growing economies, such as inadequate technical and organisational capability to achieve successful implementation of sustainable waste management approaches, as well as fractured integration between waste planning and waste legislation (Nyakudya *et al.,* 2023). The findings identified by O'Carroll *et al* (2014) in the Western Cape, South Africa, reflect those identified by Nyakudya *et al* (2023) in Harare, Zimbabwe, where a plethora of socio-economic barriers, such as regulatory complexities, budget constraints, lack of appetite for recycling, lack of investment and lack of solutions. A running theme across these studies is the regulatory framework and a regulatory environment for industrial symbiosis to thrive, in conjunction with government participation.

Industrial symbiosis' inclusion in IWMP regulatory frameworks and reports is a missed opportunity to fast-track the achievement of Sustainable Development Goals and a transition to a circular economy in complex energy-intensive environments such as Mpumalanga and other energy-generating regions in Africa and globally.

3. Methodology

Mpumalanga's unique position as the energy backbone of a leading greenhouse gas emitting country globally, its multitude of institutional, regulatory and capacity limitations as well as socio-economic and environmental pressures, make it an ideal case study to investigate waste management policy and circularity. Complex coal-dependent environments such as this exist globally, especially in Asian countries such as China, India and Indonesia, while other examples exist in European contexts such as Germany and Poland (Khan *et al*., 2018). This advocates for a Mpumalanga-based waste management case study to have relevance in global discourse.

Content and document analysis approaches were adopted for a thorough review of Mpumalanga's provincial and municipal IWMPs, as well as industrial symbiosis reports. The literature review provided a theoretical and legislative framework for this analysis. Document analysis is a qualitative analytical approach where documents are evaluated and reviewed. This includes identifying, choosing and understanding the data within the documents. It is argued that document analysis and content analysis are interchangeable; however, Bowen (2009) explained that the data produced from document analysis is structured into main ideas, subjects and examples through content analysis.

Comparative analysis is defined by Aliboeva (2022) as a process where similarities and differences are drawn from data and information. This approach was useful for comparing each IWMP against circular economy themes within the NWMS (2020), as well as industrial symbiosis programmes in other countries compared to South Africa.

The data required for the methodologies employed included:

- The Mpumalanga Provincial IWMP (2019)
- Mpumalanga District Municipality (DM) and Local Municipality (LM) IWMPs (Refer to Annexure A) and
- Mpumalanga Industrial Symbiosis Programme reports and Case Studies.

Figure 2 provides a structural depiction of the legislation and documents reviewed, their relevance to the article and their relationships to one another.

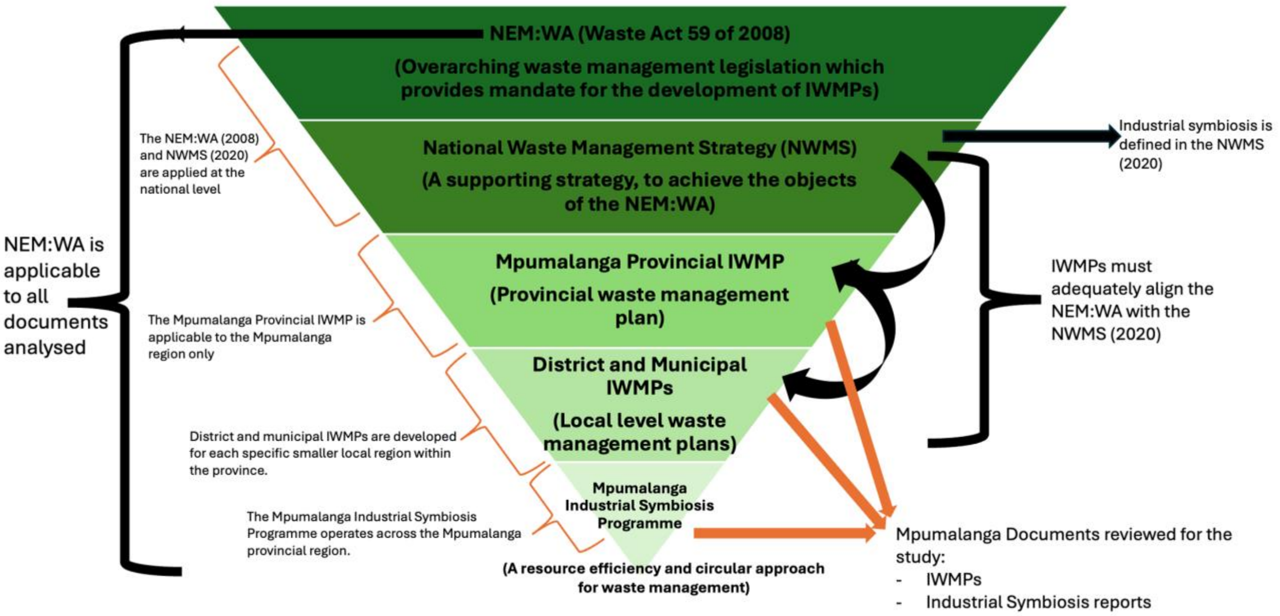

Figure 2. Hierarchical relationship between relevant legislation and analysed documents (Dune and Roberts, 2025).

Content analysis examined reference to inclusion of "industrial symbiosis" and "circular economy" terms in the IWMPs, through document word searches as well as frequency counts. This revealed the levels of buy-in, knowledge and circular economy commitment in the provinces, through the contents of their IWMPs. Given that IWMPs are facilitated by Waste Management Officers, this exercise was also used to investigate the level of buy-in and recognition of industrial symbiosis as an approach that could aid in achieving IWMP goals. IWMPs from all local municipalities (LMs), district municipalities (DMs) and the province of Mpumalanga were obtained from waste and environmental officials or online from official municipal websites. The Mpumalanga Province has three (3) DMs and 17 LMs, and IWMPs from all 20 municipalities were obtained (Refer to map and list in Annexure A). Comparative analysis was also used to highlight waste management data accuracy and reporting issues in the province.

The quantitative method for data analysis used was descriptive statistics, which is a method of describing, interpreting and summarising large volumes of data and typical examples include numerical values such as averages and percentages, as well as graphical representations of data such as graphs (Holcomb, 2016; Nick, 2007). Descriptive statistics was also utilised to analyse data inefficiencies and the statistical reporting status of IWMPs. Employing qualitative and quantitative approaches aided in synthesising emerging themes in terms of the regulation, planning and implementation of industrial symbiosis, underpinned by statistical analyses. This mixed methodology guided the study to obtain valuable opportunities, with applicability in global contexts.

3.1. Study Delimitations and Limitations

The study location, Mpumalanga, is rural and faces various challenges such as reduced institutional capacity, financial limitations, a lack of advanced waste management programmes and data, poor integration and collaboration, inefficient resource use and a lack of waste management infrastructure (Mpumalanga Provincial IWMP, 2019). This limited the quality of IWMPs, the availability and accuracy of data and ultimately, study findings. A key limitation of the study is that while all municipality IWMPs formed part of the envisaged sample, some municipalities provided outdated IWMPs that are yet to be updated. As such, this may have led to reporting inefficiencies, a lack of updated data and potential inaccuracies of current data. The qualitative methodologies are specifically document and content analysis, which are qualitative research methods. Therefore, the study is based on the contents of the available or provided documents only. In addition, only two key concepts (i.e. “industrial symbiosis” and “circular economy”) were investigated for in the available IWMPs.

4. Results and Discussion

4.1. The Status of Mpumalanga IWMPS

Document analysis of the IWMPs analysed five variables, namely a) adoption of the IWMP by the Municipal Council, b) the status of endorsement by a relevant Member of the Executive Council (MEC), c) integration into an Integrated Development Plan (IDP), d) the validity of the IWMP and e) whether annual reporting was conducted. Figure 3 illustrates the findings. This data was obtained from the Mpumalanga Department of Co-operative Governance and Traditional Affairs.

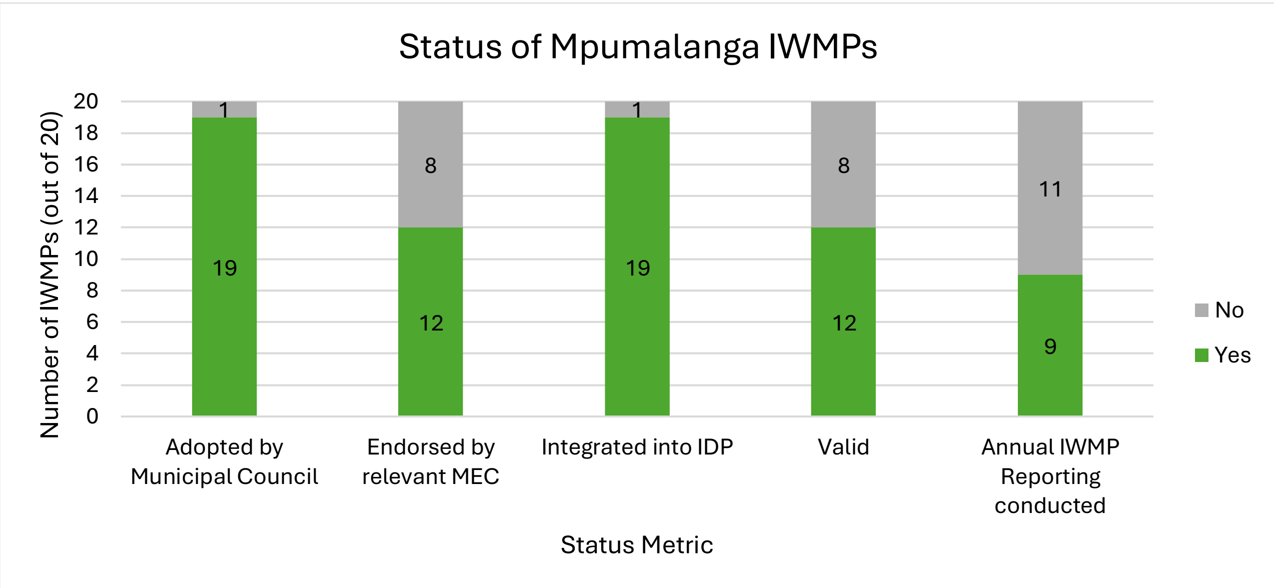

Figure 3. Status of IWMPs in Mpumalanga (Mpumalanga Department of Co-operative Governance and Traditional Affairs, 2024).

Figure 3 indicates that 19 out of the 20 municipalities have IWMPs that have been adopted by the council and have been integrated into IDP. This significantly contradicts the Mpumalanga Provincial IWMP (2019), which states that most IWMPs in the province had not been incorporated into IDPs. Twelve out of the 20 municipalities have valid IWMPs, while the remaining eight are either outdated or have not been endorsed by the relevant member of council. An IWMP validity rate of 60% may directly translate to hindered sustainable waste management in the province and further highlights limited institutional capacity, finance and skills availability. Only nine of the 20 municipalities (i.e. 45%) are conducting annual IWMP reporting, which results in the inability for municipalities to track their progress, potentially resulting in flaws and inefficient waste management service provision and programmes (Mukwevho et al., 2024; Mautla, 2022; Molaba, 2019). Trends of contradiction and inconsistent reporting evidence a lack of integration between provincial departments and further institutional and capacity issues (Venter and Hoffman, 2021). Table 1 explores issues of data management and accuracy, comparing reported volumes of waste generated and the number of disposal facilities in the province. Data from the South African Waste Information System (SAWIS, 2019) versus data from the Mpumalanga Provincial IWMP (2019) are compared.

Table 1. Comparison of waste volumes reported in the Mpumalanga Provincial IWMP (2019) and SAWIS (2019)

Municipality	Tons of waste disposed by municipalities (Mpumalanga Provincial IWMP, 2019)	Number of disposal facilities (Municipalities IWMPs 2008-2018)	Total Waste received by disposal facilities (SAWIS, 2019)	Number of disposal facilities (SAWIS, 2019)
Ehlanzeni DM			217 753.60	1
Bushbuckridge LM	87 963.00	9	Not Data Captured	
City of Mbombela LM	Undetermined	8	145 945.00	2
Nkomazi LM	24 724.00	5	109 671.60	3
Thaba Chweu LM	10 593.00	4	554 450.10	
Gert Sibande DM			3 163 306.40	4
Chief Albert Luthuli LM	7 094.00	6	Not Data Captured	
Dipaleseng LM	6 768.00	3	439 506.00	2
Dr Pixley Ka Isaka Seme LM	22 958.00	4	Not Data Captured	1
Govan Mbeki LM	96 783.00	8	10 263 172.00	4
Lekwa LM	31 970.00	2	1 718 713.00	1
Mkhondo LM	29 241.00	2	25 300.50	2
Msukaligwa LM	25 328.00	6	5 452.60	2
Nkangala DM			6 510 827.40	5
Dr JS Moroka LM	43 435.00	3	775.80	1
Emakhazeni LM	5 789.00	4	Not Data Captured	1
Emalahleni LM	Undetermined	3	2 336 113.50	1
Steve Tshwete LM	92 140.00	2	2 121 984.00	7
Thembisile Hani LM	Undetermined	2	610.70	1
Victor Khanye LM	55 182.00	1	1 713.60	1
Total	**539 968**	**72**	**27 615 295.80**	**39**

Table 1 indicates various areas of inconsistent waste management data reporting within Mpumalanga. A key discrepancy is evident where the Mpumalanga Provincial IWMP (2019) indicated a total waste generation volume of 539 968 tons, while SAWIS (2019) reported 27 615 295.80 tons, a discrepancy of over 50 times more. Discrepancies of this magnitude emphasise poor data management and weak data credibility (Fiehn and Ball, 2005; Nahman and Godfrey, 2010; Cloete, 2022). A further incongruity observed in Table 1 is the number of waste facilities in the province, where the Mpumalanga Provincial IWMP (2019) reported a total of 72 facilities, while SAWIS (2019) reported only 39. The magnitude of this variance aligns with earlier findings on untrustworthy data.

Table 1 also reveals a peculiar case of reporting, where Govan Mbeki LM was reported as having had the highest volumes of waste disposed of, both by the Mpumalanga Provincial IWMP (2019) data, i.e., 96 783 tons and SAWIS (2019) data, i.e., 10 263 172 tons. This is an unusual outcome given that the population of

Govan Mbeki (310 117) is significantly lower than larger, more industrial and more densely populated municipalities such as Emalahleni LM (434 238), Bushbuckridge (750 821) and the province's capital, Mbombela LM (818 925) (Municipalities, 2025). Inconsistent reporting, erroneous data management, poor departmental collaboration and poorly or non-functional measurement equipment at disposal facilities are persistent limitations that have also been identified in the Mpumalanga Provincial IWMP (2019) and by Mukwevho et al (2024).

The key themes and challenges identified in this subsection of the analysis of the status of Mpumalanga IWMPs are:

- Poor integration and collaboration between the departments responsible for waste management.
- A lack of accuracy in waste management data and volumes.
- Possible limited financial resources to update IWMPs and develop them to the required standards as per the NEM: WA (2008) and NWMS (2020).
- A significant misalignment of IWMPs with the contents of the NWMS (2020), further showing a lack of circular economy tools incorporated in IWMPs.
- Limited skills, capacity, competency and technical knowledge of the full IWMP process by waste management officers.
- A lack of annual reporting, compliance and enforcement.

These themes are consistent with those identified by South African IWMP-related studies by Molaba (2019), Venter and Hoffman (2021), Cloete (2022), Mautla (2022), Radzilani (2019) and Mukwevho et al (2024) in other areas of the country, echoing the need for advanced circular systems that are strengthened by credible data.

4.2. The Status of the Mpumalanga Industrial Symbiosis Programme

The Mpumalanga Industrial Symbiosis Programme was launched in 2018, in partnership with the Mpumalanga Department of Economic Development and Tourism. Poor institutional commitment hinders the regional efforts of industrial symbiosis in this province, with significant reluctance, low levels of participation and understanding of industrial symbiosis from municipal Waste Management Officers. Since its inception, a key focus for the Mpumalanga Industrial Symbiosis Programme has been support for the development of green enterprises, particularly those that use waste as a resource for new projects. As such, the programme has conducted various material testing projects for waste-to-resource projects, such as testing of fly ash for building systems, fly ash for foundry ingots, black soldier flies as animal feed, plastic waste for sustainable bricks, as well as organic waste for biochar and eco-briquettes (National Cleaner Production Centre South Africa, 2025).

The annual performance highlights reported for the 2023/24 financial year boasted a successful synergy between a local farm and a small micro-medium rural enterprise, where 270 tonnes of agricultural waste was diverted from landfills but rather used as a raw material for the production of eco-briquettes. Another article published by ReSource (2021) reported that used drums that were previously disposed of at landfills were transformed into recycled dustbins, mitigating approximately 500 tons of greenhouse gas emissions. Irrespective of these accomplishments, participation and buy-in remain limited, which may be attributed to industrial symbiosis not forming part of the mandate of waste management officers within IWMPs. Drawing literature which suggests a poor alignment of IWMPs with the NWMS (2020), i.e. circular economy and innovative instruments, all IWMPs within Mpumalanga were analysed for the inclusion of the terms "industrial symbiosis" and/or "circular economy". This aimed to identify the depth of alignment of the IWMPs with the principles of the NWMS (2020), which is underpinned by circular economy thinking and industrial symbiosis. The findings are depicted in Figure 4.

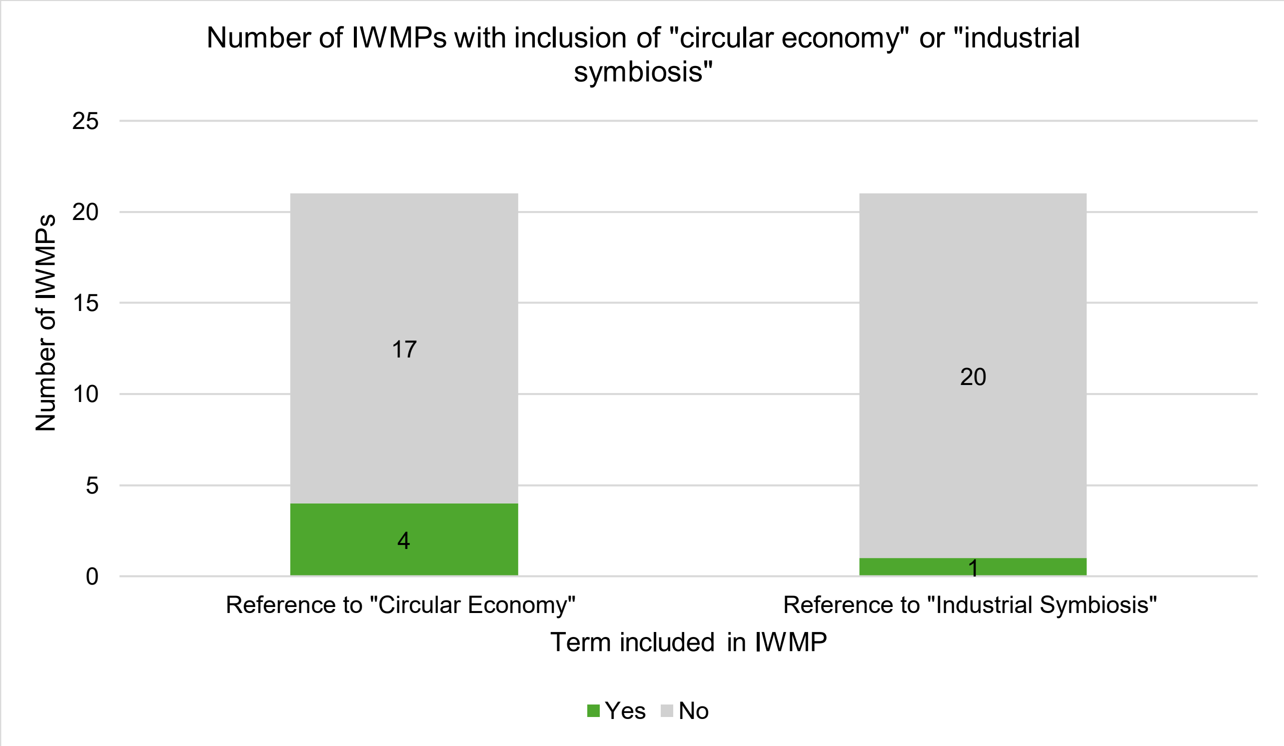

Figure 4. Number of IWMPs that refer to "circular economy" or "industrial symbiosis" in Mpumalanga (Dune and Roberts, 2025).

Document and content analysis revealed that only four municipalities refer to the "circular economy" in their IWMPs, while only one refers to "industrial symbiosis". These findings prove the lack of alignment between IWMPs and the NWMS (2020), despite this requirement as per IWMP legislative requirements. This reveals that the tools and strategies proposed in the NWMS (2020) are not adequately incorporated into IWMPs, serving as a prominent gap in Mpumalanga IWMPs. As a result, IWMPs are not progressive and innovative enough to address modern challenges of waste management, which are even more complex in low-income areas (Kubanza and Simatele, 2020).

Goal one of the Mpumalanga Provincial IWMP (2019) targets waste minimisation and diversion of waste from landfills, which are the direct goals and achievements of the industrial symbiosis programme. However, industrial symbiosis is not contained in The Mpumalanga Provincial IWMP (2019) and is only referred to in one out of 20 municipal IWMPs.

The complexities of the challenges of the Mpumalanga industrial symbiosis programme are listed below. These factors may also be themes for further research on the programme.

- Significant lack of impact reporting of the Mpumalanga industrial symbiosis programme.
- Lack of funding for the Mpumalanga industrial symbiosis programme by partner provincial departments.
- Limited buy-in or willingness to participate by municipal waste management officers.
- Lack of legislative pressure or enforcement regarding industrial symbiosis.
- Lack of technical waste management expertise in municipal departments.
- Industrial symbiosis is not being formally incorporated into waste management officers' responsibilities.
- Restricted awareness and training of officials on industrial symbiosis and its direct link to IWMPs and municipal waste management

Overall, the outcomes from the literature review, coupled with the findings above, reiterate the need for legislative rigour in the implementation of industrial symbiosis. Integrating industrial symbiosis into legislated IWMPs has the potential to regulate and institutionalise industrial symbiosis. Examples from international contexts, such as Kalundborg, Denmark indicate that policies that incorporate industrial symbiosis with integrated waste management frameworks and systematic data verification mechanisms achieve higher levels of success. To further link industrial symbiosis and IWMPs, monitoring methodologies should be integrated on inter-departmental platforms such as the South African Waste Information System, to prevent double-counting, account for data anomalies and normalise industrial symbiosis in waste management governance activities.

This chapter has addressed the prominent gaps that exist in literature, where waste management in coal-dependent economies, particularly Mpumalanga, are understudied. The South African waste management governance tool, IWMPs were identified as platforms for the inclusion of circular economy strategies, namely industrial symbiosis. IWMPs in Mpumalanga were therefore analysed for their commitment to circularity, and the results revealed a plethora of challenges listed above.

5. Integrating Industrial Symbiosis and Integrated Waste Management Plans

The structure of IWMPs includes a (i) situational analysis (ii) desired end state and goal setting, (iii) an alternatives assessment (iv) an implementation plan and (v) monitoring and evaluation as depicted in Annexure A. The approved public online advisory IWMP toolkit does not accommodate promotion of circular economy approaches, particularly industrial symbiosis. While the updated Draft IWMP Guidelines (2022) provide for the "circular waste economy" in the situational analysis, it is not integrated as an implementation instrument to achieve the goals of the IWMP.

Successful alignment of IWMPs and circular approaches can be more effectively achieved by integrating industrial symbiosis as a prominent circular and strategic implementation instrument. The implementation instruments required by the IWMP Guidelines (2022) are listed (Refer to Figure D in Annexure A), and industrial symbiosis is proposed in each as follows.

- *Partnerships:* The National Industrial Symbiosis Programme operates through partnerships. Through legislated partnerships with the National Cleaner Production Centre South Africa in IWMPs, local and provincial governments can work in collaboration with the National Cleaner Production Centre South Africa to implement industrial symbiosis and obtain technical support. Importantly, municipal Waste Management Officers will play a critical role in navigating and directing resources such as industrial symbiosis to areas where significant potential exists to divert waste from landfills or reduce illegal dumping.
- *Legislative Instruments*: Development and enforcement of by-laws – Industrial symbiosis can form part of municipal bylaws where industry is required divert waste from landfills and conduct routine reporting.
- *Funding mechanisms*: While the National Cleaner Production Centre South Africa Industrial Symbiosis Programme does not provide funding, the services are offered at a highly subsidised rate. The Industrial Symbiosis Programme also offers financial linkage assistance, where funding institutions are identified and approached to help fund sustainability projects.
- *Implementation Plan:* Inclusion of industrial symbiosis within the implementation plan may aid in performance tracking, diversion of waste from landfills, synchronised reporting and improved data management.

The sections listed above offer a practical platform for the integration of industrial symbiosis in IWMPs, addressing the issue of the lack of alignment between the NEM:WA (2008) and NWMS (2020) in IWMPs.

6. Conclusion

Waste generation and challenges continue to proliferate, while the advancement of circular strategies in legislation stagnates. Familiarity can be drawn globally from the South African context, in terms of waste management in poverty-stricken, yet industrial environments. The quality of integrated waste management and circular economy implementation continues to be crippled by a lack of knowledge and buy-in from Waste Management Officers, poor data availability and accuracy, institutional gaps, weak monitoring and reporting, low skill sets in responsible departments, diminishing landfill space with minimal initiatives in municipalities and inadequate waste management budgets. Asian regions such as China and India, that are also highly coal-dependent with significant socio-economic challenges, have embedded circularity in everyday waste management governance, and showcase models that can be adopted by South Africa.

This article encapsulates how industrial symbiosis offers a multitude of environmental, social and economic benefits that are directly aligned with municipal and provincial IWMP goals, which aid in achieving the objectives of both the NEM:WA (2008) and NWMS (2020). This article investigated the IWMPs of Mpumalanga for circular economy and industrial symbiosis commitment and found that these themes were strongly absent, exposing a gap between industrial symbiosis and waste management regulatory frameworks. The inclusion of industrial symbiosis as an implementation instrument in IWMPs can be manifested through partnerships, legislative Instruments, funding mechanisms and ultimately, within the IWMP implementation plan, filling the prominent research gap. Furthermore, the inclusion of industrial symbiosis in IWMPs could also foster a paradigm shift and change mindsets from waste management officers, as the custodians of IWMPs, to achieve improved compliance with waste management legislation. Investigating waste management and practical circularity implementation in the world's leading coal-dependent economy filled the existing research gap, where such areas are not only understudied but where a gap between the IWMP framework and practical implementation of circularity exists.

The challenges experienced in South Africa offer lessons for similar coal-dependent regions globally to drive circularity in waste management policy frameworks. The inclusion of industrial symbiosis in legislated IWMPs provides the following key offerings: (i) improved participation by stakeholders and municipal officials through institutionalisation of industrial symbiosis, (ii) a distinct paradigm shift from waste to resource through collaboration, integration and synchronisation, (iii) resilience and agile waste management that can address current environmental and socio-economic challenges which driving a circular economy and (iv) achieve the alignment of the NEM:WA (2008), NWMS (2020) and global targets through the sustainable development goals and (v) an opportunity to streamline and improve waste management data through inter-departmental, public and private partnerships. Globally relevant insights on the inclusion of industrial symbiosis in similar waste management governance frameworks, such as IWMPs, may be achieved through similar research in different environments, to ensure resilience and growth in the waste management sector.

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Data availability The data utilised in this article was obtained from individuals who signed consent forms, stipulating that their identities and questionnaire responses would remain confidential. As such, data pertaining to respondents is not available. The data is confidential.

Declarations

Competing Interests The authors declare no competing interests.

Ethics approval/consent During the proposal protocol stage of this project, the Faculty Research and Innovation Committee (FRIC) at the Central University of Technology Bloemfontein, Free State Province, South Africa, decided that standard ethical requirements are to be followed, and that no official ethical application through the ethical committee is required.

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Annexure A – Article Supporting Information

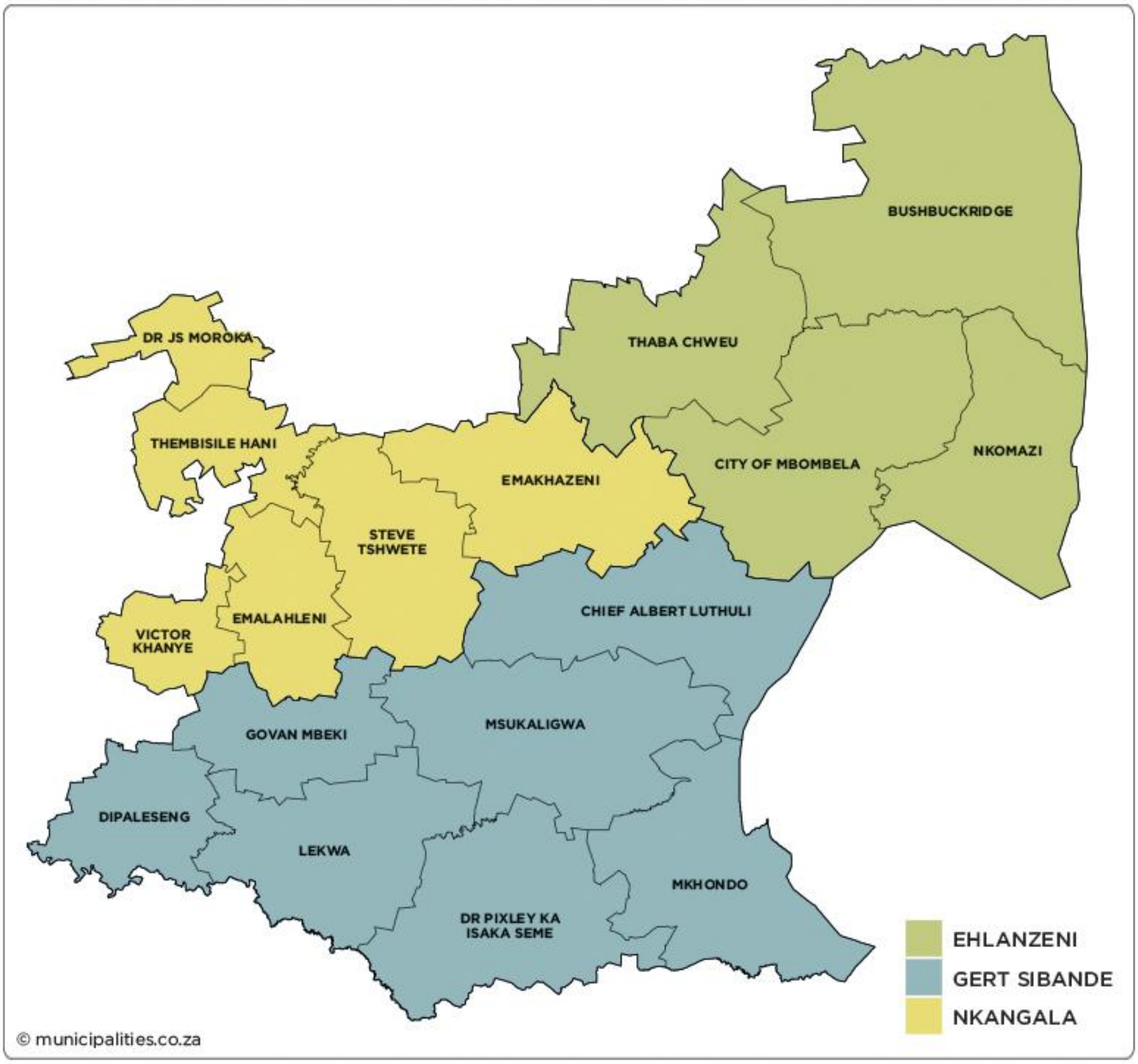

Figure A. Map of Mpumalanga district and local municipalities (Municipalities of South Africa, 2025).

List of IWMPs that form part of this article:

- Ehlanzeni DM IWMP (2023)
- Bushbuckridge LM IWMP (2019)
- City of Mbombela LM IWMP (2010)
- Nkomazi LM IWMP (2018)
- Thaba Chweu LM IWMP (2021)
- Gert Sibande DM IWMP (2024)
- Chief Albert Luthuli LM IWMP (2022)
- Dipaleseng LM IWMP (2023)
- Dr Pixley Ka Isaka Seme LM IWMP (2022)
- Govan Mbeki LM IWMP (2022)

- Lekwa LM IWMP (2022)
- Mkhondo LM IWMP (2023)
- Msukaligwa LM IWMP (2022)
- Nkangala DM IWMP (2019)
- Dr JS Moroka LM IWMP (2018)
- Emakhazeni LM IWMP (2022)
- Emalahleni LM IWMP (2023)
- Steve Tshwete LM IWMP (2024)
- Thembisile Hani LM IWMP
- Victor Khanye LM IWMP (2009) and
- Mpumalanga Provincial IWMP (2019).

The implementing partners of industrial symbiosis for each province are listed:

- Mpumalanga – Mpumalanga Department of Economic Development and Tourism
- Gauteng - Gauteng Department of Agriculture and Rural Development
- Kwazulu-Natal - The Kwazulu-Natal Department of Economic Development, Tourism and Environmental Affairs
- Limpopo – Limpopo Department of Economic Development, Environment and Tourism
- Free State – Free State Department of Economic Development, Small Business Development, Tourism and Environmental Affairs; and
- Eastern Cape - Eastern Cape Economic Development, Environmental Affairs & Tourism
- Northern Cape - Northern Cape Department of Agriculture, Environmental Affairs, Rural Development, and Land
- North West - North West Provincial government and
- Western Cape – Conducted by GreenCape.

The industrial symbiosis methodology adopted by the National Cleaner Production Centre South Africa.

- *“Step 1: Business Opportunity Workshop (Identify companies)*
- *Step 2: Identify a contact person in a company.*
- *Step 3: Company visit*
- *Step 4: Discuss waste streams.*
- *Step 5: Register stream on the database.*
- *Step 6: Finding a match for the stream to create a synergy.*
- *Step 7: Facilitate interaction between company matches.*
- *Step 8: Waste exchange takes place/waste moving.*
- *Step 9: Record synergy on database*
- *Step 10: Synergy sign-off*
- *Step 11: Follow up on synergy to maintain relationship and continuity.*
- *Step 12: Case study write-up to collect data on waste diversion, additional revenue, private investment, GHG savings, job creation, cost savings etc.”* (National Cleaner Production Centre South Africa, 2025)

The benefits of industrial symbiosis

Figure B. "Benefits of Industrial Symbiosis" (National Cleaner Production Centre South Africa, 2025)

Goals of the Mpumalanga Provincial IWMP

The key goals that were defined for the Mpumalanga province as per the Mpumalanga Provincial IWMP (2019) were as follows:

- *"Goal 1: To promote waste minimisation and diversion in the province.*
- *Goal 2: Strengthened education, capacity and advocacy towards integrated waste management.*
- *Goal 3: Improved waste management services and infrastructure planning*
- *Goal 4: Improved IndWMP and implementation for efficient waste services and infrastructure*
- *Goal 5: Develop institutional capacity to address integrated waste management in the province.*
- *Goal 6: Improved compliance with environmental regulatory framework; and*
- *Goal 7: Community-based waste management"* (The Mpumalanga Provincial IWMP, 2019).

The IWMP Process

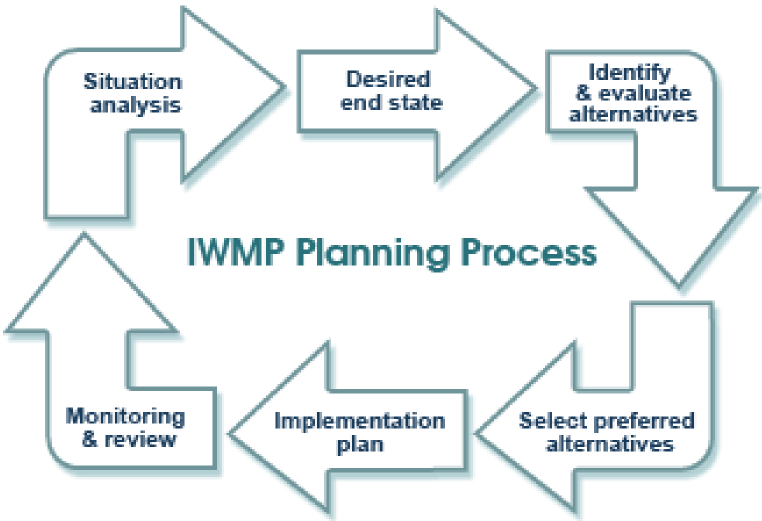

Figure C. Integrated Waste Management Plan (IWMP) Planning Process (Department of Environmental Affairs, 2012)

IWMP toolkit detailing the requirements for the Implementation Instruments chapter of the IWMP.

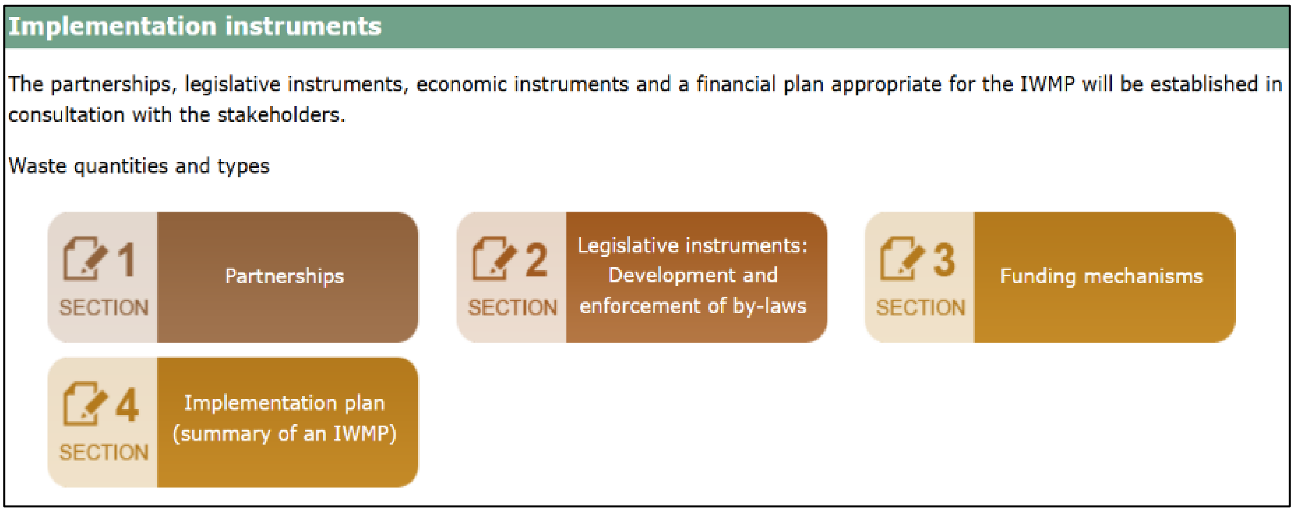

Figure D. Implementation instruments for an IWMP (Department of Environmental Affairs, 2012)