Waste-to-Energy in a Destruction Oriented System

A Technological Innovation Systems Analysis on HCRW Incineration in South Africa

Master's thesis in Management and Economics of Innovation

ALEXANDRA GULLBERG
LUKAS SJÖSTRAND

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
DIVISION OF INNOVATION AND R&D MANAGEMENT

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2026
www.chalmers.se

Waste-to-Energy in a Destruction Oriented System

A Technological Innovation Systems Analysis on HCRW Incineration in South Africa

ALEXANDRA GULLBERG

LUKAS SJÖSTRAND

Department of Technology Management and Economics

Division of Innovation and R&D Management

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2026

Waste-to-Energy in a Destruction Oriented System
A Technological Innovation Systems Analysis on
HCRW Incineration in South Africa
ALEXANDRA GULLBERG
LUKAS SJÖSTRAND

Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone +46 (0)31-772 1000

Cover: An Averda employee handling waste containers at an incineration plant.

Gothenburg, Sweden 2026

Waste-to-Energy in a Destruction Oriented System
A Technological Innovation Systems Analysis on
HCRW Incineration in South Africa

ALEXANDRA GULLBERG
LUKAS SJÖSTRAND

Department of Technology Management and Economics
Chalmers University of Technology

SUMMARY

Energy recovery from waste is often discussed as a way to address environmental pressure, resource inefficiency, and electricity insecurity at the same time. In South Africa, however, the possibility of developing waste to energy, WtE, from healthcare risk waste, HCRW, incineration raises a more complex question. Existing incinerators already perform a necessary treatment function, but they were designed to destroy hazardous waste safely, not to recover energy. This thesis therefore examines whether the surrounding system can support a shift from destruction-oriented incineration toward WtE.

The study applies a Technological Innovation Systems, TIS, framework and is based on a qualitative embedded single case study of Averda's South African HCRW treatment activities. The analysis draws on interviews, site visits, field observations, and secondary documents, including material from the case company, regulators, experts, technology suppliers, and other relevant industry actors. The empirical material was analysed through iterative thematic analysis and subsequently interpreted through TIS structures, functions, and inducement and blocking mechanisms, with attention to the justice implications of the pathway.

The findings show that the system contains some conditions that could support WtE development, including existing incineration infrastructure, operational experience, technical knowledge, and policy attention to waste and energy challenges. However, these inducements remain weak. The system is primarily organised around safe destruction, compliance, and treatment continuity rather than energy recovery. WtE development is constrained by weak market formation, unclear electricity offtake conditions, limited experimentation, ageing and manual plant infrastructure, restricted resource mobilisation, and continued dependence on established waste management practices.

The thesis concludes that WtE from HCRW incineration in South Africa is technically conceivable but systemically constrained. Under current conditions, it should not be understood as an imminent or scalable electricity generation pathway, but rather as a conditional and site specific energy recovery option within a destruction oriented system.

Keywords: Waste-to-energy, healthcare risk waste, incineration, Technological Innovation Systems, South Africa, Global South, energy transition, energy justice, waste management, systemic alignment

Acknowledgements

First and foremost, we would like to thank our supervisor, Linus Thomson, for his guidance, support, and valuable feedback throughout the thesis process. His insights and encouragement have been greatly appreciated and have helped us move this work forward. We would also like to thank our examiner, Ingrid Johansson Mignon, for her time and thoughtful input.

We would also like to express our gratitude to our case company, Averda, for making this study possible. We are very grateful to Henrico Swanepoel for his openness, support, and willingness to share his knowledge and experience with us throughout the project. His engagement has been of great importance to this research. We would also like to thank Fredrik for being so helpful during our site visit in George and for contributing valuable practical insights.

In addition, we would like to thank all interviewees and everyone else who contributed to this study by sharing their time, perspectives, and expertise. Their input has been invaluable to our work and has given us a deeper understanding of the topic.

We would also like to express our sincere gratitude to Stenastiftelsen for their financial support through the scholarship that made this research possible.

Finally, this thesis marks the end of our five years at Chalmers University of Technology, studying Industrial Engineering and Management. We would therefore also like to thank everyone who has been part of our journey during these years and who, in different ways, has contributed to making our time at Chalmers both meaningful and memorable.

Gothenburg, 28 May 2026

Alexandra Gullberg & Lukas Sjöstrand

Abbreviations

The abbreviations listed below are used throughout this thesis.

AEL	Air Emission License
DFFE	Department of Forestry, Fisheries and the Environment
ETD	Electro Thermal Deactivation
HCRW	Healthcare Risk Waste
ISWA	International Solid Waste Association
SANEDI	South African National Energy Development Institute
TIS	Technological Innovation System
UNEP	United Nations Environment Programme
WHO	World Health Organization
WtE	Waste-to-Energy

Table of Contents

List of Figures

List of Tables

1

Introduction

This introductory chapter presents the research background and identifies the problem to be addressed. It further defines the purpose of the study, outlines the research questions, and specifies the scope and delimitations.

1.1 Background

Global society is increasingly shaped by the triple planetary crisis of climate change, biodiversity loss, and pollution, which intensifies pressure across interdependent ecological and sociotechnical systems (OECD, 2025). These challenges are closely linked to how economies extract natural resources, consume energy, build and operate infrastructure, and manage the residuals of production and consumption (United Nations Environment Programme [UNEP], 2021). In this sense, waste is not only an environmental byproduct, but also a reflection of how material and energy flows are organised, governed, and valued within society. From a socio-metabolic perspective, waste streams reveal how environmental burdens and resource losses are embedded in wider production and consumption systems (D'Alisa & Demaria, 2024). Addressing waste related sustainability challenges therefore requires more than technical solutions, since such challenges emerge from the interaction between ecological conditions and the sociotechnical systems through which waste, energy, and material flows are organised.

Historically, in many industrialised high-income societies, waste management developed from relatively simple and low-cost landfill-based systems towards more advanced forms of thermal treatment as waste volumes increased, land scarcity intensified, and public health and environmental concerns became more pressing. Incineration, which in this thesis refers to the controlled high temperature combustion of waste for destruction and volume reduction, was first introduced mainly to reduce waste volumes and manage sanitary risks, but in some of these settings it gradually evolved into waste-to-energy (WtE) through advances in combustion technology, emissions control, and energy recovery systems (Makarichi et al., 2018). This shift did not occur through technological progress alone. It was also supported by policy and regulatory frameworks, stable energy markets, and long-term investments in electricity, district heating, and other infrastructure that allowed recovered energy to be absorbed and used within the wider energy system (Tobiasen & Kamuk, 2012; Nordic Council of Ministers, 2024). In this context, the distinction between the *Global North* and the *Global South* is useful as an analytical shorthand for differences in industrial development, institutional capacity, infrastructure provision, and investment conditions, rather than as a strictly geographical division. Broadly speaking, the Global North refers to higher income and more industrialised contexts where waste and energy systems have often been built up over longer periods under more stable regulatory and infrastructural conditions, while the Global South refers more broadly to lower and middle income contexts where waste governance is more often shaped by financial constraint, fragmented institutions, rapid urbanisation, and uneven service provision (UNEP, 2021 & International Solid Waste Association [ISWA], 2024). In many Global North settings, stricter environmental regulation, policy support, and long-term investment in waste and energy infrastructures helped enable a gradual transition from uncontrolled dumping towards engineered landfills and incineration facilities with energy recovery (Kaza et al., 2018; UNEP, 2021 & ISWA, 2024; D'Alisa & Demaria, 2024). The development of WtE was therefore not driven by technological availability alone, but by the presence of broader sociotechnical conditions that enabled waste management and energy provision to become more closely integrated.

In the Global South, waste systems often develop under conditions of financial constraint, fragmented governance, uneven infrastructure provision, and rapid urbanisation (Kaza et al., 2018; Marshall & Farahbakhsh, 2013). In such contexts, disposal-oriented pathways often remain dominant, not necessarily because alternative technologies are unknown, but because the surrounding system may not support their implementation and diffusion. Research within Technological Innovation Systems (TIS) shows that the presence of a technically mature solution does not lead to adoption. What matters is whether the surrounding configuration of actors, institutions, networks, and infrastructures supports processes such as legitimation, market formation, and resource mobilisation (Bergek et al., 2008; Carlsson & Stankiewicz, 1991). Where these conditions are limited, waste management can remain locked into established destruction and disposal trajectories even when recovery-based alternatives are technically conceivable (Corvellec et al., 2013).

South Africa provides a relevant illustration of these dynamics. The country's waste system remains strongly landfill oriented, while public and regulatory attention is still heavily shaped by disposal capacity, compliance, and uneven implementation across regions and municipalities (IEA Bioenergy, 2023; Kaza et al., 2018). Thermal treatment plays a limited and specialised role and is used mainly for hazardous waste streams, particularly healthcare risk waste (HCRW), where the central priority is secure destruction rather than resource or energy recovery (Olaniyi et al., 2018, World Health Organization [WHO], 2014). This makes HCRW incineration institutionally important within the waste system, but not necessarily well aligned with recovery-oriented development (IEA Bioenergy, 2023; Olaniyi et al., 2018). In other words, the system gives incineration a clear role as a treatment technology, while offering less support for its potential transformation into a WtE pathway (IEA Bioenergy, 2023; Bergek et al., 2008).

This tension becomes especially relevant in relation to existing private sector incineration facilities. In South Africa, Averda operates two HCRW incineration plants, located in George in the Western Cape and in Klerksdorp in the North West, both dedicated to the treatment of HCRW (Averda, n.d.-a). These facilities rely on high temperature thermal treatment to destroy regulated waste fractions and produce ash for disposal at hazardous waste landfill sites (Averda, n.d.-b, WHO, 2014). Although the plants handle waste streams with energy recovery potential and already operate through high-temperature incineration, the available evidence suggests that their current role is primarily linked to destruction, compliance, and operational continuity, while the extent to which they can be reoriented toward integration with local energy systems remains an empirical question (Averda, n.d.-b; IEA Bioenergy, 2023). This makes them an analytically important case. They represent settings where the technical basis for discussing WtE exists, while the systemic conditions for implementing such a shift remain uncertain (Bergek et al., 2008; IEA Bioenergy, 2023).

This uncertainty is important because WtE is often presented as a promising response to both waste and energy challenges (Makarichi et al., 2018; IEA Bioenergy, 2023). In the South African context, however, its relevance depends not only on whether energy can theoretically be recovered from incineration, but on whether regulatory priorities, infrastructure conditions, organisational capabilities, market incentives, and legitimacy dynamics make such recovery operationally and economically credible (Bergek et al., 2008; Rogge & Reichardt, 2016; IEA Bioenergy, 2023).

To examine this, the study applies a Technological Innovation Systems (TIS) perspective. A TIS refers to the set of actors, institutions, networks, and infrastructures that shape how a specific technology develops, diffuses, and becomes used in society (Bergek et al., 2008; Bergek et al., 2015). The framework is useful in this context because it shifts attention away from technology in isolation and towards the broader system conditions that enable or constrain implementation. In this thesis, the TIS perspective is used to analyse how the innovation system surrounding WtE incineration in South Africa is structured and how key system functions, such as knowledge development, legitimation, market formation, and resource mobilisation, are expressed in practice. The Averda case thereby serves as an empirical entry point for investigating whether South Africa's existing HCRW incineration system is configured in a way that can support recovery-oriented upgrading, or whether its structures and functions primarily reproduce destruction, compliance, and treatment continuity.

1.2 Problem identification

In South Africa, WtE from HCRW incineration remains weak because the surrounding system is more clearly organised around destruction and safe treatment than around recovery-oriented development (IEA Bioenergy, 2023; Olaniyi et al., 2018). The research problem is therefore not technical feasibility in isolation, but whether WtE can become institutionally legitimate, operationally manageable, and economically defensible under existing conditions.

This problem is particularly relevant in a waste system that remains strongly landfill oriented and unevenly configured, while incineration is used mainly for hazardous waste destruction with limited integration into broader energy systems (Kaza et al., 2018; Olaniyi et al., 2018; IEA Bioenergy, 2023). Although WtE is visible in policy discussions and sometimes presented as a promising response to both waste and energy challenges, policy interest does not in itself amount to coordinated system support. From a TIS perspective, the core problem is therefore to examine whether there is a mismatch between the existing system orientation and the requirements of a recovery-oriented WtE pathway. South Africa's HCRW incineration system performs an important function for secure treatment and destruction, but the same structures and priorities do not necessarily support a shift towards energy recovery. This points to weaknesses in system structures and functions, especially in relation to legitimation, market formation, and resource mobilisation, that may constrain a recovery-oriented pathway even where technical possibilities exist (Bergek et al., 2008; Bergek et al., 2015; Rogge & Reichardt, 2016).

The issue is also broader than one of implementation alone. In a Global South context marked by uneven infrastructure and competing priorities, WtE incineration is only one possible pathway within the wider waste and energy transition (WHO, 2014; WHO, 2019). It also occupies a contested position in relation to the waste hierarchy, where waste prevention, reuse, and recycling are generally prioritised above energy recovery, raising questions about whether WtE complements or displaces higher order pathways in practice (D'Alisa & Demaria, 2024). The problem is therefore not only whether WtE can be advanced, but whether the surrounding system can support a pathway that is technically credible, institutionally aligned, and justifiable within broader sustainability and justice concerns (McCauley & Heffron, 2018).

1.3 Purpose and research questions

To address this problem, the purpose of this study is to examine the systemic conditions for implementing WtE incineration in South Africa. Using a TIS framework, the study analyses how the surrounding innovation system is configured and how it functions, with attention to the inducement and blocking mechanisms that enable or constrain WtE development. Through an in-depth case study of Averda, the study further seeks to explain what these system dynamics reveal about the possibilities, limits, and justice implications of WtE as an energy transition pathway in a Global South context.

Table 1.1 An overview of the research questions

Research Question	Description
1	How is the innovation system surrounding WtE incineration configured, and how does it function in South Africa?
2	Which inducement and blocking mechanisms enable or constrain the development of WtE within this system?
3	What do these system dynamics reveal about the possibilities, limits, and justice implications of WtE as an energy transition pathway in a Global South context?

1.4 Scope and delimitations

This thesis examines the systemic conditions for WtE incineration in South Africa, with a primary focus on existing incineration plants that treat HCRW. It is conducted as an in-depth case study of Averda, centred on its facilities in George and Klerksdorp, while also drawing on interviews with regulators, experts, technology suppliers, and other industry actors to situate the case within the wider South African HCRW incineration field.

The study is delimited primarily to possible WtE development in relation to existing HCRW incineration infrastructure, making retrofit and upgrade options the main empirical entry point. At the same time, the analysis also considers new build alternatives at a conceptual level where relevant to broader questions of system alignment, scale, credibility, and implementation. The analysis is therefore concerned with systemic and innovation related conditions rather than detailed plant design or project level engineering optimisation.

2

Theoretical Background

This chapter outlines the theoretical background of the study. It begins by positioning WtE within a broader transitions perspective and then narrows into the energy transitions literature in order to clarify why implementation pathways must be understood as systemic rather than purely technical. Building on this framing, the chapter introduces the TIS framework as the main analytical lens of the thesis. It then presents the structural components, system functions, and functional dynamics that guide the empirical analysis. Finally, the chapter contextualises the TIS framework through Global South conditions, justice related concerns, and key limitations of the approach.

2.1 Transitions as a systemic challenge

Transitions research is concerned with how sociotechnical systems change over time in response to broader societal pressures and sustainability challenges (Köhler et al., 2019; Markard et al., 2012). Rather than treating technological change as a linear process driven mainly by invention and adoption, the literature emphasises that transitions involve long-term reconfigurations of technologies, institutions, infrastructures, markets, and social practices (Markard et al., 2012). In this perspective, implementation and diffusion are shaped not only by whether a technology performs well in technical terms, but also by the wider sociotechnical and political conditions that support or constrain its development.

This framing is important because it shifts attention away from technology in isolation and towards the broader conditions under which technologies are implemented, adapted, and scaled. Upgrading incineration toward electricity generation as a WtE configuration cannot be understood only through plant-level engineering performance. It is also shaped by governance conditions, institutional alignment, political economy, and broader system dynamics (Geels, 2002; Rogge & Reichardt, 2016). Transitions are therefore not neutral or automatic processes. They involve choices about which pathways are prioritised, which trade-offs are accepted, and which forms of change become credible and legitimate over time (Köhler et al., 2019; Markard et al., 2012).

A related implication is that diffusion should not be understood as a simple process of linear uptake. Empirical work shows that transitions often involve adaptation, recombination, and incremental adjustment rather than straightforward scaling of a stable solution. Outcomes depend on whether actors can establish the organisational capabilities, learning processes, and coordination routines required to sustain development over time (Fernandez & Watson, 2022; Tomai et al., 2024). This is particularly relevant for technologies that depend on multiple sectors and regulatory domains, where system development requires not only technological readiness, but also institutional coherence and coordinated support (Bergek et al., 2015; Rogge & Reichardt, 2016).

The transitions literature also highlights that system change is shaped by path dependence and lock-in. Existing infrastructures, established rules, incumbent practices, and long-lived assets can stabilise current configurations and make alternative pathways difficult to implement, even when technically feasible options exist (Markard et al., 2012; Unruh, 2000). This helps explain why transitions often proceed unevenly and why apparently promising technologies may struggle to move beyond isolated pilots or marginal applications. From this perspective, the relevant question is not only whether a new technology exists, but whether the surrounding system is configured in ways that allow it to develop, diffuse, and become legitimate over time.

Building on this broader transitions perspective, energy transitions provide a more specific lens for understanding how changes in energy systems unfold, and why such changes often remain contested, uneven, and dependent on wider system conditions.

2.1.1 Energy Transitions

Energy transitions research examines how energy systems change in response to intertwined socio-ecological challenges such as climate change, environmental degradation, and persistent inequality (Köhler et al., 2019; Markard et al., 2012). Energy systems matter because they shape emissions, resource use, and development outcomes, while also influencing who benefits from change and who bears its costs (IPCC, 2023; Köhler et al., 2019). The literature therefore emphasises that energy transitions are not neutral processes. They involve choices about which goals should be prioritised, which pathways should be supported, and how trade-offs should be handled across different groups in society (Köhler et al., 2019). At the same time, global emissions have continued to increase despite extensive policy efforts, which underlines why it remains important to explain why change is often slow and contested, and why there is rarely a single agreed transition pathway (IPCC, 2023; Köhler et al., 2019).

Energy transitions can be defined as long-term reconfigurations in how energy services are produced, distributed, and used. Such change is shaped by interactions between technologies, institutions, markets, infrastructures, and societal priorities (Markard et al., 2012). This also means that energy-related decisions are assessed through multiple logics at the same time, rather than only through technical or economic performance. Energy systems are embedded in and interact with ecological, social, and economic systems, meaning that changes in energy production and use can influence emissions, resource use, service reliability, investment requirements, and social legitimacy simultaneously (Yang et al., 2024). Figure 2.1 illustrates these interactions.

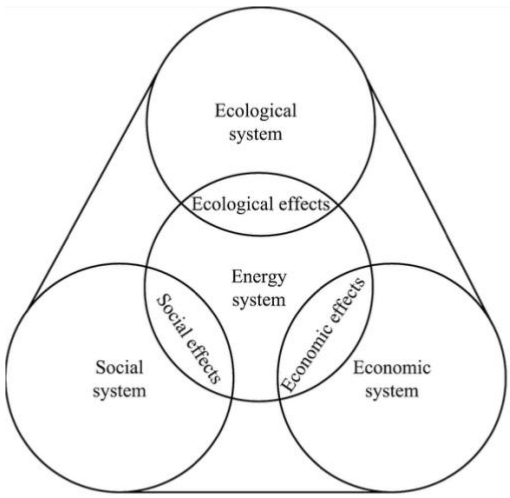

Figure 2.1. The energy system embedded in ecological, social, and economic systems. (Yang et al., 2024).

In the context of WtE, this embeddedness is particularly important. Upgrading incineration toward energy recovery is not judged only by whether electricity can technically be produced from waste heat. It is also evaluated in relation to environmental consequences, economic credibility, institutional acceptability, and the ability of the surrounding system to absorb and support the recovered energy (Makarichi et al., 2018; Markard et al., 2012). WtE therefore occupies a position between waste management and energy provision, which makes its development dependent on alignment across both sectors (IEA Bioenergy, 2023; Rogge & Reichardt, 2016).

Research on energy transitions includes several complementary strands. The multi-level perspective is one influential strand that describes transitions as interactions between niches, regimes, and broader landscape pressures (Geels, 2002). Policy mixes perspectives add emphasis on how interacting policy instruments shape direction, credibility, and investment conditions, which is particularly relevant for understanding diffusion in capital-intensive systems (Rogge & Reichardt, 2016). Together, these perspectives help explain why technical feasibility is rarely sufficient for diffusion, since lock-in and path dependence are reinforced by long-lived assets, established rules, and dominant routines (Markard et al., 2012; Unruh, 2000).

For this thesis, these insights are important because they make clear that the central analytical problem is not simply whether WtE can work in principle, but whether the surrounding system supports its implementation and diffusion. WtE depends on governance capacity, credible market arrangements, regulatory alignment, organisational capabilities, and coordination across sectors (Bergek et al., 2008; Markard & Truffer, 2008). The literature therefore points toward the need for an analytical framework that can examine these broader system conditions more explicitly around a focal technology. This is where the TIS framework becomes useful (Bergek et al., 2008).

2.2 TIS as the main analytical framework

The TIS framework is well established for analysing how a technological field develops by focusing on the conditions that enable or constrain innovation (Bergek et al., 2008). Rather than explaining change through individual firm strategies or isolated policy measures, TIS highlights the co-evolution of actors, institutions, networks, and infrastructures that shape innovation trajectories over time (Markard & Truffer, 2008). This perspective is particularly relevant for sustainability technologies, where progress depends on coordination across sectors, regulatory alignment, and the creation of legitimacy and markets, not only technical feasibility

(Markard et al., 2015). In this thesis, TIS is used as the main analytical framework because it provides a structured way to examine why a pathway that appears technically conceivable may remain weak in practice.

System performance is commonly assessed through a functions perspective that captures the key processes required for a technology field to grow and stabilise (Hekkert et al., 2007). This enables a structured diagnosis of constraints, for example, when market formation, resource mobilisation, or legitimation remain weak (Bergek et al., 2008). Recent work shows that TIS has become influential in sustainability transitions research because it connects these processes to broader socio-technical change and helps identify leverage points for intervention (Weckowska et al., 2025).

TIS is particularly relevant for this study because the research problem concerns why energy recovery from waste incineration remains difficult to develop and scale in a specific national context, despite the apparent availability of technical solutions. Addressing this type of problem requires an analytical lens that can capture how technological upgrading depends on changes in regulation, infrastructure, organisational capabilities, and market incentives, and how weaknesses in any of these areas can limit development (Bergek et al., 2008; Markard & Truffer, 2008). In other words, the study is not only interested in whether energy recovery is technically feasible, but in whether the surrounding system provides the conditions needed for implementation, diffusion, and sustained operation (Bergek et al., 2008).

Moreover, the shift from incineration as a disposal practice toward incineration with energy recovery is shaped by interactions with both the waste system and the energy system, including established practices and institutional arrangements (Ulmanen & Bergek, 2021). The TIS framework is therefore used to assess whether the structural conditions and system functions required for implementation and diffusion are present in the South African case. Figure 2.2 summarises the TIS framework applied in the thesis.

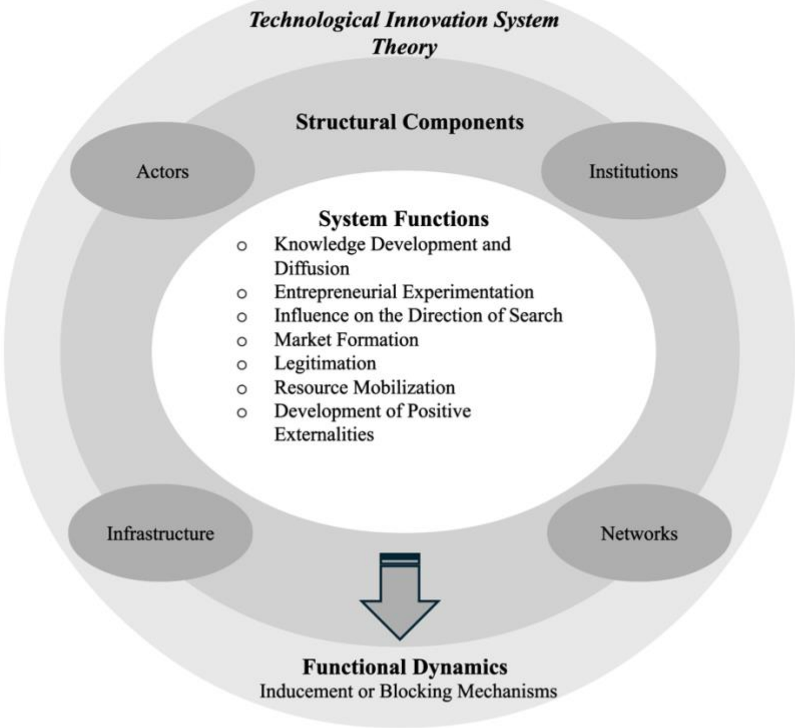

Figure 2.2. Overview of the Technological Innovation System framework applied in this thesis. (Own Illustration).

In this study, TIS is used to move from describing contextual constraints to explaining system level causes of limited diffusion through structures, functions, and their interactions (Bergek et al., 2008; Hekkert et al., 2007). To operationalise this analysis, the next sections first map the structural components of the focal system and then assess functional strengths, weaknesses, and dynamics.

2.2.1 Structural components

The TIS framework conceptualises structural components as foundational elements that shape how a technology field develops and how innovation activities are coordinated over time. Mapping these structures is a core step in TIS analysis because it clarifies which actors are involved, how they interact, and which institutional and material conditions enable or constrain system development (Bergek et al., 2008). In this thesis, the structural analysis focuses on four commonly applied components, namely actors, institutions, networks, and infrastructure, since these elements strongly influence system functioning and the direction and pace of technological change (Markard & Truffer, 2008; Wieczorek & Hekkert, 2012). At the same time, these structures should be understood as embedded in broader contextual settings, meaning that sectoral and technological environments can shape actor roles, institutional alignment, and access to resources and capabilities (Bergek et al., 2015). This section therefore outlines each structural component to provide a clear basis for the subsequent analysis of system functions and system dynamics in the technological innovation system.

2.2.1.1 Actors

Actors are the individuals and organisations that create, diffuse, adopt, regulate, finance, contest, or otherwise shape the focal technology field. They typically include firms across the value chain, public authorities and regulators, research organisations and universities, financial actors, intermediaries, and civil society organisations (Carlsson & Stankiewicz, 1991; Bergek et al., 2008). In the WtE incineration context in South Africa, this includes commercial waste operators and plant owners, municipalities, environmental regulators, energy offtakers, technology suppliers, and financiers. Actors matter because they carry resources and capabilities, make strategic choices under uncertainty, and engage in coordinated or conflicting activities that influence system direction and momentum (Markard & Truffer, 2008). Local communities and Non-Governmental Organisations may also influence legitimation and permitting outcomes for incineration-based WtE. In many technological innovation systems, actor constellations also reflect power relations and incumbency dynamics, where established actors may stabilise existing practices while new entrants push alternative trajectories (Geels, 2002). In WtE, incumbency dynamics may relate to established landfill-based disposal practices and existing electricity procurement arrangements.

2.2.1.2 Institutions

Institutions refer to the “rules of the game” that structure behavior in the system, including both formal rules such as laws, standards, permits, and policy instruments, and informal rules such as norms, shared expectations, and culturally embedded beliefs (North, 1990; Scott, 2014). Institutions shape what is considered legitimate and feasible, how risks are perceived, and how quickly new solutions can be implemented through, for example, permitting and compliance requirements (Bergek et al., 2008). For WtE, this includes incineration permitting and emissions compliance requirements, waste classification, handling rules, municipal procurement requirements, and electricity market and grid-connection rules for selling recovered energy. Institutional alignment is particularly important in sustainability-oriented technology fields, where conflicts between policy goals, regulatory mandates, and social acceptance can strongly influence investment and diffusion (Markard et al., 2015).

2.2.1.3 Networks

Networks capture how actors are connected and how they exchange knowledge, coordinate activities, form alliances, and mobilise support. These interactions occur through formal collaborations such as partnerships, joint ventures, industry associations, and R&D projects, as well as through informal ties that facilitate information flow and trust-building (Powell et al., 1996; Granovetter, 1985). Network structures influence how quickly learning spreads, how collective expectations are formed, and whether the system can coordinate around shared problem definitions and solutions (Edquist, 2005). In the WtE incineration context, networks are often centred on waste-system coordination between municipalities, waste operators, and waste generators, for example around collection regimes, segregation practices, contracting processes, and arrangements that secure stable waste volumes and quality. In TIS terms, networks are central because they shape collective action capacity, reduce uncertainty, and can either strengthen system-building processes or reinforce fragmentation and lock-in (Bergek et al., 2008; Markard & Truffer, 2008). Fragmentation may be visible if these coordination arenas are weak, if contracting is short-term, or if learning and coordination remain limited across the waste management system.

2.2.1.4 Infrastructure

Infrastructure refers to the material and organisational foundations that enable a technology field to function and scale. This includes physical infrastructure such as plants, grids, logistics, and measurement systems, but also "soft" infrastructure such as skills, standards, testing facilities, and organisational routines that support reliable operation and system coordination

(Hughes, 1987; Bergek et al., 2015). Infrastructure matters because it shapes feasibility and costs, creates path dependencies, and can lock systems into established configurations that make alternative pathways harder to develop (Unruh, 2000). In the WtE context, this can include existing incineration facilities and retrofit readiness, stable waste logistics for feedstock supply, grid access and connection capacity, and monitoring systems for emissions and energy output. From a TIS perspective, infrastructure is therefore both an enabling condition and a potential barrier, depending on whether it aligns with the needs of the focal technology field and the broader transition direction (Geels, 2002; Markard et al., 2015). For example, limited grid capacity or unclear grid-connection processes can constrain WtE implementation even if plant-level upgrading is feasible.

2.2.2 System functions

System functions provide a process-oriented way to assess how well TIS performs by focusing on the key innovation processes that need to be present for a technology field to emerge, expand, and stabilise (Hekkert et al., 2007). In this approach, system development is understood as the outcome of seven interrelated functions: *knowledge development and diffusion*, *entrepreneurial experimentation, influence on the direction of search*, *market formation*, *legitimation*, *resource mobilisation*, and *development of positive externalities* (Hekkert et al., 2007; Bergek et al., 2008). Importantly, these functions rarely operate in isolation, they reinforce one another through cumulative feedback processes that create momentum, or they may remain weak and generate stagnation when key processes fail to develop (Bergek et al., 2008; Markard et al., 2015). The functions perspective is therefore widely used in TIS research to diagnose system strengths and weaknesses and to explain why technology fields progress in some contexts but struggle in others (Hekkert et al., 2007; Weckowska et al., 2025). The following section presents each system function in turn as the main analytical lens for evaluating current dynamics in the focal technology field and identifying critical constraints and potential intervention points (Bergek et al., 2008).

2.2.2.1 Knowledge development and diffusion

Knowledge development and diffusion refer to the generation of new scientific, technical, and operational knowledge about the focal technology, and the extent to which this knowledge spreads across relevant actors in the system (Hekkert et al., 2007). In emerging TISs, knowledge development is not limited to R&D outputs, it also includes learning from feasibility studies, pilot and demonstration projects, operational experience, environmental monitoring, and the development of managerial and regulatory know how (Bergek et al., 2008). In the WtE incineration context, this can include plant performance data (e.g., availability, efficiency), emissions monitoring results, residue/ash handling practices, and lessons from permitting and compliance processes. Diffusion is crucial because system growth depends on whether knowledge becomes shared, accessible, and usable across firms, regulators, municipalities, investors, and intermediaries, rather than remaining concentrated within a small number of organisations (Rogers, 2003).

This function tends to be stronger when there are stable arenas for exchange such as industry associations, research consortia, joint projects, workshops, and standardized reporting practices that turn project experience into reusable lessons (Markard et al., 2015). Conversely, it remains weak when data are scarce, contested, or not transparent, when results from pilots are not disseminated, or when capabilities are not institutionalised in routines, training, and standards that enable replication (Bergek et al., 2015). In TIS terms, weak knowledge diffusion often becomes a bottleneck because it sustains uncertainty for decision makers, delays permitting and finance, and limits the ability of actors to coordinate around credible expectations and viable configurations (Hekkert et al., 2007).

2.2.2.2 Entrepreneurial experimentation

Entrepreneurial experimentation captures how actors test different technological designs, organisational arrangements, and business models under real world conditions (Bergek et al., 2008). This function is particularly important in the formative stage, where uncertainty is high and the system needs variety to identify which technical variants, governance models, and value propositions are robust enough to scale (Markard & Truffer, 2008). Experimentation can include pilot plants and demonstration projects, but also experimentation with contracting structures, feedstock sourcing models, grid integration solutions, and compliance and monitoring practices. Such experimentation creates learning effects and provides visible proof of feasibility that can reduce uncertainty for other actors (Kemp et al., 1998). In the WtE incineration context, experimentation may involve retrofitting existing incinerators with energy recovery, testing different offtake arrangements for electricity, or evaluating alternative contracting models for securing feedstock and revenue stability.

Strong entrepreneurial experimentation is often characterised by multiple trials, variation in approaches, iterative learning between project generations, and mechanisms that codify and distribute lessons beyond the individual project (Hekkert et al., 2007). Empirically, this could appear as a pipeline of incremental upgrades across sites rather than a single one-off project. Weak experimentation is visible when projects are rare, repeatedly delayed, or designed as one-off initiatives that do not create a pipeline and do not generate transferable learning. In this context, repeated postponement of pilot energy-recovery units can signal that risks and uncertainties remain unresolved. From a functional dynamics perspective, experimentation can trigger positive feedback if it strengthens expectations, attracts resources, and contributes to legitimacy, which in turn enables additional projects and further learning (Suurs & Hekkert, 2009).

2.2.2.3 Influence on the direction of search

Influence on the direction of search refers to how expectations, priorities, and signals guide actors toward certain technological pathways and away from others (Hekkert et al., 2007). This includes guidance through policy targets, planning documents, regulatory clarity, and credible expectations about future demand and acceptability, which together shape where attention, investment, and organisational resources are directed (Bergek et al., 2008). For WtE incineration, key signals may include how national and municipal plans position incineration relative to landfill, recycling, and diversion priorities, and whether energy recovery is recognised within energy planning and procurement frameworks. Expectations are not merely reflections of "what will happen"; they are performative in the sense that they influence commitment, investment, coalition building, and the perceived legitimacy of solution pathways (Borup et al., 2006).

Direction of search tends to be stronger when policy goals are stable over time, responsibilities across sectors are aligned, and there is a shared understanding among key actors of what problem is being addressed and how the focal technology contributes (Markard et al., 2015). It tends to be weaker when objectives conflict, policy signals shift, or the focal pathway is ambiguously positioned relative to competing options. In sustainability transitions, this function also depends on how the focal TIS interacts with its context, since incumbent regimes and competing technologies shape the selection environment and can dilute or amplify signals (Bergek et al., 2015). Because TIS analyses are often used to identify "system weaknesses" that matter for policy, direction of search is a particular policy relevant function in transition-oriented settings (Jacobsson & Bergek, 2011).

2.2.2.4 Market formation

Market formation refers to how demand conditions are created and stabilised so that a new technology can be deployed, improved, and scaled, especially when established markets are dominated by incumbent solutions (Bergek et al., 2008). In early phases, markets are often "protected" or supported through policy instruments, procurement, contractual frameworks, or pricing mechanisms that reduce risk and allow actors to learn and invest. Over time, markets may expand, diversify, and become more competitive as uncertainty decreases and performance improves (Hekkert et al., 2007). Market formation is therefore a dynamic process where early uptake creates learning effects and cost reductions, which in turn can enable further diffusion (Bergek et al., 2008). In the WtE incineration context, market formation can depend on long-term waste supply contracts, gate fees, and payment arrangements for recovered energy.

Strong market formation can be indicated by a visible project pipeline, predictable revenue models, supportive contracting arrangements, and mechanisms that allow the technology to compete on more stable terms. Weak market formation is typically visible when projects do not reach implementation due to unclear revenue streams, limited customer willingness, or absent and inconsistent policy support (Bergek et al., 2008). In transitions contexts, market formation is closely tied to policy mixes, because scaling often requires both instruments that create opportunities for niche solutions and instruments that reduce the competitiveness or stability of incumbent practices. This highlights that market formation is not only about "creating demand" but also about shaping the competitive environment in which the technology is expected to grow (Kivimaa et al., 2020).

2.2.2.5 Legitimation

Legitimation concerns the extent to which the technology and its associated practices are perceived as appropriate, credible, and socially acceptable by key stakeholders (Hekkert et al., 2007). Legitimation is shaped through public discourse, advocacy, regulatory approval, scientific credibility, and alignment with policy objectives and societal values. In many sustainability-related technological innovation systems, legitimacy is contested, meaning that actor groups may disagree about environmental impacts, distributional effects, or the “fit” with broader sustainability goals (Markard et al., 2015). Legitimation therefore influences political support, permitting outcomes, and investors’ willingness to engage, and it can be a decisive factor even when technical feasibility exists (Bergek et al., 2008). In the WtE incineration context, legitimacy is closely tied to whether the technology is framed as a necessary treatment option for residual and hazardous waste, or as an approach that risks undermining waste prevention and recycling priorities.

Strong legitimation can be indicated by supportive policy narratives, stable regulatory approval processes, low levels of stakeholder resistance, and broad acceptance among influential actor groups. Weak legitimation can be visible through disagreement, persistent opposition, distrust in operators or regulators, reputational challenges, or ambiguity about whether the technology aligns with higher-order goals such as circular economy ambitions (Markard et al., 2015). In a TIS perspective, legitimation is also dynamic: demonstration projects, transparent monitoring, and credible governance arrangements may strengthen legitimacy over time, while incidents, weak oversight, or misalignment with policy narratives may weaken it (Bergek et al., 2008).

2.2.2.6 Resource mobilisation

Resource mobilisation refers to the system’s ability to secure the financial, human, organisational, and political resources required for technology development and diffusion (Bergek et al., 2008). This includes investment and project finance, skilled labour, engineering capacity, organisational capabilities for implementation and operation, and institutional capacity within public authorities to plan, permit, and oversee projects (Hekkert et al., 2007). Resource mobilisation is particularly important for capital-intensive technology pathways, where high upfront costs and long lead times make investor confidence and risk management critical (Markard & Truffer, 2008). For WtE incineration, resource mobilisation often depends on access to project finance, availability of experienced operators and maintenance capabilities, and municipal/regulatory capacity to process permits and contracts efficiently.

Strong resource mobilisation is reflected when projects reach financial close, when capable actors and contractors are available, and when governance capacity supports timely decision-making and implementation. Weakness is indicated by financing gaps, lack of skilled operators, limited institutional capacity, or high perceived risk due to unstable policy frameworks and uncertain revenue streams (Bergek et al., 2008). In this context, weak resource mobilisation may be indicated by limited desire among lenders due to uncertain revenue models or by skills gaps for running energy recovery units reliably. Resource mobilisation also interacts with legitimation and market formation: credible markets and legitimacy reduce perceived risk, which can unlock capital and attract capable actors, creating reinforcing feedback loops (Bergek et al., 2008; Markard et al., 2015).

2.2.2.7 Development of positive externalities

This function captures the broader system-level benefits that emerge as the technological innovation system develops, such as knowledge spillovers, specialised suppliers, standards, skilled labour pools, shared infrastructure, and improved routines that lower costs and reduce uncertainty for subsequent projects (Hekkert et al., 2007). In the WtE incineration context, this can include standardised templates for permits and Environmental Impact Assessments, accepted routines for emissions monitoring and reporting. As well as a growing pool of experienced operators, maintenance technicians, and compliance specialists. These positive externalities often arise through cumulative learning, clustering effects, and the formation of complementary service ecosystems that make the technology easier to implement and govern (Bergek et al., 2008). Over time, positive externalities can strengthen the entire system by enabling faster diffusion and by making the technological innovation system less dependent on individual "champion" projects or actors (Markard et al., 2015).

Empirically, strong development of positive externalities is indicated by supplier markets, standardised procedures, training programmes, established professional communities, and a growing base of experienced practitioners. Weakness is visible when each project remains isolated, supply chains do not develop, expertise is not retained, and "starting costs" remain high for every new initiative, preventing cumulative system momentum (Hekkert et al., 2007).

In many cases, the absence of positive externalities becomes a hidden barrier because it keeps transaction costs high and prevents scaling even when individual projects appear feasible (Bergek et al., 2008).

2.2.3 Functional dynamics: Inducement and blocking mechanisms

A central contribution of the TIS approach is that it not only describes structural components and individual system functions but also explains how functions interact over time to produce either system build-up or stagnation (Bergek et al., 2008; Hekkert et al., 2007). These interactions are commonly referred to as functional dynamics and are often characterised by feedback processes, where improvements in one function strengthen others and create self-reinforcing development paths (Suurs & Hekkert, 2009). Conversely, persistent weakness in one or several functions can generate negative feedback and lock the system into low-momentum trajectories (Bergek et al., 2008).

Within this perspective, inducement mechanisms and blocking mechanisms provide an explanatory bridge between observed functional performance and the underlying causes of that performance. Johnson and Jacobsson (2001) introduced these concepts to explain how different pressures, incentives, and enabling conditions can stimulate the emergence of a new industry, while other factors inhibit development. In later TIS work, inducement and blocking mechanisms have been used to explain why some functions remain weak and why emerging TISs often struggle in environments that are biased in favour of established technologies and practices (Bergek et al., 2008; Bergek et al., 2015).

Inducement mechanisms refer to factors that strengthen one or several functions and thereby support system expansion. These mechanisms can be internal to the TIS, such as learning effects from pilot projects that improve knowledge diffusion and legitimacy, or the entry of capable actors that increases experimentation and resource mobilisation (Hekkert et al., 2007; Suurs & Hekkert, 2009). They can also be external, such as changes in policy, sectoral priorities, or market conditions that improve the selection environment for the focal technology (Bergek et al., 2015; Johnson & Jacobsson, 2001). In sustainability transitions, inducement mechanisms are frequently associated with policy instruments that create early markets, reduce perceived risk, and provide clearer direction of search, which then attracts resources and encourages further experimentation (Jacobsson & Lauber, 2006; Kivimaa & Kern, 2016). The key point is that inducement mechanisms often operate through feedback loops, where initial support or early success triggers cumulative causation and gradually strengthens multiple functions simultaneously (Suurs & Hekkert, 2009).

Blocking mechanisms describe factors that lead to weak function fulfilment and hinder system development. These mechanisms may be endogenous, for example fragmented actor networks, lack of capable intermediaries, or weak knowledge diffusion that prevents coordinated action (Bergek et al., 2008). They may also be exogenous, such as institutional misalignment, unfavourable market rules, or competing technologies and incumbent regimes that make it difficult for the focal technology to secure legitimacy, resources, and market space (Bergek et al., 2015; Markard et al., 2015). A useful way to interpret blocking mechanisms is to view them not as isolated barriers, but as causal pathways that connect underlying systemic problems to poor system functioning, often through interdependent chains of effects across functions (de Oliveira et al., 2020).

Focusing on inducement and blocking mechanisms helps move the study from describing what is weak to explaining why it is weak and what would need to change for the system to develop (Bergek et al., 2008; Jacobsson & Bergek, 2011). In this thesis, the inducement and blocking mechanisms lens is used to interpret observed strengths and weaknesses across system functions in relation to the development of waste incineration with energy recovery in South Africa, and to identify the mechanisms that either enable or hinder progress from incineration as disposal toward viable WtE implementation and diffusion (Johnson & Jacobsson, 2001; Bergek et al., 2008).

2.3 Contextualising TIS: Global South conditions, justice, and limitations

While TIS provides a useful framework for analysing system strengths and weaknesses, its categories should not be treated as universally transferable without considering the institutional, infrastructural, socioeconomic, and governance conditions in which the technological system is embedded (Bergek et al., 2008; Wieczorek, 2018). This is particularly important because much of the empirical and conceptual development of TIS and wider transitions research has been shaped by Global North cases, where analyses often assume comparatively stable infrastructures, stronger formal institutions, more mature markets, and higher levels of policy coordination (Tomai et al., 2024; Wieczorek, 2018). In Global South contexts, these assumptions may not hold in the same way. Concepts such as market formation, legitimation, and resource mobilisation therefore need to be interpreted in relation to local governance capacity, infrastructure provision, informality, investment conditions, and competing development priorities (Ramos-Mejía et al., 2018). This matters in the present study because the focal pathway is not examined in a setting characterised by stable infrastructures, highly coordinated institutions, or mature markets. Instead, WtE is analysed in a context where uneven capacity, fragmented governance, and competing social and economic priorities shape what can be implemented and sustained in practice.

Global South conditions are therefore not treated in this thesis as a general background category, but as part of how the TIS framework is interpreted. Recent research argues that transitions in Global South contexts should be analysed with stronger attention to poverty and inequality, informality, limited state capacity, external dependence, and uneven infrastructure provision (Tomai et al., 2024; Wieczorek, 2018). These factors influence not only whether a technology can be implemented, but also which pathways become credible, which actors gain influence, and whose needs are prioritised. A key implication is that energy transitions in the Global South are often shaped less by gradual optimisation of stable regimes and more by disruptions, urgent service needs, and strong landscape pressures (Tomai et al., 2024).

This does not mean that Global South contexts should be understood only through deficits or institutional weakness. Rather, the point is that transition pathways are shaped by different combinations of constraints, capabilities, priorities, and informal practices, which may make system functions operate differently than in the cases from which much transitions theory has been developed (Ramos-Mejía et al., 2018; Wieczorek, 2018).

This perspective is particularly relevant for WtE because the pathway sits between the waste system and the energy system. It depends on coordination across waste regulation, environmental permitting, electricity market rules, grid connection processes, and investment conditions (Rogge & Reichardt, 2016). If these domains are not aligned, technical possibility may not translate into practical implementation. Evidence from Ghana's WtE transition illustrates this broader point. International capital flows, donor relations, macroeconomic shocks, overlapping rule sets, and unclear actor roles can shape which niche options gain support and how far they can develop (Tomai et al., 2024). For this thesis, the implication is that WtE cannot be assessed only as a plant-level technology. It must also be understood as a pathway whose viability depends on governance capacity, institutional alignment, market credibility, and local operational capabilities.

This contextual reading also affects how justice is understood within the thesis. In Global South energy transitions, questions of system development are closely connected to questions of fairness, because transition choices are made under conditions of uneven service provision, poverty, fragmented authority, and unequal capacity to influence decisions (Tomai et al., 2024; Wieczorek, 2018). Justice is therefore not only a normative concern that can be added after the system analysis. It is part of how legitimacy, directionality, and system support are formed. A pathway may appear technically feasible or institutionally possible, but still be contested if it distributes risks unevenly, excludes affected groups, or fails to respond to local needs.

Just transitions theory adds this normative dimension to energy transitions research by arguing that change should not be evaluated only in terms of speed, efficiency, or technological success, but also in relation to fairness and the social distribution of its consequences (Newell & Mulvaney, 2013). In energy research, this has developed into the literature on just energy transitions, which emphasises that changes in energy systems are never only technical or economic. They are also political and distributive processes that shape who benefits from system change, who bears its costs, whose voices are recognised, and whose needs are prioritised in decision making (McCauley & Heffron, 2018). From this perspective, a transition pathway cannot be understood as desirable simply because it may contribute to energy recovery or emissions reduction. It must also be assessed in relation to the process through which it is pursued and the social outcomes it produces.

A common way to operationalise this perspective is through energy justice, which distinguishes between distributional justice, procedural justice, and recognition justice (Jenkins et al., 2016; McCauley et al., 2013). Distributional justice concerns how benefits, costs, risks, and burdens are allocated across groups in society. Procedural justice concerns who is included in decision making, whose perspectives shape implementation, and whether participation is meaningful rather than merely formal. Recognition justice concerns whose experiences, vulnerabilities, and interests are acknowledged as legitimate within policy and governance processes. Together, these dimensions show that justice in transitions is not reducible to a single issue such as affordability or inclusion, but concerns the broader question of how system change is structured, legitimised, and experienced. Figure 2.3 summarises the energy justice dimensions applied in this thesis.

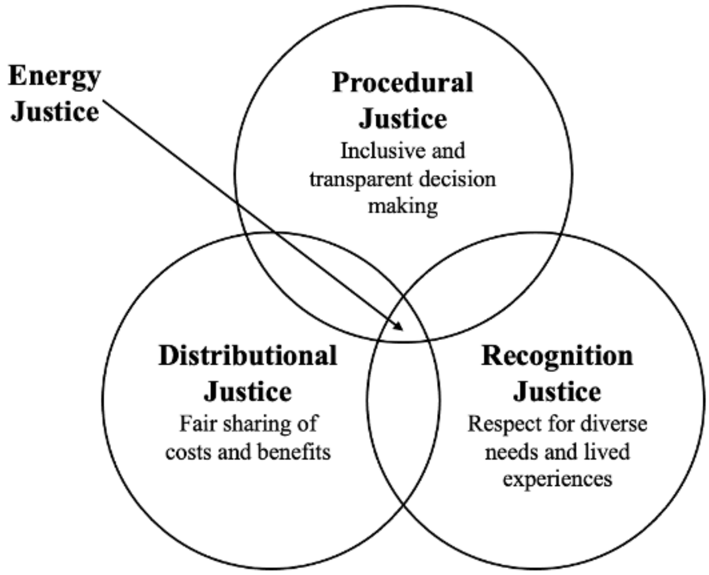

Figure 2.3. Energy justice dimensions in just transitions research. (Own illustration adapted from Jenkins et al., 2016; McCauley et al., 2013).

These justice concerns are especially important for WtE because the pathway is connected to environmental risk governance, public health, waste management, and energy provision. In such a setting, questions of fairness are closely tied to questions of viability. If environmental burdens, operational risks, or economic benefits are distributed unevenly, this can affect public acceptance, permitting, and long-term legitimacy (Jenkins et al., 2016; McCauley et al., 2013). Similarly, if affected communities, workers, municipalities, or other stakeholders are not meaningfully included, the pathway may struggle to build the legitimacy and coordination required for system development. Justice therefore helps clarify that WtE should not only be assessed in terms of whether it can recover energy, but also in terms of what kind of recovery pathway is being enabled, for whom it becomes valuable, and whose interests may be marginalised.

In this thesis, justice is therefore used to deepen the interpretation of TIS rather than as a separate theory standing next to it. TIS remains the main analytical structure, but justice helps interpret the quality and direction of system development. A system may, for example, show movement in the direction of search, market formation, or resource mobilisation, while still reproducing unequal distributions of risk and benefit or excluding affected groups from meaningful participation. In this sense, justice changes how key TIS functions are read. Legitimation is not understood only as growing acceptance or political support, but also in relation to whether the pathway is perceived as fair, whose concerns are recognised, and how environmental and social burdens are distributed. Influence on the direction of search is not treated only as strategic guidance, but also as a question of which futures are prioritised and which alternatives are deprioritised. Market formation and resource mobilisation are similarly not treated as neutral achievements in themselves, since they also raise questions about who can invest, who captures value, and whether resources are channelled toward broader public value or mainly narrow commercial viability (Bergek et al., 2008; Jenkins et al., 2016; McCauley & Heffron, 2018).

This way of using justice also strengthens the relevance of the Global South framing. In the present study, Global South conditions are used to interpret why system functions may operate differently than they do in more stable or mature transition contexts. Weak market formation may not only reflect limited demand, but also uncertain regulatory conditions, restricted access to finance, and unclear offtake conditions, meaning uncertainty around who would use or purchase the recovered electricity or heat, at what price, and under what contractual arrangement. Limited resource mobilisation may reflect not only firm-level hesitation, but also broader investment risk, skills constraints, and competing priorities. Weak legitimation may not only indicate low acceptance of WtE, but also concern over fairness, compliance, institutional trust, and the distribution of risks. Global South context and justice are therefore integrated into the TIS analysis by shaping how structural components, system functions, and mechanisms are interpreted (Ramos-Mejía et al., 2018; Tomai et al., 2024; Wieczorek, 2018).

This contextual and justice-sensitive reading strengthens the explanatory value of TIS, but it also makes it necessary to acknowledge the framework's limitations. Since TIS analysis depends on how systems are bounded, how functions are interpreted, and how power and legitimacy are understood, the framework must be applied reflexively rather than as a neutral checklist. Several limitations of the TIS framework are therefore important for how it is applied in this thesis. First, TIS analyses depend on how the system is described in terms of technology scope, geographical boundaries, and time period. Different boundary choices can lead to different interpretations of what the key system weaknesses are (Bergek et al., 2015; Markard et al., 2015). This is particularly important in the present study because WtE incineration can be understood narrowly as energy recovery from existing HCRW facilities, or more broadly as part of South Africa’s wider waste and energy transition. Transparency in boundary setting is therefore essential.

Second, the functions approach can risk becoming overly descriptive if it is applied as a checklist rather than used to explain dynamics and relationships between functions (Bergek et al., 2008). TIS scholars have therefore emphasised the importance of analysing functional interactions, feedback loops, and mechanisms rather than only assessing whether a function appears present or absent (Suurs & Hekkert, 2009). This is especially relevant in the present study, where weaknesses in market formation, resource mobilisation, and legitimation are likely to reinforce one another. A related challenge is that empirical assessment of functions often relies on qualitative judgement and proxy indicators, which can introduce interpretive bias and make triangulation across data sources important (Hekkert et al., 2007).

Third, TIS may underemphasise power relations and political conflict, particularly in transition contexts where incumbent actors can shape institutions and markets in ways that constrain new pathways (Markard et al., 2015). This limitation becomes particularly important in Global South settings, where uneven institutional capacity, fragmented governance, and dependence on external finance and expertise may influence which pathways become credible and whose priorities are reflected (Tomai et al., 2024; Wieczorek, 2018). The justice perspective used in this thesis partly addresses this limitation by drawing attention to legitimacy, recognition, participation, and the distribution of risks and benefits. However, justice does not replace the TIS framework. Rather, it helps make visible dimensions of system development that a functional assessment may otherwise understate.

Accordingly, the TIS framework is used in this thesis as the main analytical structure for examining how the conditions for WtE development are configured and how they function in practice. At the same time, the framework is interpreted through a Global South and justice-sensitive lens. This means recognising that system development is shaped not only by actors, institutions, networks, infrastructures, and functions, but also by uneven institutional capacity, fragmented governance, contested legitimacy, and the distribution of risks and benefits. Read in this way, TIS provides a structured basis for the empirical analysis while remaining sensitive to the contextual and justice-related conditions that shape how WtE can be understood and assessed in the South African setting.

3

Methodology

This following chapter describes the methodological framework of the study, outlining the research strategy, design, and methods used to address the research questions. It also accounts for the data collection and analysis procedures.

3.1 Research strategy

The report follows a qualitative research strategy, which enables the exploration of complex organisational phenomena within their real-world context (Yin, 2018). A qualitative approach centred on textual narratives and emergent patterns is particularly well suited to this study, since the aim is to understand how different actors perceive the conditions for possible WtE implementation in relation to existing HCRW incineration in South Africa. This required close engagement with the accounts of case company representatives, regulators, industry experts, and technology related actors, rather than the measurement of predefined variables. A qualitative strategy therefore supports an in-depth examination of how technical, regulatory, organisational, and market related conditions are understood and experienced by actors situated in the field (Bell et al., 2022).

3.2 Research design

To develop an empirically grounded understanding of the systemic conditions associated with upgrading waste incineration toward energy recovery, the study requires a solid understanding of the research domain. The thesis therefore adopts an exploratory research approach, as it is well suited to generate in depth insights into phenomena that remain insufficiently explored and to support knowledge and theoretical development (George, 2021). This was particularly relevant in the study, since WtE development in relation to existing HCRW incineration in

South Africa is not only weakly studied, but also shaped by a combination of technical, institutional, and contextual conditions that could not be meaningfully understood in advance through a more tightly predefined design. The exploratory approach therefore made it possible to investigate how the broader innovation system around WtE is configured, how it functions in practice, and how different actors understand the possibilities and limits of this pathway in the South African context.

Further, an abductive approach supports the project to move iteratively between theoretical concepts and empirical observations. In practice, this involves integrating inductive, data driven insights from field studies and interviews with deductive, theory driven perspectives from existing literature, allowing the study to develop context specific explanations relevant to the technical and regulatory conditions of the project (Bell et al., 2022). In this thesis, the abductive logic was reflected in the continuous movement between the TIS framework and the empirical material collected through interviews, site visits, observations, and documents. Early empirical insights from the Averda case, particularly concerning plant conditions, treatment practices, and perceived barriers to WtE, informed which system dimensions required greater analytical attention. At the same time, the theoretical framework helped structure the interpretation of these findings by directing attention to actors, institutions, infrastructures, and system functions. This iterative movement was important because the study did not seek only to describe whether WtE appeared technically feasible, but to explain why this pathway remained weakly supported in practice.

3.2.1 Embedded single-case study

To further strengthen the analysis, the single-case design takes an embedded form, which enables examination of multiple analytical units within the overall case context (Yin, 2003, 2018). In this thesis, the embedded character of the design refers to analytical units within the same focal case, rather than to separate organisational cases. This clarification is important because the study draws on empirical material from several companies, sites, and external actors, but these sources are not treated as independent cases. Instead, they are used to contextualise, compare, and triangulate insights generated from the focal case.

The focal case is Averda's South African HCRW treatment activities in relation to the possible upgrading of existing incineration toward WtE. Within this case, three embedded analytical units were defined. First, facility-level upgrading options and operational conditions were examined, including current incineration performance, technical constraints, and the feasibility of integrating energy recovery. Second, actor interfaces surrounding the focal system were analysed, including the case company, regulators, municipalities, technology suppliers, and industry experts who shape decision-making and coordination. Third, institutional and infrastructural interfaces were examined, including permitting and compliance requirements, grid connection and electricity market arrangements, and waste contracting and logistics.

These embedded units were not treated as separate cases, but as analytical entry points within the focal case. The primary empirical plant settings were Averda's facilities in George and Klerksdorp, which together provided the main basis for examining plant-level conditions and possible upgrading pathways. Additional material from other organisations and sites was included as supplementary empirical input, but not as separate cases in the research design.

Specifying these embedded analytical units clarifies how the empirical material was organised and supports alignment with the TIS focus on actors, institutions, infrastructure, and interaction patterns in shaping opportunities for WtE development (Bergek et al., 2008; Yin, 2018). It also helps distinguish between the focal case, the primary empirical settings, and the broader set of external sources used to situate the case within the wider South African waste and energy context.

3.2.2 Case boundaries and empirical settings

This section clarifies how the empirical scope of the study was defined and how the firms included in the material were positioned within the research design. The South African HCRW incineration field is concentrated to a limited number of firms. In practice, the national HCRW incineration landscape was found to be concentrated around a small number of facilities and operators. Averda's two facilities, George and Klerksdorp, form the empirical core of the focal case, while A-Thermal and BCL are included only as external contextual and comparative sources. However, the study is not structured as a multiple case study. Instead, it is centered on one focal case, while the additional firms are included in more limited roles to support contextualisation, comparison, and triangulation. This distinction is important because it helps clarify how the empirical material relates to the overall case and how different sources contributed to the analysis.

The focal case is Averda's South African HCRW treatment activities in relation to the possible upgrading of existing incineration toward WtE. Within this focal case, George and Klerksdorp were treated as two distinct empirical settings. George formed the strongest plant-level basis of the study, since it combined direct site access, plant interviews, observational material, and a regulatory inspection. It therefore provided the most complete empirical basis for analysing day to day operations, plant conditions, and practical constraints related to possible WtE upgrading. Klerksdorp was also part of the focal case but entered the study in a different way. Rather than through direct site observation, it was examined mainly through interviews, consultant input, and case related documents. Its main role was therefore to broaden the internal case perspective and to show whether the conditions observed around one Averda facility also appeared relevant in a second plant setting.

A-Thermal was not treated as a second case company, but as a supplementary empirical source. Its role in the study was to provide an external operator perspective from within the same broader field of thermal waste treatment in South Africa. The interview with A-Thermal was useful because it added an additional industry view on implementation conditions, licensing challenges, and possible WtE related opportunities outside the focal case. However, since access to A-Thermal was limited to one interview and did not include repeated engagement, internal material, or site observation, its role remained supportive rather than central to the case design.

BCL had an even more limited role in the study. It was not included as a directly studied company, since no direct interview or site visit was conducted there. Instead, BCL entered the material indirectly through consultant-based comparisons, shared documents, and references in interviews where it was discussed alongside other South African incineration facilities. BCL therefore functioned only as a narrow comparative point in relation to permitting, compliance, and the broader treatment landscape. Because the access was indirect and materially weaker than for both Averda and A-Thermal, BCL was used cautiously and was not treated as a substantive empirical setting.

This boundary setting was important for analytical clarity. It ensured that the study remained a single case study of Averda, while still making use of carefully selected external material to support triangulation and to situate the focal case within the wider South African HCRW incineration field (Yin, 2018). Table 3.1 summarises how the three firms were positioned in the empirical design and how valuable their material was in relation to the study's analytical purpose.

Table 3.1. Overview of firms and empirical settings included in the study

Site	Role in the study	Main empirical material	Main contribution	Empirical value
Averda, George	Primary empirical setting within the focal case	Site visits, plant interviews, direct observations, field notes, case related documents	Main basis for analysing plant operations, practical constraints, compliance conditions, and possible WtE upgrading at facility level	High
Averda, Klerksdorp	Secondary empirical setting within the focal case	Interviews, consultant input, case related documents	Broadened the focal case beyond George and provided a second plant related basis for assessing whether key constraints and opportunities extended across Averda's incineration activities	Medium to high
A-Thermal	Supplementary external source	One interview	Added an external operator perspective on treatment conditions, licensing, and possible WtE related development outside the focal case	Medium
BCL	Limited comparative source	Indirect comparative input and supporting material	Used cautiously to contextualise the broader field of HCRW incineration in South Africa	Low

3.3 Industry context

South Africa's waste management system remains strongly shaped by structural landfill dependence and uneven municipal capability, which influences both general and hazardous waste outcomes. National policy reporting indicates that South Africa generated approximately 123 million tonnes of waste in 2017 and 11 percent was diverted from landfill**.** The disposal pathways remain dominant, reinforcing continued pressure on landfill airspace and highlighting persistent challenges related to planning, enforcement, and implementation capacity (Department of Forestry, Fisheries and the Environment [DFFE], 2020). In practical terms, this context implies that system performance is shaped not only by available treatment technologies, but also by institutional capacity and the credibility of governance routines that determine whether diversion, recovery, and higher value pathways can be implemented and sustained.

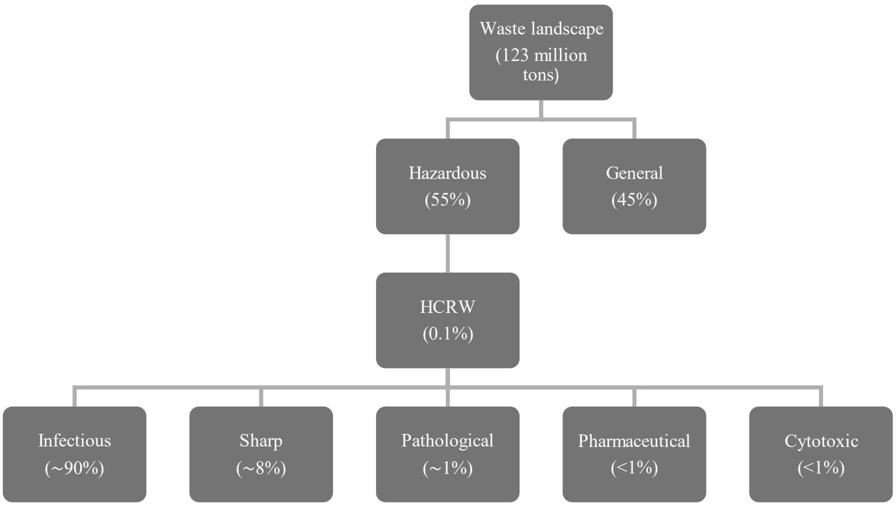

Figure 3.1. Waste landscape in South Africa. (Own illustration with data adapted from DFFE (2025) and Averda).

Within this broader waste system, HCRW constitutes a small share of total volumes yet carries high consequence risks due to infection hazards, toxicity, and the need for traceability and controlled handling (WHO, 2014). The National Waste Management Strategy identifies HCRW as a regulatory priority area and emphasises reporting and governance requirements for generation, treatment, and disposal within national information systems (DFFE, 2020). Sector level reporting further suggests that HCRW treatment quantities have been relatively stable in recent years, with a notable increase around the COVID 19 period followed by a return toward pre peak levels (DFFE, 2024). In methodological terms, this makes HCRW an analytically useful niche for studying system constraints and enabling conditions because treatment decisions are comparatively rule bound and politically visible, and because failures carry immediate public health and legitimacy implications.

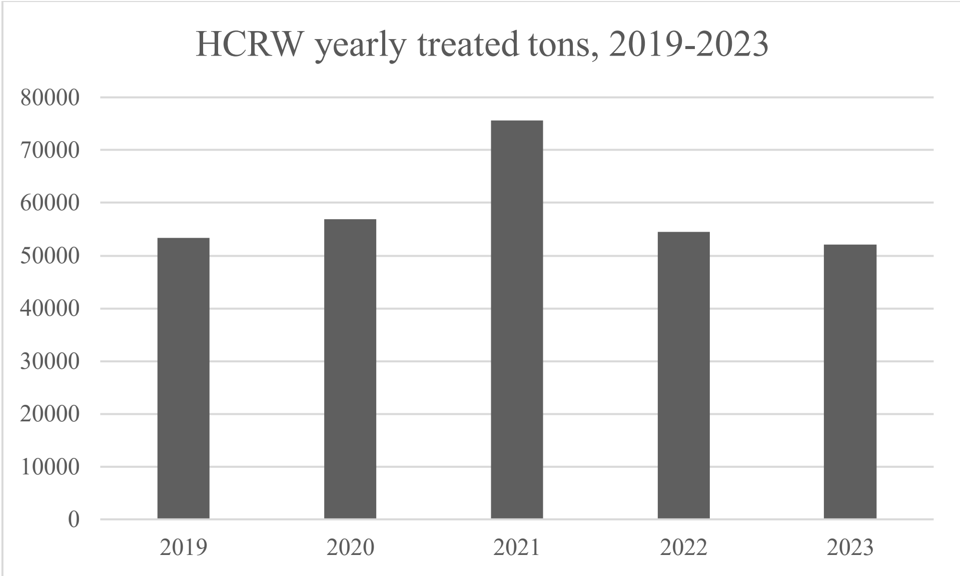

Figure 3.2. HCRW yearly treated. (Own illustration, adapted from DFFE (2025)).

HCRW is typically described as a mixed stream where the majority resembles general waste, while a smaller fraction is hazardous and requires specialised treatment. A commonly cited approximation is that 75 to 90 percent of HCRW is comparable to general waste, while 10 to 25 percent is hazardous, with the hazardous share increasing where segregation at source is weak (Olaniyi et al., 2018). Hazardous categories include infectious waste, sharps, pathological or anatomical waste, pharmaceutical waste, and cytotoxic waste, each associated with distinct handling and treatment requirements (Olaniyi et al., 2018). In this thesis, the HCRW fractions are described in line with Figure 3.1. Infectious waste represents the largest fraction and refers to materials suspected to contain pathogens in sufficient concentration to pose a disease transmission risk, such as blood contaminated dressings, swabs, and certain laboratory waste. Sharps waste includes items capable of cutting or piercing skin such as needles and scalpels and is treated as high risk due to combined injury and infection exposure. Pathological waste comprises tissues, organs, body parts, and related fluids from clinical or laboratory procedures and is managed as a high consequence category due to biohazard and ethical considerations. Pharmaceutical waste includes expired, unused, or contaminated medicines where risks relate to toxicity, misuse, and environmental release. Cytotoxic waste consists of materials contaminated with cytotoxic or antineoplastic drugs used in cancer treatment and is managed as highly hazardous due to mutagenic, teratogenic, and carcinogenic properties (Olaniyi et al., 2018).

Thermal treatment is institutionally important in this risk context, and national practice requirements for specific fractions should be stated explicitly. Pathological waste and pharmaceutical waste are treated as fractions for which incineration is mandatory within the South African regulatory and compliance context, as confirmed through direct communication with the DFFE (DFFE Director, personal communication, March 2, 2026). This matters for WtE because it clarifies that a portion of the HCRW stream is effectively locked into a destruction-oriented treatment pathway, which shapes feasible upgrading options and places emphasis on operational reliability, emissions control, and the compliance credibility of any energy recovery configuration.

Incineration is also legitimacy sensitive. Across African contexts, thermal treatment is often discussed as attractive because it reduces waste volume substantially and can, in principle, enable energy recovery through steam systems or electricity generation if operating conditions, scale, and emissions controls are sufficient (Chisholm et al., 2021). At the same time, the same literature emphasises that weak combustion conditions and insufficient emissions control can generate harmful pollutants and public opposition, making social acceptance and regulatory credibility decisive for diffusion (Chisholm et al., 2021; Olaniyi et al., 2018). This dual character is central for the thesis because it positions HCRW incineration as both a necessary risk control practice for certain fractions and a contested technology where governance capacity, monitoring, and trust strongly influence implementation outcomes.

Against this industry background, the Averda case provides an embedded empirical entry point into how these system conditions translate into operational realities and upgrading constraints. Averda is an end-to-end waste management and recycling company operating in South Africa and forms part of the privately held Averda Group (Averda, n.d.-b). In the HCRW segment, Averda operates two of South Africa's four dedicated HCRW incineration facilities, located in George (Western Cape) and Klerksdorp (North West), and complements these with an Electro Thermal Deactivation plant for specific infectious and sharps waste categories (Averda, n.d.-b). This positioning means Averda both operates core treatment assets and interfaces directly with key infrastructures and compliance practices that shape feasibility, including waste logistics, downstream disposal routes for residues, and traceability routines for hazardous HCRW. The case therefore enables the thesis to examine WtE upgrading as a cross sector challenge rather than a plant-level optimisation problem, since moving from destruction oriented incineration toward electricity generation through WtE requires alignment across waste governance and energy system governance, including permitting routines, grid connection processes, and revenue arrangements that influence investment incentives and operational feasibility (Geels, 2002; Markard et al., 2012; Rogge & Reichardt, 2016). In addition, because HCRW is closely tied to public health risks and local environmental exposure, legitimacy and perceived fairness become important determinants of whether WtE upgrading can mobilise support and resources (Jenkins et al., 2016; McCauley & Heffron, 2018; Newell & Mulvaney, 2013). This motivates the subsequent analysis where system conditions are assessed through a TIS lens, with particular attention to legitimation, market formation, and resource mobilisation.

3.4 Research design phases

The research process was structured into four main steps, as illustrated in Figure 3.3, and further elaborated in the following sections. First, the study was planned and designed by establishing the purpose, research questions, scope, and analytical lens. As part of this phase, a structured review of academic literature was conducted to build domain understanding, refine the study purpose and research questions, and justify the selection of the TIS framework for analysing waste incineration and the potential for WtE in South Africa. Second, preparatory activities were conducted to support data collection, including the development of the sampling approach and interview guide. Third, data were collected through a combination of primary and secondary sources. Fourth, the material was analysed through a staged analytical procedure that informed the synthesis of findings and the development of recommendations to answer the research questions. While the process is presented in a sequential manner, several activities were conducted iteratively, where emerging insights informed subsequent steps (Bell et al., 2022; Yin, 2018).

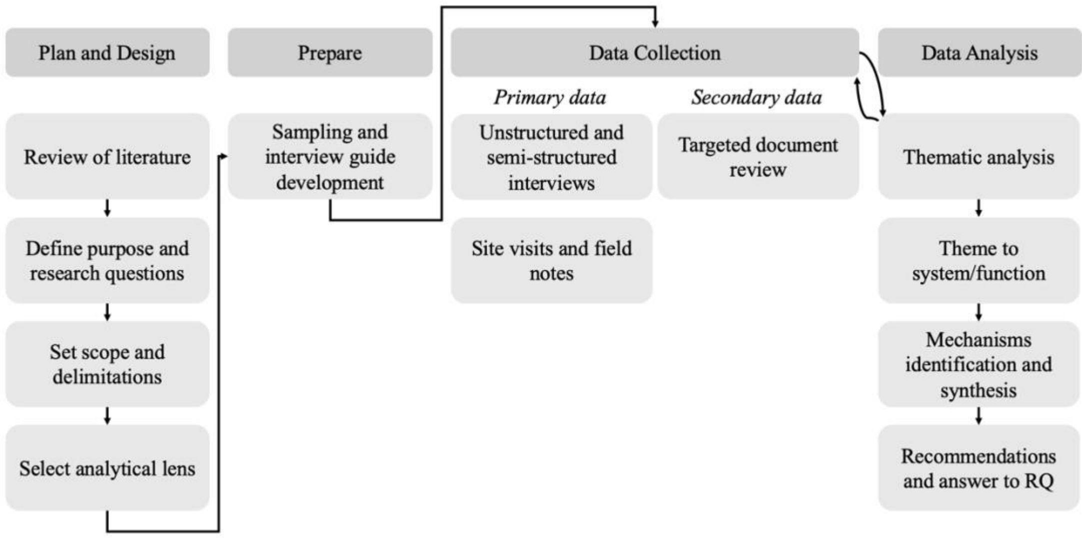

Figure 3.3. Overview of the research design.

3.5 Data collection

The report is based on a combination of primary and secondary data sources. Primary data are generated through interviews, field notes, and site visits, providing direct empirical input to the project. Secondary empirical material was collected through the analysis of publicly available and internal industry documentation. This section outlines the collection of the different data types.

3.5.1 Primary data collection

Interviews served as the primary data source, intended to generate new insights that had not previously been articulated or integrated, thereby guiding the process of addressing the research questions (Dalén, 2015). The project applied two complementary interview formats. Unstructured interviews were conducted with representatives from the case company's head office to support an exploratory understanding of the industry and the specific case context (Bell et al., 2022). In addition, semi-structured interviews were carried out with a broader set of stakeholders, guided by an interview framework aligned with the research questions (Bryman, 2018). These stakeholders represented five main actor groups, namely the case company, waste operators and plant owners, public authorities, industry organisations and experts, and energy actors. In total, 22 interviews were conducted, see Table 3.2.

This approach was selected because it combines a systematic interview structure with sufficient flexibility, allowing respondents to expand on key topics while maintaining a consistent basis for data collection (Brinkmann & Kvale, 2015). With participants' informed consent, interviews were audio recorded and subsequently transcribed using TurboScribe. The transcripts were reviewed by the researchers to correct evident transcription errors and ensure consistency with the recorded material (Miles et al., 2014). Where specific technical or factual details were uncertain, follow-up contact was used to verify information and reduce the risk of misinterpretation (Shenton, 2004). Anonymity was handled by excluding personal names and, in cases where a specific job title could make an individual readily identifiable, using a more general role description.

Table 3.2. Overview of interviews conducted in the study, including actor group, ID, organisation, respondent role, date, duration, and interview location or mode.

Actor Group	ID	Company	Position	Date	Duration	Location
Industry organisations, experts and technology suppliers	IO1	Renova	Production Engineer	2026-01-18	45 min	Savenas, Gothenburg, Sweden
Case Company	CC1	Averda	Business Unit Head, Western Cape	2026-02-02	87 min	Blackheath, Cape Town, South Africa
Case Company	CC2	Averda	Managing Director	2026-02-16	60 min	Blackheath, Cape Town, South Africa
Industry organisations, experts and technology suppliers	IO2	Circular Innovation South Africa	Manager/Professor	2026-02-19	72 min	Online
Waste operators and plant owners	WP1	EnviroServ	Process Operations Manager	2026-02-19	45 min	Online
Case Company	CC3	Averda	Plant Manager	2026-02-23	120 min	Groeneweide Park, George, South Africa
Case Company	CC4	Averda	Plant Shift Supervisor	2026-02-24	28 min	Groeneweide Park, George, South Africa
Public authorities and regulators	PR1	Garden Route District Municipality	Director	2026-02-24	32 min	Groeneweide Park, George, South Africa

Industry organisations, experts and technology suppliers	IO3	Recor	Business Development	2026-02-25	63 min	Online
Public authorities and regulators	PR2	DFFE	Chief Directorate Hazardous Waste Management & Licensing	2026-03-02	56 min	Online
Public authorities and regulators	PR3	Western Cape	Director	2026-03-03	42 min	Online
Industry organisations, experts and technology suppliers	IO4	City University of New York	Professor	2026-03-04	48 min	Online
Industry organisations, experts and technology suppliers	IO5	Kleynhans & Associates	Engineer	2026-03-05	57 min	Online
Industry organisations, experts and technology suppliers	IO6	ISWA	Chair Member	2026-03-05	62 min	Online
Industry organisations, experts and technology suppliers	IO7	Waste TT/ISWA	CEO/Chair Member	2026-03-10	83 min	Online
Waste operators and plant owners	WP2	A-Thermal	Project Manager	2026-03-11	65 min	Online
Case Company	CC1	Averda	Business Unit Head, Western Cape	2026-03-23	84 min	Blackheath, Cape Town, South Africa
Industry organisations, experts and technology suppliers	IO3	Recor	Business Developer	2026-03-23	84 min	Blackheath, Cape Town, South Africa
Industry organisations, experts and technology suppliers	IO8	"OCR supplier"	Business Developer	2026-03-24	42 min	Online
Industry organisations, experts and technology suppliers	IO9	WtERT® – Global Waste-to-Energy Research and Technology Council	Vice President, International Relations	2026-03-30	56 min	Online
Electricity, grid, and procurement conditions	E1	SANEDI	Project Manager	2026-04-01	46 min	Online
Industry organisations, experts and technology suppliers	IO10	Kyoto University	Professor	2026-04-01	42 min	Online

3.5.1.1 Sampling

Both types of interviews were conducted using generic purposive sampling and snowball sampling to identify informants with relevant knowledge, experience, and roles in relation to the research questions (Bell et al., 2022). The aim was not statistical representativeness, but analytical breadth. Respondents were therefore selected to capture variation across the stakeholder positions most relevant to HCRW incineration and the potential for WtE development. The sampling sought to include actors from the case company, public authorities, industry organisations and experts, technology suppliers, and the energy side of the system.

The study began with a small set of key informants and expanded through referrals, with sampling decisions adjusted iteratively based on emerging insights and identified knowledge gaps (Bell et al., 2022; Bryman, 2018).

Access was, however, uneven across actor groups, and despite efforts to broaden coverage on the energy side, only one interview was secured directly from that part of the system. At the same time, energy related issues were discussed extensively in several other interviews, which still provided a broader understanding of electricity conditions, grid related constraints, and the practical role of energy recovery. To reduce these risks, the study sought variation not only across organisational roles but also across geographical and professional backgrounds. Several interviewees were based outside South Africa but had substantial experience from African waste and energy contexts. This added comparative distance to the material and reduced the likelihood that all accounts would be shaped by local institutional or organisational loyalties alone. Snowball sampling also involves a risk of drawing on overlapping professional networks and thereby reproducing similar perspectives (Bell et al., 2022). In addition, some respondents may have had reasons to frame the issue in particular ways, for example due to organisational interests, regulatory positions, or commercial incentives. The interview material was therefore treated critically and interpreted in relation to the respondent's role and position rather than as neutral descriptions of reality. Several respondents also requested anonymity, which likely made it easier for them to speak openly about sensitive operational, institutional, and commercial issues. Finally, these limitations were addressed through triangulation with site visits, observations, and secondary material (Bryman, 2018; Yin, 2018).

3.5.2 Site visits

Site visits were used as a complementary source of evidence to the interviews, enabling direct observation of waste handling practices and facility conditions in their real-world context (Yin, 2018). The visits, summarised in Table 3.3, were conducted both at the case company's facilities and at Renova's WtE plant in Gothenburg, Sweden. The Renova visit was included as a contextual benchmark to provide practical insight into how a mature WtE facility operates and to inform the assessment of conditions relevant to potential upgrading toward energy recovery in the South African setting. It was not treated as a separate case study or used for systematic comparison, but rather as a reference point for contextualising the empirical material from the focal case. The visits ranged from planned walkthroughs focused on specific processes to more informal observations conducted in connection with interviews. During these visits, the researchers kept a field diary with observations and reflections, which added contextual depth to the interview material and supported a more practice-oriented understanding of the case (Emerson et al., 2011). Where relevant, observations were documented through notes and photography to support later analysis and strengthen the evidentiary base through multiple sources (Yin, 2003; Merriam & Tisdell, 2016).

Table 3.3. Overview of site visits conducted in the study, including organisation visited, subject of observation, date, duration, and location.

Company	Subject of Observation	Date	Duration	Location
Renova	Benchmarking visit to a mature WtE facility to observe overall plant operations	2026-01-19	105 min	Savenas, Gothenburg, Sweden
Averda	Observation of Electro Thermal Deactivation (ETD) sterilisation and related HCRW handling and logistics	2026-02-05	64 min	Killarney, Cape Town, South Africa
Averda	Walkthrough of the incineration process, operations, and key constraints	2026-02-23	240 min	Groeneweide Park, George, South Africa
Averda	Observation of a DFFE and Garden Route regulatory inspection focused on compliance and operational issues	2026-02-24	321 min	Groeneweide Park, George, South Africa

3.5.3 Secondary data collection

Secondary data collection in the empirical phase consisted of a targeted document review used to generate complementary secondary empirical material for triangulation with interviews and site observations (Yin, 2003, 2018). This included policy and regulatory documents, publicly available reports, and internal industry documentation provided by the case company. As shown in Table 3.4, these documents covered different document types and were used for different analytical purposes, including the mapping of governance priorities, permitting and compliance requirements, institutional roles, and market and infrastructure conditions relevant to WtE related development. More specifically, the material helped inform the analysis of system level conditions shaping TIS function performance, particularly legitimation, market formation, and resource mobilisation (Bergek et al., 2008; Hekkert et al., 2007; Yin, 2003).

Table 3.4. Overview of secondary empirical documents included in the study, their source type, and how they informed the empirical analysis.

Document Type	Source/organisation	Examples of Documents	Analytical Contribution
Policy and regulatory documents	DFFE, provincial and municipal authorities	Waste strategies, licensing requirements, emissions rules, oversight material	Helped explain governance, formal rules, compliance requirements, and the role of public authorities in HCRW treatment
Company and operational documents	Averda, A-Thermal & BCL	Internal plant documents, operational records, compliance documents, public company information	Helped describe plant infrastructure, daily operations, treatment scope, and case specific conditions for possible WtE development
Industry and sector reports	ISWA, industry actors, consultants	Sector reports, WtE guidance, incineration reports	Helped explain technology options, market conditions, and wider sector developments related to WtE
International and expert documents	WHO, research organisations, expert authors	WHO guidance, technical studies, research reports	Helped provide knowledge on treatment standards, technical feasibility, and international experience relevant to the analysis

3.6 Data analysis

The empirical material, including interview transcripts, field notes from site visits, and relevant secondary empirical documents from the secondary data collection, was analysed through an iterative thematic analysis and subsequently interpreted through the TIS framework. In line with Burnard (1991), analysis began during data collection and continued in a more systematic form during the later analytical phase. This means that coding, interpretation, and further data collection developed in parallel rather than as fully separate stages. The thematic analysis was broadly guided by the six stages shown in Figure 3.4, proposed by Braun and Clarke (2006), while remaining adapted to the abductive and iterative logic of the study (Bell et al., 2022). To make the analytical chain transparent, the study moved from raw empirical material to open codes, clustered coding categories, candidate themes, final themes, TIS functions, qualitative function appraisal, and finally to inducement and blocking mechanisms that informed the recommendations.

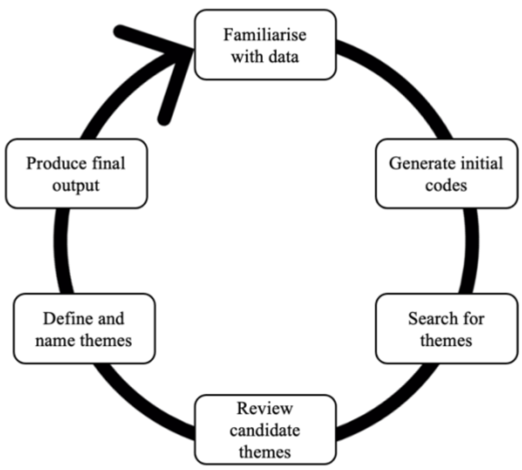

Figure 3.4. Iterative stages of thematic analysis used as a guiding analytical structure in the study (own illustration adapted from Bell et al., 2022).

3.6.1 Thematic coding and theme development

The first step consisted of repeated familiarisation with the empirical material through close reading of interview transcripts, site visit notes, and selected documents. During this stage, the researchers wrote analytic notes and highlighted recurring issues, constraints, opportunities, actor relations, and institutional conditions that appeared relevant to the research questions. The material was then coded openly, meaning that codes were initially generated from the empirical content rather than forced into predetermined TIS categories. Examples of such early codes included unstable operating conditions, limited plant scale, existing engineering knowledge, strict compliance demands, landfill cost advantage, and weak municipal enforcement.

Coding was conducted across the full dataset rather than within single interviews only. This allowed codes to be compared between different actor groups and data types, including case company interviews, external expert interviews, site observations, and documents. As the analysis progressed, similar codes were merged, some broad codes were divided into more precise categories, and others were reformulated to better capture the meaning of the material. In this way, the coding process remained iterative.

In the next step, related codes were grouped into clustered coding categories and then into candidate themes. These candidate themes were reviewed against the full dataset to assess whether they were sufficiently supported by the empirical material, internally coherent, and clearly distinguishable from one another (Braun & Clarke, 2006). Final themes were not selected based on frequency alone. They were also assessed in relation to their analytical relevance for the research questions and for the subsequent TIS interpretation. This was important because some issues appeared less frequently in the dataset but still had high explanatory significance for understanding WtE conditions in the South African context. The final themes therefore reflected both recurring empirical patterns and their analytical importance.

3.6.2 Operationalisation of the TIS framework

After the thematic analysis had produced a set of final themes, these were interpreted through the TIS framework. Figure 3.5 illustrates how the finalised themes were carried forward into the six step TIS analysis. The focal TIS was defined as the system surrounding possible WtE development through upgrading existing HCRW incineration in South Africa. This meant that the analysis focused not only on the plants themselves, but on the wider configuration of actors, institutions, networks, and infrastructures that shape whether such upgrading becomes credible and feasible (Bergek et al., 2008).

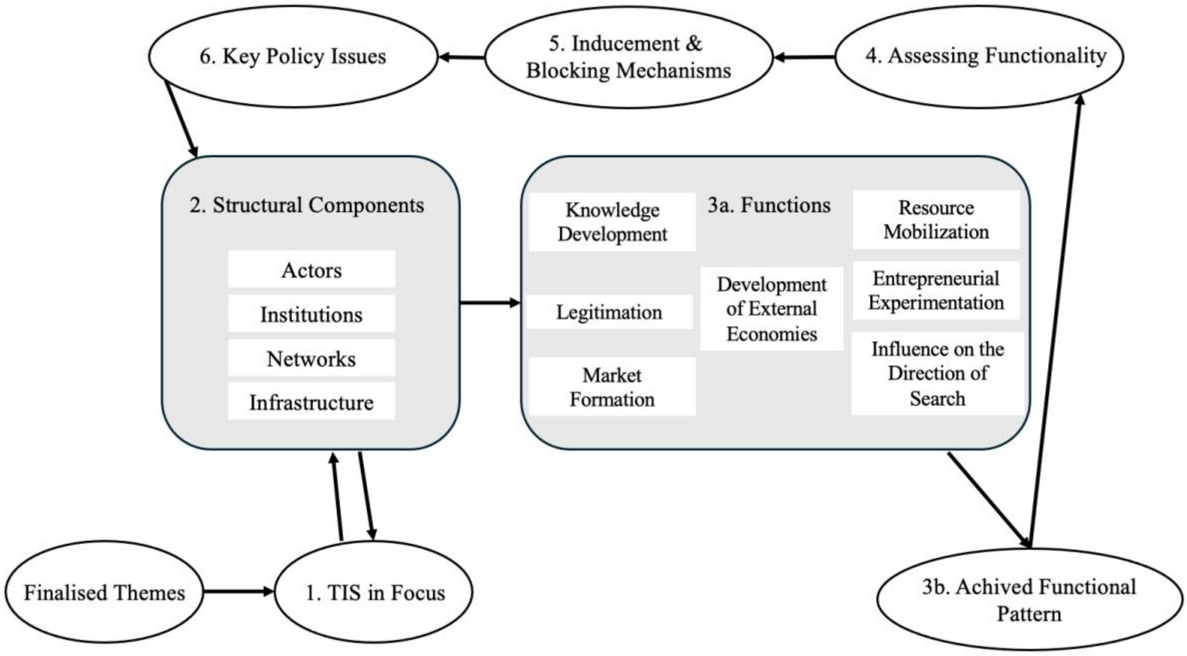

Figure 3.5. From finalised themes to the six step TIS analysis (own illustration adapted from Bergek et al., 2008).

To operationalise the framework, each final theme was compared with the analytical meaning of the seven TIS functions. The functions were interpreted in the empirical material as follows. Knowledge development and diffusion referred to evidence of technical, operational, or regulatory learning, and the extent to which such knowledge was shared across actors. Entrepreneurial experimentation referred to pilots, feasibility studies, trial projects, or active exploration of alternative technical and organisational solutions. Influence on the direction of search referred to expectations, policy signals, strategic priorities, and indications of how actors understood the future role of WtE. Market formation referred to actual or emerging economic conditions that could support WtE, such as demand, offtake arrangements, tariff clarity, pricing logic, willingness to invest, or protected space for implementation. Legitimation referred to perceived appropriateness, credibility, acceptance, and support among relevant stakeholders. Resource mobilisation referred to access to finance, technical competence, personnel, external expertise, and organisational capacity. Development of positive externalities referred to spillovers, complementary services, network effects, and shared infrastructures or routines that could facilitate broader system development (Hekkert et al., 2007; Bergek et al., 2008).

Several themes contributed to more than one function at the same time. For example, a theme concerning unclear conditions for electricity sales could inform not only market formation, but also legitimation and resource mobilisation, since tariff ambiguity, weak offtake clarity, and uncertain rules affected both perceived credibility and willingness to invest. Similarly, a theme concerning the presence of technical know-how, but limited upgrade activity could contribute to both knowledge development and diffusion and entrepreneurial experimentation. Table 3.5 provides illustrative examples of how final themes were linked to one or several TIS functions and carried forward into the subsequent analytical appraisal. A theme to function matrix was therefore used to map how final themes related to one or several functions and to preserve the analytical complexity of the material.

Table 3.5. Examples of the analytical chain from empirical material to TIS interpretation

Example empirical material	Open codes	Final theme	Linked TIS function(s)	Analytical interpretation
Strong operational knowledge was present, but WtE knowledge remained narrow and concentrated	operational knowledge; compliance knowledge; narrow WtE expertise; expert dependence; limited diffusion	Technical knowledge exists, but remains narrow and unevenly distributed	Knowledge development and diffusion	**Moderate,** since relevant knowledge was present but narrowly distributed
Retrofit options were discussed, but no pilot or demonstration project was in place	retrofit discussions; technical proposals; no pilot; cautious exploration; limited implementation	WtE experimentation remains exploratory rather than practical	Entrepreneurial experimentation	**Weak,** since activity remained mainly exploratory
Material pointed more toward landfill diversion and internal use than toward a clear WtE pathway	landfill diversion; waste minimisation; internal use; weak coordination; no clear WtE target	WtE remains a secondary pathway within the wider transition agenda	Influence on the direction of search	**Weak,** since WtE was visible but not clearly prioritised
Commercial conditions for electricity recovery remained unclear and weak	gate fees; unclear offtake; wheeling uncertainty; weak business model; scale constraints; competing treatment routes	Weak commercial conditions for electricity recovery	Market formation; Resource mobilisation	**Weak,** since no credible commercial pathway was evident
Incineration was accepted for treatment, but less clearly for energy recovery	necessary treatment; destruction legitimacy; weaker energy legitimacy; circular economy tension; public concern	Legitimacy is stronger for treatment than for recovery	Legitimation	**Moderate,** since support was stronger for destruction than for WtE
Upgrading was constrained by high capital needs, limited skills, and demanding implementation conditions	high capex; skills shortage; external dependence; implementation difficulty; narrow upgrade capacity	Upgrade capacity remains restricted under current conditions	Resource mobilisation	**Weak**, since finance, skills, and implementation capacity were limited
HCRW treatment routines existed, but WtE specific spillovers remained weak	existing routines; compliance relationships; few reference cases; weak supplier base; limited spillovers	WtE specific spillovers remain underdeveloped	Development of positive externalities	**Weak**, since broader system support for WtE remained limited

3.6.3 Function appraisal and identification of inducement and blocking mechanisms

Once themes had been linked to the TIS functions, function performance was appraised qualitatively as weak, moderate, or strong, as shown in the fifth column of Table 3.5. These assessments were based on explicit analytical decision rules and guided by the theoretical role of each system function in a TIS. Accordingly, the empirical material was interpreted in relation to what the literature suggests each function should contribute to technology development and diffusion.

To make the appraisal more transparent, each function was assessed against three criteria: empirical presence, system distribution, and transition orientation. Empirical presence refers to whether the material showed concrete activities, resources, practices, or constraints related to the theoretical role of the function. System distribution refers to whether this evidence appeared across several sources, actor groups, or empirical settings, rather than only in isolated statements. Transition orientation refers to whether the function supported WtE as a recovery-oriented pathway, or whether it mainly reproduced existing treatment, destruction, or compliance-oriented practices. These criteria were used to ensure that the appraisal did not only capture whether a function existed, but also how broadly it was supported and what kind of system development it contributed to. In addition to these three criteria, the appraisal applied the Global South and justice sensitive interpretation developed in the theoretical framework, meaning that functions were assessed not only by their presence, distribution, and transition orientation, but also by how contextual conditions such as fragmented governance, uneven enforcement, limited domestic WtE experience, labour conditions, and the distribution of risks and benefits shaped their contribution to a credible and socially defensible recovery oriented pathway. The decision rules used for the qualitative appraisal are summarised in Table 3.6.

Table 3.6. Decision rules for qualitative appraisal of TIS functions

Appraisal	Decision Rule	Empirical Implication
Strong	The material shows repeated and relatively consistent evidence across several sources, actor groups, or empirical settings that the function actively supports WtE development in line with its theoretical role	The function is present, broadly distributed, and clearly contributes to a recovery-oriented pathway
Moderate	The material shows that the function is present and partly supportive, but that supportive dynamics are partial, localised, inconsistent, weakly institutionalised, or dependent on a limited number of actors or settings	The function is present, partly distributed, and clearly contributes to a recovery-oriented pathway
Weak	The material shows little evidence of supportive activity, or indicates that the function is largely absent, fragmented, or dominated by persistent constraints	The function does not meaningfully support WtE development, or mainly reproduces existing treatment, destruction, or compliance-oriented practices

A function was assessed as strong when the material showed repeated and relatively consistent evidence across several sources or actor groups that it actively supported WtE development in line with its theoretical role. A function was assessed as moderate when supportive dynamics were clearly present, but remained partial, localised, inconsistent, weakly institutionalised, or dependent on a limited number of actors or settings. A function was assessed as weak when the material showed little evidence of supportive activity, or when the function was largely absent, fragmented, or dominated by persistent constraints.

This distinction was important for avoiding overly broad or intuitive ratings. For example, legitimation was not assessed only by asking whether incineration was accepted or contested in general. Instead, the appraisal considered whether WtE specifically was seen as legitimate, credible, and desirable as a recovery-oriented pathway. Similarly, knowledge development and diffusion was not assessed only by the existence of technical knowledge, but by whether such knowledge was distributed, shared, and translated into coordinated learning, feasibility work, or system-building activities. In this way, the ratings reflected both the presence of relevant evidence and its contribution to WtE development.

The appraisal was therefore systematic, but not quantitative. The intention was not to count statements, but to judge the overall presence, distribution, consistency, and transition orientation of supportive dynamics visible in the empirical material. These judgements were strengthened through triangulation across sources and actor perspectives (Miles et al., 2014; Yin, 2018). Interpretations were not based on isolated interview statements. Greater empirical weight was given to patterns that recurred across different data types, such as cases where interview material, site observations, and documents pointed in the same direction. At the same time, contradictory accounts were not removed from the analysis. Instead, they were treated as analytically important, since disagreement or inconsistency could itself indicate fragmentation, uncertainty, or uneven development within the system. In this sense, contradiction was used not as a problem to be eliminated, but as evidence of system characteristics.

Inducement and blocking mechanisms were then identified by examining how patterns across themes, structural components, and function appraisals interacted. These mechanisms were therefore not treated as a separate coding layer detached from the rest of the analysis. Rather, they were developed through explanation building, where several empirical observations pointing in the same direction were interpreted as part of a broader causal pattern (Bergek et al., 2008; Johnson & Jacobsson, 2001). For instance, when weak market formation coincided with regulatory uncertainty, unclear electricity sales conditions, and limited pilot activity, this was interpreted as a broader blocking mechanism rather than as several isolated observations. In the same way, where existing incineration capacity, available technical expertise, and policy attention to waste and energy issues aligned, these were interpreted as inducement mechanisms that could support further development, even if only partially.

In addition, system orientation was treated as an empirical question rather than as an assumption. A recovery-oriented system would have been indicated by evidence that energy recovery was not only discussed as a possible technical addition, but actively supported through coordinated investment plans, WtE-specific permitting practices, energy offtake arrangements, dedicated technical studies, operational data collection for recovery purposes, pilot or demonstration activity, and actor expectations that positioned WtE as a credible development pathway. Conversely, a destruction-oriented system was indicated where infrastructure, regulation, operational routines, investment priorities, and actor expectations primarily supported safe treatment, compliance, and continuity of hazardous waste destruction, while energy recovery remained secondary, speculative, or weakly institutionalised.

3.6.4 Synthesis into recommendations

The final analytical step consisted of synthesising the identified inducement and blocking mechanisms into policy relevant and managerial recommendations. These recommendations were not derived from individual statements in the material, but from the broader explanation generated through the TIS analysis. In practice, this meant that the recommendations were formulated to strengthen the inducement mechanisms that were already present and to reduce the blocking mechanisms that most clearly constrained system development. Policy recommendations were primarily directed at systemic conditions such as regulatory alignment, market formation, and institutional credibility, while managerial recommendations were directed at issues such as plant readiness, internal capability development, operational stability, and realistic implementation pathways. This final step completed the movement from raw empirical material to system level explanation and action-oriented synthesis, in line with the purpose of the six step TIS analysis (Bergek et al., 2008).

3.7 Research quality and ethics

Research quality in this qualitative case study is supported through a transparent research process and several steps to strengthen trustworthiness. Credibility was strengthened by triangulating interviews, site visits, and relevant secondary documents, which made it possible to check important statements across different sources rather than relying on single informants (Shenton, 2004; Yin, 2018). The thematic analysis was conducted iteratively, meaning that transcripts and field notes were revisited, codes were refined, and themes were adjusted until they were well supported by the empirical material (Braun & Clarke, 2006; Nowell et al., 2017).

Because the study applies the TIS framework, quality considerations also relate to how the empirical themes were interpreted and mapped to TIS structures and functions. The TIS lens offers a systematic way to assess system conditions and dynamics, but several analytical steps involve judgement, for example when assessing whether evidence indicates enabling or blocking mechanisms or when appraising function performance. For this reason, the mapping was based on multiple types of evidence and discussed continuously between the researchers to reduce the risk that results reflect individual assumptions rather than the case material (Miles et al., 2014; Yin, 2018).

Reliability and bias risks were addressed through practical measures during data collection. Both researchers were present during interviews, which supported consistent probing and enabled immediate cross checking of what was heard and how it was interpreted (Miles et al., 2014). A key threat to external reliability is that several interviews were conducted with the case company, who may be influenced by organisational narratives or commercial interests. To mitigate this risk, interviews were also conducted with external stakeholders without direct connection to the case company, which helped balance perspectives and reduce the influence of a single viewpoint (Shenton, 2004). In addition, reflexivity was treated as a quality practice throughout the study, since access to facilities and internal documentation was arranged by the case company and could influence what was observable, shareable, or emphasised in accounts. To strengthen confirmability, the researchers maintained a structured documentation trail through interview guides and field notes, and critically discussed how access conditions, stakeholder positions, and the researchers' own assumptions could shape interpretations. These reflections were actively used to guide triangulation choices and to challenge early interpretations during the iterative coding and TIS mapping process (Miles et al., 2014; Shenton, 2004). Finally, transferability is supported through clear description of the case context, enabling analytical rather than statistical generalisation to similar settings where WtE is shaped by comparable institutional and infrastructure conditions (Lincoln & Guba, 1985; Yin, 2018).

3.7.1 Ethical, societal and ecological considerations

The project was carried out in alignment with the Swedish Research Council's principles for Good Research Practice (2024). Ethical considerations were integrated throughout the research process, with particular emphasis on responsible data management, accuracy in reporting, and transparency in methodological choices (Vetenskapsrådet, 2024). All individuals participating in the study were informed about the purpose and scope of the project, and their participation was based on informed consent, with the option to remain anonymous if requested. The project further ensured that confidentiality was maintained and that the use of empirical material was clearly defined and communicated (Bryman, 2018).

From a societal perspective, the project considered the broader implications of upgrading waste incineration facilities in South Africa, particularly in relation to public health, regulatory compliance, and the impact on local communities. Poorly controlled incineration is associated with negative health outcomes, and the study therefore acknowledged the societal relevance of identifying technological solutions that reduce harmful emissions and improve operational transparency.

Ecological considerations were central to the analysis, given the project's focus on energy recovery, emissions reduction, and resource efficiency. In this study, ecological considerations refer to the environmental performance dimensions that are most directly relevant to WtE in the HCRW context. These included local air quality and emissions control (e.g., pollutants of concern from thermal treatment), the efficiency of energy conversion and utilisation, and the extent to which embedded energy in waste could be recovered and integrated into existing energy infrastructures. Rather than viewing these considerations as purely technical measures, they were examined in relation to the wider system conditions, including regulation, infrastructure, and day-to-day operational practices, that shape how environmental performance is understood and managed.

4

Empirical Findings

This chapter presents the empirical findings through a TIS analysis of the HCRW incineration system in South Africa. Based on interviews, site visits, and document analysis, it analyses the structural components, system functions, and the inducement and blocking mechanisms that influence the potential for WtE development. The empirical findings are used to examine whether the studied system shows signs of recovery-oriented development, or whether its structures and functions primarily support existing treatment, compliance, and destruction routines. System orientation is therefore treated as an empirical question rather than as an assumption.

4.1 Structural components

This section presents the structural components of the studied HCRW incineration system in South Africa. It focuses on actors, institutions, networks, and infrastructure to describe how the system is currently organised and operates in practice. As summarised in Table 4.1, the section provides a descriptive overview of the system's composition and context, which forms the empirical basis for the subsequent analysis of system functions and the prospects for WtE development.

Table 4.1. Summary of structural components

Structural component	Key empirical finding	Role in the TIS	Main enabling or constraining effect	Transition observation
Actors	A few operators, regulators, and experts shape the system, while energy actors remain limited	Defines who can influence treatment, permitting, upgrading, and possible WtE development	Enables action through existing incumbents and expertise, but constrains broader alignment around WtE	Dependence on a small actor group limits broader participation
Institutions	Formal rules support safe destruction and emissions compliance, while weak enforcement and landfill norms shape practice	Determines what is legitimate, permissible, and economically attractive	Supports necessary HCRW treatment, but constrains recovery-oriented development	Safe treatment priorities and uneven enforcement reinforce current practices
Networks	Waste flows and expert ties exist, but WtE collaboration remains fragmented	Connects actors operationally and circulates knowledge	Enables day to day coordination, but limits coordinated WtE implementation	Networks support operations but not broader transition coordination
Infrastructure	Existing plants and logistics support incineration, but the system is old, manual, and not designed for energy recovery	Provides the physical and operational base of the system	Enables continued treatment, but constrains stable and scalable WtE operation	Service continuity orientation and ageing infrastructure constrain upgrading

4.1.1 Actors

There are several actor groups that shape the current system surrounding HCRW incineration and the prospects for WtE in South Africa. These include commercial waste operators and plant owners, waste generators and collection intermediaries, public authorities and regulators, industry organisations, experts and technology suppliers, energy system actors, and labour. Labour is included because workforce conditions are central to how the system functions in practice. Together, these actors influence how waste is collected, classified, transported, treated, regulated, and, in some cases, considered for energy recovery. However, the actor landscape is uneven. It is relatively well developed around treatment and compliance, but much weaker around energy recovery, commercial offtake, and long-term system coordination.

4.1.1.1 Commercial waste operators and plant owners

A first central actor group consists of commercial waste operators and plant owners, referring to firms that own, manage, and operate treatment infrastructure. These actors carry the main responsibility for plant performance, regulatory compliance, and potential future upgrading decisions. Within the studied system, Averda occupies a particularly important position, as it operates two of South Africa's four dedicated HCRW incinerators. The empirical material therefore extends beyond the George facility. Klerksdorp was included as a second Averda plant setting through interviews, consultant input, and case related documents, while A-Thermal and BCL was used more cautiously as comparative reference points within the broader South African HCRW incineration field. Taken together, this indicates that Averda holds a structurally significant position in the national treatment landscape.

At the same time, the wider operator base appears narrow, meaning that the system depends on a limited number of facilities and actors. This creates vulnerability when one plant is offline, under repair, or unable to operate under compliant conditions. Such vulnerability is particularly important because certain nationally significant waste fractions, especially anatomical waste, remain dependent on incineration. Interruptions at a small number of facilities may therefore affect treatment capacity beyond the individual plant level. However, the operator landscape should not be interpreted as uniformly weak. One industry expert described a duality in the

South African waste sector, noting that there are also “world class facilities operating by the private sector” (IO2). This suggests that private operators hold important operational capabilities, but that these capabilities are concentrated within a narrow actor base.

4.1.1.2 Waste generators and collection intermediaries

A second actor group consists of waste generators and collection intermediaries, mainly hospitals, clinics, laboratories, and the licensed firms that collect and transport HCRW to treatment facilities. This actor group is important not only because it generates the waste stream, but also because upstream segregation practices directly affect downstream combustion conditions, safety, and reliability. As one respondent explained, “You’re not allowed to open the box to see what’s in it” (IO5), while another noted that “once the bag has been sealed at the healthcare facility, you do not always know what is inside” (PR2). Together, these accounts illustrate how sealed healthcare containers limit visibility into the actual waste composition entering the plant. As a result, the waste entering treatment may differ from what operators expect. In practice, plant performance is therefore partly shaped by upstream behaviours that plant operators cannot fully control.

4.1.1.3 Public authorities and regulators

Public authorities and regulators constitute a central actor group in the South African HCRW system. Their roles span national licensing and policy development, provincial implementation and oversight, and local inspection related functions.

Environmental governance in South Africa operates through several administrative levels. As one respondent from DFFE explained, “environment is a concurrent function” in which “there’s the national department, and then you’ve got provincial authorities”, while hazardous waste management facilities differ because “the licensing of such facilities is the core mandate of the national department” (PR1). National authorities therefore shape licensing and formal decision making, provincial authorities are more closely tied to implementation and incident response, and district or municipal actors become visible in plant-level oversight and compliance follow up. This was particularly visible during the George site visit, where a regulatory inspection brought operational issues, oversight practices, and compliance concerns into direct interaction. Public authorities therefore shape not only whether plants are permitted, but also how closely their operation is monitored in practice.

4.1.1.4 Industry organisations, experts, and technology suppliers

A fourth actor group consists of industry organisations, experts, and technology suppliers. These actors do not usually control permits or own treatment infrastructure, but they influence the system by contributing knowledge, benchmarks, technical assessments, and possible technology routes. Their role is mainly supportive and intermediary, as they connect research, policy priorities, operational experience, and available technical options. This is reflected in how one respondent described their position, stating that “my role is to manage the waste research, development and waste management 10-year plan for South Africa” (IO2). Another respondent highlighted the international dimension of this support, explaining that “international experts have done some documents to try to help decision makers in Global South to see how to build the pathway to build incineration facilities” (IO7).

This actor group includes both national and international actors. Research and intermediary actors contribute through projects involving universities, science councils, government, and private sector partners, thereby linking knowledge production to public sector priorities and industry related development. References were also made to ISWA and its Energy Recovery working group, as well as to associations such as CEWEP and ESWET. This indicates that parts of the knowledge base around incineration and WtE are internationally connected. Experts with engineering and operational knowledge contribute in a more practical way by assessing how technical changes may affect plant conditions and performance. Their role is to clarify how existing plants function in practice, what technical limitations are present, and what kinds of modifications may be possible under current operating conditions. Technology suppliers form part of the same actor group by providing equipment and technical solutions relevant to both incineration and possible WtE applications. In this way, they influence which retrofit options are considered technically available and what level of technical support may be required for implementation and operation. At the same time, the material also suggests that expert support is tied less to identifying a generic WtE solution and more to judging whether a specific solution fits local conditions. Respondents stressed the importance of waste characterisation, calorific value, moisture content, and institutional conditions before a suitable pathway can be identified.

At the same time, this actor group also reveals a limitation in the South African setting. WtE related expertise exists, but it remains concentrated in a relatively narrow circle of specialists, consultants, suppliers, and project specific contacts rather than in a broad domestic ecosystem with deep implementation experience.

4.1.1.5 Energy system actors

Energy system actors are present in the wider system surrounding WtE, but their role remains limited in relation to HCRW incineration itself. The main energy related actors include Eskom, municipal electricity authorities, renewable energy agencies, and public organisations working with energy planning, innovation, and implementation. This also includes actors such as SANEDI, which works with renewable energy, technology commercialisation, and applied energy research and development, and where WtE is treated as one among several waste related energy options rather than as a standalone pathway. Their relevance lies less in direct involvement with HCRW treatment and more in shaping the broader electricity side conditions under which recovery might become possible. This peripheral role was reflected by an energy system respondent, who explained that “most of the projects that you’ll see, particularly in the energy space and particularly with electricity, will be for own use,” while “channeling electricity back to the grid you don’t find very often” (E1). Energy actors therefore matter for WtE mainly through grid access, tariff conditions, and possible offtake arrangements, rather than through direct involvement in HCRW treatment.

4.1.1.6 Labour

A further actor group that should be made visible in this system is labour. This was particularly clear at the George plant, where everyday operation depends heavily on frontline workers and shift supervisors in a process that remains highly manual. Operators repeatedly handle, move, and feed waste into the incinerator at short intervals to maintain stable combustion conditions. As one case company respondent explained, “there is a lot of labour-intensive [activity] that needs to be done to get the waste to the point of being burned” (CC3). Labour therefore sits close to the operational core of the system, and plant performance depends not only on technical design, but on whether workers arrive, coordinate, and carry out physically demanding and hazardous tasks with sufficient consistency.

At the same time, labour appeared as one of the more fragile parts of the actor landscape. Problems related to lateness, absenteeism, alcohol use, and weak health and safety discipline were described in unusually direct terms, including workers being fired due to alcohol related incidents. In a plant with small shifts and limited staffing margins, even minor disruptions quickly become operational problems. This is also significant in socio-economic terms, since workers at these facilities were described as operating close to minimum wage conditions, and South Africa's statutory national minimum wage is R30.23 per ordinary hour worked (approximately USD 1.77) from 1 March 2026.

This is reinforced by insecure employment conditions. Parts of the workforce were described as short term or unstable, which creates a difficult combination of high operational dependence and low workforce stability in a process that already leaves little room for error. The George case also shows how these conditions are shaped by the wider setting, including limited public transport, long travel distances, and a relatively small pool of skilled labour. Labour should therefore not be treated as a neutral background variable, but as part of how the system takes shape under the constrained social and infrastructural conditions of this South African context. At a wider sector level, low cost labour was also described as economically essential to how the existing waste economy functions, with one respondent referring to South Africa's reliance on the informal sector as a form of "free labour" that allows recovery related activities to take place at all under current conditions (IO2). This wider observation is consistent with the plant-level pattern, where work remains highly manual and continues to depend on workers operating close to minimum wage conditions.

4.1.2 Institutions

Institutions comprise the formal and informal rules that shape how HCRW treatment is organised and what is regarded as permissible, feasible, and legitimate in relation to WtE.

4.1.2.1 Governance, licensing, and permit structures

A central formal institution in the system is the governance structure surrounding HCRW treatment. Responsibility for environmental governance is shared across levels, but hazardous waste licensing is anchored at the national level. This was reflected clearly in how regulatory respondents described the licensing process. As one respondent explained, "the licensing of such facilities is the core mandate of the national department" (PR2). The same respondent also clarified the procedural timeline by noting that "usually it's 107 days from the date of acceptance to the time that we make a decision on it" (PR2), while adding that if stakeholders remain dissatisfied, "they can appeal that decision and then it goes through to our minister to make a decision" (PR2).

Formal licensing therefore includes not only technical review and administrative decision making, but also public participation and the possibility of appeal. This shows that WtE is not blocked by the absence of a legal route, but by a route that is demanding, contestable, and potentially slow. The A-Thermal material illustrates this clearly, as the process of securing a WtE related license stretched across several years and involved appeals from neighbors as well as extended public participation. This indicates that moving from incineration to WtE requires not only technical readiness, but also institutional patience, legitimacy, and the ability to withstand delay.

4.1.2.2 Waste classification and treatment rules

Another important formal institution concerns the classification of waste and the treatment routes permitted for different fractions. In the studied system, waste classification is directly linked to which treatment technologies are regarded as acceptable in practice. This creates a clear institutional distinction between waste streams that can be sterilised through non burn treatment and those that remain tied to incineration under existing rules and expectations. As one respondent put it, "incineration is the only accepted way in which we deal with anatomical waste" (CC1). Pharmaceutical waste was described in similar terms, with another respondent stating that "pharmaceutical waste has to be incinerated" (PR2).

Regulatory and expert respondents also described this dependence as a current capacity concern rather than only a classification issue. Anatomical waste was presented as a fraction for which alternatives are being discussed but not yet regarded as complete or sufficiently supported solutions in the South African context. This means that incineration remains the only accepted route in practice for anatomical and pharmaceutical waste.

The classification of waste also shapes the practical scope of facility operations and permit conditions. While autoclaving is described as the more common route for several HCRW fractions, license conditions include specific restrictions on waste that cannot be treated through that method. In this way, waste classification does not only determine how waste should be handled after collection but also structures which technologies can be used at facility level and which treatment configurations are considered compliant within the system.

4.1.2.3 Emissions compliance

Air emissions compliance is one of the most important institutional conditions surrounding incineration. Among the country's licensed HCRW treatment facilities, only four are described as incinerators, while the remaining thirteen use non burn technologies. This is closely linked to the fact that incinerators are, as one respondent noted, "much more difficult to comply with your licenses because of the air emissions" (WP1). Combustion and emissions compliance is governed by formal technical requirements, such as minimum temperatures, residence time, and flue gas monitoring, which is also evident in the Averda case.

At the same time, the interview material suggests that the practical compliance environment is shaped not only by the standards themselves, but also by how they are interpreted and enforced across jurisdictions. Respondents described how restart after noncompliance depends on formal regulatory sign off, how plants may remain offline for extended periods while compliance related work is carried out, and how oxygen correction requirements were reportedly applied differently across sites. This points to an important institutional inconsistency in the South African context, where enforcement does not appear to be uniformly applied across provinces, municipalities, and districts. In practice, this means that compliance is shaped not only by the formal emissions standards themselves, but also by how different authorities choose to interpret, compare, and enforce them.

4.1.2.4 Electricity, grid, and procurement conditions

For WtE, the institutional environment extends beyond waste regulation itself. Electricity related rules are described as a separate set of conditions that shape whether recovered energy can be used on site, supplied to other users, or sold externally. Long term contracting is also described as difficult in the municipal setting, with one respondent noting that “with our five-year political window, municipalities are very, very reluctant to sign on to a long-term contract” (IO2). This places procurement conditions and political time horizons as part of the wider institutional context surrounding WtE, particularly where investments depend on long term agreements. It also suggests that even technically feasible electricity recovery options may struggle to move forward if there is no institutional willingness to enter durable contractual arrangements.

This becomes more important given the need for a longer-term implementation logic around WtE, including finance mobilisation, stakeholder coordination, and more durable project structures. The material indicates that electricity arrangements are difficult in practice and that several broader conditions linked to recovery-oriented development are still only weakly in place. This is also consistent with the wider guidance material, which argues that developing countries should first work towards a more integrated waste management system before developing and financing WtE facilities for non-recyclable waste.

Several respondents described on site use as more realistic than export. As one respondent explained, “most of the projects that you’ll see, particularly in the energy space and particularly with electricity, will be for own use, while channeling electricity back to the grid you don’t find very often” (E1). The same respondent also noted that “the regulations are still a bit fuzzy on how that works and so are the tariffs” (E1). This indicates that electricity-related institutions do not only shape whether recovery is technically possible, but also whether the recovered value can be translated into a workable commercial model.

4.1.2.5 Enforcement, landfill norms, and legitimacy

Alongside these formal rules, the system is also shaped by informal institutional conditions related to enforcement, expectations, and dominant practices. A recurring pattern is the gap between regulation on paper and implementation in practice. This was illustrated by one respondent, who remarked that “we don’t see non-compliant hospitals or clinics” and that “we don’t see municipalities being held accountable for non-compliance” (IO2). A related example concerned municipal landfill practices, where municipalities were described as intentionally setting landfill sites alight to create additional airspace, despite national legislation prohibiting open burning of waste. As another respondent put it, “it’s not for a lack of policy and legislation and regulation. It’s purely the enforcement of that” (WP1).

This indicates that the institutional environment is not only defined by the existence of rules, but also by how consistently they are applied in practice. South Africa’s broader waste problem is less about the absence of policy ambition and more about weak implementation, uneven accountability, and the continued attractiveness of cheap disposal. This creates an institutional duality in which hazardous waste treatment can be tightly regulated on paper, while the wider waste economy remains shaped by landfill dependency, tolerated non-compliance, and limited political willingness to force more expensive alternatives. The continued dominance of landfill is also reinforced by substantial cost differences between disposal and thermal treatment. According to an estimate from the case company, incineration costs approximately ZAR 10 per kg, while landfill disposal costs around ZAR 0.50 per kg (CC1). This means that incineration can be roughly twenty times more expensive than landfill disposal, creating a strong economic reason to avoid thermal treatment unless regulation requires it. In the HCRW segment, this distinction is particularly important because anatomical and pharmaceutical waste remain tied to incineration, while other fractions may be treated through non-burn technologies before final disposal. The cost gap therefore reinforces an institutional logic in which incineration is treated primarily as a necessary compliance route for specific waste fractions, rather than as a broadly attractive recovery pathway. As a result, WtE must compete not only with technical and regulatory complexity, but also with a disposal-oriented cost structure that continues to make landfill the default option for much of the wider waste system. Informal legitimacy also shapes the position of incineration more broadly. Older negative associations remain present, and incineration is described as connected to earlier experiences of poor operation and visible pollution.

This broader institutional context is also shaped by a more visible waste crisis that extends beyond the HCRW segment itself. Respondents described weak and uneven waste collection, widespread illegal dumping, and growing open burning. One respondent stated that “the open burning of plastic and the open burning of waste in general is a significant problem for South

Africa" (IO2). This is consistent with broader national patterns, since only around half of South African households have access to removal, while roughly 55% to 63% have their refuse removed regularly. Respondents also pointed to the continued importance of waste pickers in the wider waste economy, especially under conditions of poverty, unemployment, and limited formal collection and separation systems. In practice, this means that political and operational attention is often directed toward basic waste control, landfill pressure, and visible service failures rather than toward HCRW based WtE. The wider waste system therefore creates a context in which HCRW WtE remains comparatively peripheral, even if it is technically discussed and seen as relevant in principle.

4.1.3 Networks

The system is shaped by interlinked networks connecting waste generators, collection actors, treatment facilities, regulators, and external experts. At the operational level, these networks are visible in how waste flows are coordinated between healthcare facilities, collection operations, intermediate storage points, and incineration plants. Transportation and treatment are organisationally distinct but operationally interdependent, meaning that plant operation depends on how effectively actors coordinate deliveries, timing, volumes, and waste fractions across the chain. These flows are not organised through a fixed and stable delivery rhythm. Instead, volumes are moved across the network in response to storage pressure, backlogs, and operational conditions at other sites. As one respondent explained, "it depends on whether the third parties, their storages are full, so they bring it to us on request" (CC3). This suggests that plant intake is shaped not only by local treatment needs but also by wider coordination across the collection and storage network.

Networks matter not only for transport, but also for how waste is distributed between treatment routes. The network perspective also helps explain why Klerksdorp matters empirically, even though George was the main site visit location. Several respondents described waste flows as being distributed between George and Klerksdorp depending on volumes, storage pressure, and treatment needs. Klerksdorp therefore appears not as a separate case, but as part of the same internal treatment network through which Averda balances capacity, geography, and waste fractions. Since infectious waste can be treated through cheaper alternatives, while pharmaceutical and anatomical waste remain tied to incineration, coordination is required to direct the appropriate fractions to the incineration plants. One respondent from Averda described how waste is first received in Killarney in Cape Town and then distributed onward in relation to plant needs rather than simply being forwarded directly to George, noting that "normally we receive everything there and then we push it down… we push enough for George to run, but we don't push more than what George needs" (CC1).

The required ratio is maintained because infectious waste helps sustain combustion conditions, whereas anatomical waste makes the feed more difficult to burn. As one respondent explained, the use of a higher infectious fraction is "done to increase the heat in your primary chamber" and to "maintain it", while anatomical waste was described as "like throwing water on a fire" (CC3). Killarney therefore functions not only as a transfer point, but also as a balancing point where waste is managed in relation to combustion needs. This coordinating role is especially important because the incinerators are also limited in how much waste they are allowed to store onsite before treatment. As a result, the flow of waste must be managed carefully to avoid excessive buildup while also ensuring that the right fractions are available for combustion. This also helps explain why the plants need to stop regularly, not only for maintenance and cleaning, but also to stabilise the flow of waste and secure a workable mix of fractions for continued incineration. Third party actors and competitors also form part of this network, since external deliveries and regional storage backlogs influence both daily intake and plant operation. The network surrounding HCRW incineration therefore extends beyond plant ownership to include collection, transfer, storage, and delivery relationships that shape waste availability and waste composition at plant-level.

Beyond plant operations, broader knowledge and governance networks connect public authorities, research actors, and industry. These are visible in both joint oversight activities and research-based collaboration. Repeated references to actors such as South African National Energy Development Institute (SANEDI), DFFE, the Western Cape Government, A-Thermal, and technical experts indicate that WtE related information currently circulates mainly through expert contacts and project-based interactions. At the same time, these networks appear much less mature around WtE specifically. WtE related knowledge appears to circulate through a relatively narrow circle of actors, meaning that the network structure supports destruction and compliance more clearly than WtE experimentation and diffusion.

4.1.4 Infrastructure

Infrastructure consists of treatment facilities, waste handling and transport arrangements, storage and transfer capacity, emissions control and monitoring equipment, electricity related connections, and the organisational routines needed to keep plants functioning.

South Africa's HCRW incineration infrastructure is small, concentrated, and operationally fragile. National treatment capacity depends on a very limited number of facilities, meaning that plant specific breakdowns, compliance failures, or extended maintenance periods can have wider system consequences. The infrastructure also appears uneven in condition and strongly dependent on manual operation.

This small scale is also visible at national level. Respondents suggested that South Africa has an approximately 80 to 20 split between non-combustion and combustion treatment routes, meaning that most HCRW is treated outside the incineration segment altogether. At the same time, respondents described anatomical waste as a growing fraction that still requires incineration, which places disproportionate pressure on this very small thermal treatment base. One respondent from DFFE explained this capacity risk clearly, stating that "if one goes down, then you pretty much compromise the entire country from a treatment perspective" (PR1). This indicates that the physical base available for any HCRW specific WtE pathway is narrow not only at plant-level but also at national system level.

This became particularly visible during the site visit to the George facility. The plant was observed as small and physically constrained, with large parts of the treatment process relying on direct operator involvement rather than automated systems. Visible wear, including a damaged roof and outdoor exposure, reinforced the impression of a plant operating under strained conditions rather than within a stable and well-maintained environment. These observations indicate that the existing infrastructure is organised around continued treatment under constrained conditions rather than around energy recovery. The Klerksdorp material further suggests that several of these infrastructural constraints are not unique to George. Although Klerksdorp was described as larger and somewhat different in layout, the material still pointed to similar challenges around emissions compliance, cleaning requirements, manual handling, and limited suitability for WtE upgrading.

Figure 4.1a. George HCRW incineration facility. The image shows the small scale of the plant, its dual chamber setup with a rotary kiln, the damaged roof, and that large parts of the work are carried out manually. (Own photograph, George site visit, February 2026)

Figure 4.1b. George HCRW incineration facility. The image shows that large parts of the facility are located outdoors, which makes the plant exposed to weather conditions. The high levels of rain in George contribute to wear and rust. (Own photograph, George site visit, February 2026)

To further contextualise these observations, the site visit to Renova in Gothenburg provides an illustrative benchmark of a more mature WtE facility. The two cases are not directly comparable in terms of waste stream or system purpose, the comparison remains analytically useful because it highlights differences in scale, automation, and plant condition. In contrast to the manual and spatially constrained setup observed in George, the Renova facility displayed a much larger and more integrated system, where waste handling is automated and several chambers operate within a cleaner and more technically complete plant environment. The benchmark also showed that Renova's system is not based on electricity generation alone, but on combined recovery of electricity and heat within a district heating context. This is analytically important because it illustrates that the Swedish case rests on a wider infrastructural setting that is materially different from the South African HCRW context.

Figure 4.2a. Renova WtE facility in Gothenburg. The image shows that waste handling is automated and illustrates the large waste volumes managed at the facility. (Own photograph, Renova site visit, January 2026)

Figure 4.2b. Renova WtE facility in Gothenburg. The image shows a larger and more complete plant setup with several chambers, as well as a clean and well-maintained operating environment. (Own photograph, Renova site visit, January 2026)

The benchmark does not suggest that South African plants should mirror a large scale municipal WtE facility. However, it does show that the current HCRW setup is materially, spatially, and operationally far from the infrastructural conditions usually associated with mature WtE systems. The existing infrastructure therefore provides a base for continued destruction, but not yet for energy recovery.

Plant-level infrastructure is also closely tied to compliance and control. The site visit in George and the observed regulatory inspection showed that the incineration infrastructure includes not only the combustion process itself, but also the equipment and routines needed for safe operation, emissions control, and regulatory oversight. In this way, measurement, inspection, and reporting form part of the operational infrastructure surrounding the plant rather than existing separately from it. No dedicated energy recovery equipment was observed at the facilities. More advanced WtE systems typically require additional components such as waste pits, steam turbines, expanded flue gas treatment systems, and analysers, which were not present in the studied HCRW setup.

A further infrastructural element concerns electricity related connections. Although WtE was discussed as a possible future pathway, grid related infrastructure and connection conditions are not yet in place. As one respondent described it, “it’s quite a difficult process ... a lot of paperwork ... getting into the grid and selling it off has become the bottleneck” (WP1). This indicates that the relevant infrastructure challenge is not limited to physical connection alone but also includes the procedural and administrative arrangements required to make external electricity supply possible.

Infrastructure also includes plant specific operational know how. Daily operation depends on staff who manage combustion conditions, waste handling, maintenance, and compliance routines. This means that the system relies on practical and organisational infrastructure alongside the physical plant itself. Taken together, the current infrastructure is configured for destruction, handling, and compliance rather than for electricity generation.

4.2 System functions

This section analyses the functional performance of the studied HCRW incineration system in South Africa through the TIS framework. While the previous section described the system’s structural components, this section examines how the system functions in relation to WtE development. Table 4.2 summarises the seven system functions, their main empirical indications, and their performance appraisal, including how they relate to broader transition conditions in the South African context. The section identifies the main strengths and weaknesses shaping the prospects for WtE and provides the basis for the subsequent analysis of inducement and blocking mechanisms.

Table 4.2. Summary of system functions and their performance appraisal

System function	Actors involved	Main empirical indication	Performance appraisal	Transition observation
Knowledge Development and Diffusion	Waste operators and plant owners Industry organisations, experts, and technology suppliers	Strong operational and compliance knowledge exists, but WtE specific knowledge remains limited, concentrated, and supported by few comparable reference cases in the Global South	<u>Moderate</u>	Knowledge relevant to transition is present, but remains narrow, unevenly distributed, and supported by few comparable reference cases in the Global South
Entrepreneurial Experimentation	Waste operators and plant owners Industry organisations, experts, and technology suppliers	WtE experimentation is mainly expressed through retrofit discussions, technical proposals, and incremental plant adjustments, while no pilot or demonstration project is operating at the case plants	<u>Weak</u>	Experimentation remains cautious, exploratory, and site specific rather than demonstrative of a broader transition pathway
Influence on the Direction of Search	Public authorities and regulators Waste operators and plant owners Energy system actors	Attention is directed more towards landfill diversion, waste minimisation, and internal energy use than towards a coordinated WtE pathway	<u>Weak</u>	WtE remains a secondary pathway, shaped more by immediate service and energy pressures than by coordinated transition direction
Market Formation	Waste operators and plant owners Energy system actors Public authorities and regulators	Revenue conditions remain tied mainly to gate fees and treatment economics, while electricity sales, offtake structures, and stable commercial models remain unclear	<u>Weak</u>	Weak commercial conditions limit the translation of technical potential into a stable transition pathway for WtE
Legitimation	Public authorities and regulators Waste operators and plant owners Waste generators and collection intermediaries	Incineration is more accepted as a necessary treatment route for hazardous healthcare waste than as an energy solution	<u>Moderate</u>	Legitimacy exists, but it is stronger for safe destruction and compliance than for energy recovery as a transition option
Resource Mobilisation	Waste operators and plant owners Industry organisations, experts, and technology suppliers Public authorities and regulators	High capital requirements, limited skilled labour, external technology dependence, and demanding implementation processes constrain WtE development.	<u>Weak</u>	Upgrade capacity remains restricted by finance, specialist competence, and implementation capacity under current conditions
Development of Positive Externalities	Industry organisations, experts, and technology suppliers; Waste operators and plant owners Public authorities and regulators	Some supportive routines exist around HCRW incineration, but WtE specific spillovers, supplier structures, and shared learning remain underdeveloped.	<u>Weak</u>	Cumulative system support for WtE remains limited, with weak spillovers and few locally embedded transition supports

4.2.1 Knowledge development and diffusion

Knowledge development and diffusion in the studied system is visible primarily through operational, compliance related, and engineering knowledge. Plant managers, engineers, external experts, and research related actors hold detailed knowledge about HCRW incineration, including waste composition, operating temperatures, flue gas characteristics, air flow, emissions constraints, maintenance requirements, and possible retrofit routes. At the George plant, operational routines included internal production sheets used to capture treated tonnages, downtime, obstacles, and stoppage reasons. This indicates that some structured learning takes place at plant-level. In addition, research oriented actors described ongoing work through universities and science councils, while engineering respondents contributed detailed knowledge on plant design, corrosion risks, emissions constraints, and possible energy recovery options.

The material also shows that some WtE relevant knowledge exists. Several discussions focused on the technical information needed to assess energy recovery, including calorific value, moisture content, stable temperatures, flue gas flow, pressure drop, and the operating margins of existing equipment. One respondent explained that the waste mix is not perfect but provides a starting point, with anatomical waste around 5 MJ per kg, some pharmaceutical fractions reaching around 40 MJ per kg, and an overall target around 26 MJ per kg. The same respondent described typical moisture content of approximately 5.5%, primary chamber temperatures of 850 to 950°C, secondary chamber temperatures of 1050 to 1100°C, and further temperature reductions after lime introduction (IO5). This indicates that actors possess meaningful technical knowledge for assessing whether energy recovery could be technically explored.

However, the material also shows important limitations in both knowledge quality and knowledge diffusion. Some key parameters are not continuously verified in a strict monitoring sense, meaning that parts of the assessment still rely on practical plant experience rather than exact and consistently available data. Knowledge of the waste stream is also constrained upstream because sealed boxes and bags cannot be opened once they leave healthcare facilities. This creates uncertainty around waste composition and combustion behaviour, both of which are important for WtE feasibility.

A second limitation concerns the distribution of WtE specific knowledge. Knowledge about possible upgrading pathways is not yet broadly shared, even within the operator side. One respondent observed that “our corporate team just don’t necessarily understand what is at the plant and what can be achieved” (CC1). WtE related change was also described as requiring substantial internal motivation and a more formal study before larger investment could be considered. Knowledge diffusion therefore occurs mainly through direct contacts, engineering consultations, research projects, and project based exchanges rather than through a broad and mature HCRW WtE field.

A further limitation concerns operator capability and workforce embeddedness. Day to day knowledge is closely tied to supervisors, plant managers, and a small number of technically knowledgeable individuals. Respondents described skills shortages, high turnover, health and safety discipline problems, poor attendance, and difficulties retaining operational competence. As one respondent put it, “you don’t have 5,000 skilled artisans looking for jobs, you’re lucky if you have five” (CC3). This makes it difficult for operational knowledge to become broadly embedded across shifts and over time.

Taken together, knowledge development and diffusion is appraised as moderate. The function is not weak, because relevant technical, operational, regulatory, and engineering knowledge is clearly present across operators, experts, consultants, and research actors. However, it is not strong, because WtE specific knowledge remains narrow, unevenly distributed, weakly institutionalised, and supported by few comparable reference cases in the Global South. The knowledge base is therefore sufficient to support continued exploration, but not yet strong enough to underpin coordinated WtE implementation.

4.2.2 Entrepreneurial experimentation

Entrepreneurial experimentation related to WtE in the HCRW incineration context is visible mainly through technical proposals, retrofit discussions, incremental plant adjustments, and exploratory ideas about future conversion. Several possible energy recovery routes were discussed for the existing plants, including heat extraction from the secondary chamber, steam generation through heat exchangers, turbine related solutions, and ORC based recovery from lower temperature heat streams. These options were assessed in relation to flue gas temperatures, pressure drop, corrosion, permit conditions, and the need to maintain operating conditions required for emissions compliance.

The idea of conversion is also present within the actor environment. One respondent noted that "we've had a couple of people knocking at the door saying they would like to buy the plant but want to convert it to a waste energy plant" (CC3). Another respondent stated that "there must be means and ways with the heat that we get in our plant to change that heat into something else" (CC1). These statements indicate that WtE is not absent from operational or strategic thinking. The wider material also includes examples from outside the focal case, including Southeast Asia and Indonesia, where governments have moved from poorly controlled landfilling toward incineration based WtE in what one respondent described as "a sort of leapfrogging" (IO9). This suggests that more ambitious forms of experimentation are imaginable under different institutional and planning conditions.

The A-Thermal material further illustrates that WtE related experimentation in South Africa can move beyond the early idea stage. In that example, a WtE related project had progressed into licensing, engineering work, and market engagement, even though it had still not materialised in practice. This supplementary operator perspective indicates that technical concepts can be developed, and that implementation could proceed relatively quickly under the right commercial conditions. One respondent explained that "if we had those contracts in place, we would do construction and start commissioning within one to two years" (WP2).

However, the material also shows that experimentation remains limited and cautious. No dedicated pilot or demonstration project for electricity recovery is operating at the case plants. Plant-level experimentation remains focused mainly on incremental improvements within the existing treatment process, such as gas cleaning, more continuous feeding, and plant stability. A screw based feeding solution, for example, was considered but not pursued due to cost and development requirements. This indicates that experimentation is shaped by the immediate need to sustain treatment reliability rather than by a wider effort to demonstrate WtE.

The constraints are also broader than technical design. Respondents repeatedly framed WtE as technically conceivable but difficult to realise under current South African conditions. As one interviewee put it, "my first thought of waste to energy is yes, possible. If you put South Africa behind that, no" (IO7). The A-Thermal material shows a similar pattern. The main barrier was described as market readiness rather than the absence of a technical solution, with one respondent explaining that "the main one is getting the clients to commit to the contracts at the pricing" (WP2). This suggests that experimentation is constrained by weak willingness to pay, uncertain market formation, and the continued availability of cheaper treatment and disposal alternatives.

The material also shows that retrofitting older plants is more difficult than the concept of "adding recovery" initially suggests. In the A-Thermal material, the preferred route was not a simple retrofit of the existing plant, but a larger new line with a new chamber and system configuration designed for WtE. This preference was linked to spatial constraints, difficult integration into a plant not originally designed for energy recovery, and the financial challenge of modifying an operating plant while losing revenue during the upgrade period. One respondent explained that "retrofits is quite hard if the line isn't designed for waste energy in the beginning. To just add something to generate electricity, it is hard to make it work financially, you need a new chamber designed for energy recovery, and that is the most expensive part of the plant" (WP2).

Taken together, entrepreneurial experimentation is appraised as weak. The function is not completely absent, since technical options are discussed, external interest exists, and supplementary South African material shows that WtE related licensing and engineering work can occur. However, the function remains weak because no pilot or demonstration project is operating at the case plants, experimentation is not yet producing transferable learning, and implementation remains constrained by cost, market readiness, operational fragility, and the limited redundancy of the current treatment system. The empirical material therefore points to exploratory experimentation rather than a functioning experimental pathway for WtE.

4.2.3 Influence on the direction of search

The direction of search in the studied system is shaped by several pressures that make WtE visible. Energy insecurity, unstable electricity supply, landfill pressure, and broader waste transition debates all create some attention toward recovery based thinking. Respondents described internal electricity use and reduced grid dependence as more realistic than electricity export, particularly because these options could support plant operations under conditions of energy instability. One respondent stated that facilities are more likely to "reduce their own consumption rather than putting back onto the grid" (IO6). This indicates that WtE is partly considered in relation to operational resilience and internal energy security.

The broader waste policy environment also creates some transition pressure. Respondents referred to priorities such as landfill diversion, waste minimisation, expanded infrastructure, and higher value recovery. These priorities indicate that the waste system is not static and that actors are aware of the need to move beyond simple disposal. In this sense, WtE remains visible as one possible response to waste and energy pressures.

However, the material shows that WtE is not the dominant or clearly coordinated pathway within the wider direction of search. The broader direction is oriented more strongly toward landfill diversion, waste minimisation, and higher value recovery than toward incineration based electricity generation. As one regulatory respondent explained, “the first clearly stated priority is the diversion of organic waste from landfill by 2027. A further priority is to enable municipalities to minimise waste through expanded infrastructure” (PR3). At the same time, no clear policy target, procurement framework, or formal planning signal was identified that specifically directs attention toward WtE in the HCRW incineration field.

The material also suggests that stronger inducements often appear outside HCRW incineration itself. Several consultants, government organisations, and experts pointed to pilots and projects using tyres, pyrolysis, ETD outputs, residues, or other waste derived fractions as inputs for industrial combustion, fuel production, or power generation. This indicates that recovery oriented activity is present in the broader field, but that clearer guidance and experimentation often sit in pathways other than incineration based WtE.

Taken together, influence on the direction of search is appraised as weak. The function is not absent, since energy insecurity and waste system pressure keep WtE visible and create some space for recovery based thinking. However, it remains weak because this attention is fragmented, indirect, and not supported by a coherent policy signal, procurement pathway, or shared system level expectation around HCRW based WtE. WtE is therefore kept in view by necessity rather than by coordinated transition direction.

4.2.4 Market formation

Market formation for WtE in the HCRW field shows limited supportive activity. The strongest potential market logic concerns internal electricity use, where recovered energy could reduce operating costs and improve resilience against grid instability. Several respondents described internal use as more realistic than external electricity sales, particularly where generation could support plant continuity. Some respondents also discussed possible external options such as grid export, wheeling, and long term offtake arrangements under the right regulatory and commercial conditions. This indicates that a possible value proposition exists, but it remains conditional.

The treatment market also provides a partial starting point. HCRW treatment already generates revenue through gate fees, and incineration is required for certain fractions such as anatomical and pharmaceutical waste. This means that any WtE pathway would be attached to an existing treatment function rather than a completely absent market. Respondents also acknowledged that WtE could be attractive if the balance between treatment revenue, capital expenditure, and energy value could be made workable.

However, the material shows that market formation remains weak. Revenue conditions are tied mainly to treatment economics rather than to an established electricity market or a stable commercial model for energy recovery. One respondent stated that “finding the balance between the gate fees and the capital expenditure is hard since higher investment would require higher gate fees while landfill remains the cheaper option” (WP1). Another respondent similarly explained that “WtE depend on the gatefee you have to charge, and the revenue you get from it” (CC2). These accounts show that the business case for WtE remains rooted primarily in treatment, not energy sales.

The material also indicates that the central market barrier is not a lack of interest in WtE as such, but uncertainty over whether it would generate a credible return in practice. Respondents questioned whether WtE would create substantive value or mainly function as a marketing tool. Electricity revenue remains uncertain and secondary, while internal electricity savings are not automatically large enough to justify the investment. This uncertainty is reinforced by the need to maintain backup grid connection even when electricity is generated internally, since the grid remains necessary when the plant is not running.

External electricity sales are also weakly institutionalised. In the A-Thermal material, no revenue from surplus electricity was included in the business case despite the possibility of future export under the right conditions. Respondents referred to licensing requirements, grid related barriers, and limited willingness to pay for green electricity as reasons why electricity sales could not yet be treated as a stable revenue stream. The market weakness is therefore not only about electricity price. It also concerns the absence of reliable offtake structures, bankable contracts, and institutional arrangements that could support investment.

A further constraint concerns scale and feedstock. Several respondents described HCRW volumes as too low for strong standalone electricity generation and noted that medical waste alone may not provide a sufficiently attractive base for a robust WtE project. This is reinforced by competition from ETD within the HCRW treatment system itself. Although regulation allows incineration of a broader set of fractions, ETD is retained because it is materially cheaper for infectious and sharps waste, which constitute the largest share of the HCRW stream. Since these fractions can in principle be directed either to incineration or ETD, the lower cost ETD route reduces the volume base available for incineration and therefore for any WtE model attached to it.

Taken together, market formation is appraised as weak. The function is not entirely absent, since treatment revenue exists and internal electricity use provides a possible value proposition. However, the function remains weak because there is no stable project pipeline, standardised offtake structure, reliable electricity revenue model, or sector wide commercial model for WtE from HCRW incineration. Market formation therefore does not yet translate technical potential into a credible recovery based business model.

4.2.5 Legitimation

Legitimation in the studied system is partly supported by the recognised need to treat certain hazardous healthcare waste fractions through incineration. Several respondents described incineration as necessary for specific HCRW streams. One respondent stated that "healthcare risk waste makes absolute sense to incinerate" (IO7), while another explained that "incineration is the only accepted way in which we deal with anatomical waste, alternatives currently lack sufficient support and complete downstream solutions" (CC1). This gives HCRW incineration a stronger legitimacy base than broader municipal waste incineration, since it is connected to public health, safe destruction, and compliance requirements.

Formal regulatory approval processes also contribute to legitimacy by creating a recognised route through which facilities can be assessed. Facility changes and expansions pass through public participation and compliance based regulatory review. One regulatory respondent explained that “if a facility is not compliant then we would be hard pressed to issue a positive decision [for WtE licensing] whereas compliant facilities with no issues or complaints are viewed more favourably” (PR2). This shows that legitimacy is linked not only to the technology itself, but also to demonstrated compliance performance and institutional trust in the operator.

However, the material also shows that legitimation is conditional and contested. Incineration faces resistance from some stakeholders, strong compliance requirements, and continued negative associations linked to earlier poor operating experiences. One respondent emphasised that “the biggest challenge at the moment is obviously to meet the stringent emission standards” (CC3), while another noted that “some organisations are very much against incineration because equipment in the past caused problems” (IO6). These statements show that legitimacy depends heavily on environmental credibility, emissions control, and confidence in safe operation.

WtE also faces legitimacy challenges on the energy side. Respondents described PV and grid electricity as more familiar to business owners and decision makers. One respondent explained that many actors “know and understand ESKOM electricity” and “know and understand, to a certain extent, PV with BESS,” but “they don’t know and understand other technologies,” and in such situations “little red flags go off” (IO10). This suggests that WtE is harder to legitimise not only because of its association with incineration, but also because it is less familiar and less legible as an energy option than technologies already more widely understood.

A further contestation concerns how WtE fits within broader sustainability priorities. Incineration is more easily legitimised as a necessary treatment route for specific hazardous fractions than as a recovery oriented transition pathway. This distinction matters because the legitimacy of destruction does not automatically transfer to the legitimacy of energy recovery. From a just transitions perspective, the material also suggests that legitimacy depends on who is involved in decision making, whether environmental risks are credibly controlled, and whether the burdens and benefits of upgrading are fairly distributed.

Taken together, legitimation is appraised as moderate. The function is not weak, because incineration has a recognised and institutionally accepted role for certain HCRW fractions, and WtE is viewed as potentially relevant under specific conditions. However, it is not strong, because legitimacy remains conditional, contested, and more secure when incineration is framed as necessary treatment than when it is framed as an energy transition solution. The function therefore supports treatment continuity more clearly than recovery oriented system transformation.

4.2.6 Resource mobilisation

Resource mobilisation shows some supportive capacity in the studied system. Existing operators, engineers, consultants, technology suppliers, and regulatory actors provide a base of organisational and technical resources. One respondent from the case company suggested that larger investments could, in principle, be financed internally or externally. The existence of operating facilities, established waste logistics, and engineering expertise also means that WtE would not begin from a completely absent resource base. These conditions provide some foundation for further exploration.

However, the material indicates that the resources required for WtE are substantially greater than those needed to maintain the current destruction oriented system. High capital requirements, limited skilled labour, reliance on external equipment and expertise, and demanding preparation processes all constrain implementation capacity. As one respondent explained in relation to automation and plant modifications needed to meet air emission targets, “all those things cost a lot of money and capital hasn’t been there” (CC2). WtE related development is therefore described as expensive and difficult to prioritise, especially when existing plants already require maintenance, compliance spending, and operational improvements.

The resource challenge also emerges before implementation begins. Several respondents emphasised that substantial costs arise during preparation, including authorisations, equipment, technical studies, engineering support, and project development. A respondent from the hazardous waste authority described WtE as extremely expensive and noted that developers may “run out of money along the way” (IO7), since costs accumulate before the operational phase is reached. This indicates that resource mobilisation is constrained not only by capital expenditure, but also by the long and costly process required to reach an investable project.

Labour and organisational resources are also limited. One respondent noted that “the manpower that we have at the plant is unskilled to semi-skilled and you’ll have to change your personnel base when upgrading to WtE, which would make the facility more expensive to run" (IO5). Current plant operations already depend on manual feeding, repeated cleaning, and continuous maintenance. Much of the available operational capacity is therefore tied to keeping the existing incineration process running rather than preparing for more advanced recovery functions. Respondents also noted that a retrofit would likely require downtime, interrupting treatment revenue and creating service continuity risks.

A further constraint concerns equipment access and technical support. Specialised equipment often needs to be sourced from outside South Africa, while project preparation is associated with delays related to shipping, permitting, and adaptation to local conditions. Transition capacity is therefore tied to a relatively narrow set of financial, technical, and organisational resources.

Taken together, resource mobilisation is appraised as weak. The function is not entirely absent, since some operational capability, engineering expertise, and potential financing routes exist. However, it remains weak because the resources required for WtE exceed the current system's readily available financial, human, organisational, and technical capacity. Under current conditions, upgrading is constrained by capital intensity, skills shortages, external technology dependence, preparatory costs, and limited implementation capacity.

4.2.7 Development of positive externalities

Some positive externalities are visible around HCRW incineration generally. Existing routines have developed around operations, compliance procedures, inspections, reporting, and relationships between operators, regulators, consultants, and technical experts. These routines help sustain the current treatment system and provide some basis for knowledge exchange. The system also includes practical experience in combustion, emissions monitoring, maintenance, and hazardous waste handling, all of which could provide partial spillovers for future WtE exploration.

However, the material shows that WtE specific positive externalities remain underdeveloped. Respondents pointed to the very limited presence of established WtE infrastructure across Africa more broadly. One interviewee noted that there is "not much in the way of waste to energy, other than in Addis" (IO7), referring to the large plant in Addis Ababa. This limits the availability of nearby reference cases, regionally embedded implementation experience, and opportunities to learn from comparable African examples.

The material also does not indicate a mature base of specialised WtE suppliers, standardised commercial arrangements, training programmes, or a broader professional community with direct implementation experience of WtE from HCRW incineration. Discussions around WtE are instead tied mainly to individual actors, site specific ideas, or external technology providers. Equipment and technical solutions are often described as originating from outside South Africa, suggesting that domestic support capacity for this type of system remains limited.

The absence of cumulative spillovers keeps starting costs high for each potential initiative. Technical assessment, permitting, engineering design, supplier search, and implementation planning appear to need to be developed project by project rather than supported by established routines or shared infrastructure. This prevents WtE from benefiting from the type of accumulated learning that would reduce uncertainty and make subsequent projects easier to implement.

Taken together, development of positive externalities is appraised as weak. The function is not completely absent, because existing HCRW incineration routines and compliance relationships provide some indirect support. However, WtE specific spillovers remain limited, with few locally embedded reference cases, weak supplier structures, limited shared learning, and no mature professional ecosystem around HCRW based energy recovery. The function therefore provides little cumulative system support for WtE development.

4.3 Functional dynamics: Inducement and blocking mechanisms

Building on the analysis of structural components and system functions, this section identifies the inducement and blocking mechanisms that shape the development trajectory of WtE in the studied system. While the previous sections assessed how individual functions are currently fulfilled, the inducement and blocking mechanisms perspective helps explain why certain functions appear strengthened while others remain weak or underdeveloped. In line with the TIS framework, these mechanisms are interpreted as causal processes that influence how functions interact over time and whether the system moves toward expansion or stagnation (Bergek et al., 2008; Hekkert et al., 2007).

The analysis indicates that the current HCRW incineration system in South Africa is primarily configured around destruction and regulatory compliance. While certain conditions provide inducements that could support future WtE development, several blocking mechanisms simultaneously constrain the strengthening of key functions such as market formation, resource mobilisation, and entrepreneurial experimentation. The central issue is therefore not only whether energy recovery is technically conceivable, but whether a system built around treatment, compliance, and operational survival can carry the additional complexity of WtE. This is also where the transition perspective becomes important. The case does not point toward system replacement in the short term, but rather toward the more limited possibility of adapting existing assets under difficult operating conditions. Table 4.3 provides a summary of the identified inducement and blocking mechanisms.

Table 4.3. Summary of inducement and blocking mechanisms

Type of dynamic	Mechanism	Empirical expression	Functions affected	Result	Transition observation
Inducement 1	Existing incineration infrastructure and operational capability	Existing plants, logistics systems, and combustion know how already in place	Knowledge development, resource mobilisation, experimentation	Creates a possible starting point for WtE	Transition potential lies in incremental asset adaptation rather than system replacement
Inducement 2	Technical knowledge and expert networks	Engineers, researchers, and experts can identify retrofit routes and constraints	Knowledge development, knowledge diffusion, guidance of search	Supports continued exploration	Relevant capability exists but remains concentrated within a narrow expert network
Inducement 3	Policy attention to waste and energy transitions	Energy instability, load shedding, and broader waste transition debates keep WtE visible	Direction of search, legitimation	Provides weak but real pressure toward recovery thinking	Energy reliability and service pressure create transition relevance despite limited WtE support
Blocking 1	Institutional orientation toward destruction rather than energy recovery	Regulation and permitting are built around safe destruction, not value recovery	Direction of search, legitimation, market formation	Keeps WtE secondary	Treatment and compliance priorities narrow the space for recovery-oriented change
Blocking 2	Weak market formation for electricity from HCRW incineration	Grid barriers, uncertain offtake, low willingness to pay, low scale	Market formation, resource mobilisation, experimentation	Weakens investment incentives	Unstable market conditions undermine credible recovery-based business models
Blocking 3	Limited entrepreneurial experimentation and unstable operation	No pilot plant, repeated stoppages, downtime, manual work, fragile continuity	Experimentation, knowledge development, legitimation	Prevents credible testing and scaling	Technically demanding options face high implementation thresholds under fragile operating conditions
Blocking 4	Structural dependence on established waste management practices	Cheap landfill, weak enforcement, and low-cost disposal continue to dominate	Market formation, legitimation, direction of search	Reinforces the current system path	Existing disposal structures reinforce path dependence and lock in missed recovery opportunities

4.3.1 Inducement Mechanism 1 – Existing incineration infrastructure and operational capability

A first inducement mechanism concerns the presence of an existing infrastructure base for high temperature waste incineration. The system already includes incineration plants, logistics arrangements for waste collection and transfer, and established plant-level routines for combustion, handling, and compliance related operation. WtE, if pursued, would therefore not need to begin from a completely absent technical base. The existing plants and their surrounding operational systems create a possible starting point from which energy recovery can be considered.

This inducement mainly affects knowledge development, resource mobilisation, and experimentation. Existing plants create environments where actors can observe real operating constraints, understand combustion behaviour, and assess where recovery options may or may not fit. They also reduce the distance between current destruction practice and possible future recovery thinking, since key physical assets and logistics systems are already in place. The infrastructure does not represent WtE readiness in itself, but it does create a material base for continued exploration.

From a transition perspective, this means that any realistic near term WtE potential lies more in incremental asset adaptation than in full system replacement. The case therefore points less toward a large scale transition leap and more toward the possibility of modifying and building on what already exists, even if that possibility remains constrained by the limitations of the current plants. This is important in the South African context, where capital intensive system replacement is difficult and where transition pathways are likely to be shaped by adaptation of existing infrastructure rather than by immediate greenfield transformation.

4.3.2 Inducement Mechanism 2 – Technical knowledge and expert networks

A second inducement mechanism is the presence of technical knowledge and expert networks surrounding incineration and possible energy recovery. Engineers, researchers, plant actors, and external experts can identify both potential retrofit routes and key technical constraints, including temperature windows, airflow dependence, corrosion, pressure drop, and operational instability. This knowledge is held mainly by plant managers, engineers, external technical experts, consultants, and a limited set of research and intermediary actors, rather than by a broader operational or implementation community. A substantial share of it is also international, in the sense that relevant expertise, technology understanding, and solution references are often located outside South Africa and accessed through external suppliers, specialised consultants, or international technical networks.

This mechanism mainly strengthens knowledge development, knowledge diffusion, and the direction of search. It allows actors to frame WtE not merely as a speculative idea, but as a technically assessable option with identifiable conditions, limits, and tradeoffs. At the same time, the capability remains unevenly distributed, since WtE related knowledge circulates through a relatively small group of engineers, consultants, research actors, and project based contacts rather than through a broader and more self reinforcing implementation network. Knowledge diffusion is therefore partly dependent on access to international expertise that is not deeply embedded in local operational practice.

The transition observation is therefore somewhat double edged. On the one hand, the presence of relevant expertise means that the system is not entirely closed to WtE. On the other hand, the narrow concentration of that expertise limits wider diffusion and makes further development dependent on a small number of knowledgeable actors. In the South African context studied here, where comparable WtE reference cases remain limited and technical support ecosystems appear relatively thin, this concentration becomes significant because it raises the threshold for moving from exploration to implementation.

4.3.3 Inducement Mechanism 3 – Policy attention to waste and energy transitions

A third inducement mechanism is the broader policy attention directed towards WtE transitions in South Africa. WtE remains present in the policy and strategic landscape not because of a clearly articulated support regime, but because it intersects with a set of wider system pressures, particularly energy instability, load shedding, landfill related concerns, and the continuing search for alternative waste and energy pathways. WtE therefore appears less as an established policy priority in its own right and more as a residual possibility kept visible by the strain within adjacent systems. Broader climate policy also contributes to this background visibility. South

Africa's carbon tax has been in force since 2019, and the current legislative path raises the rate to R462 per tCO_2e in 2030, which adds a general decarbonisation signal to the wider policy landscape. In this case, however, that signal appears indirect rather than decisive, since respondents did not describe carbon tax as a direct driver of HCRW WtE investment.

This mechanism primarily affects the direction of search and legitimation. Recurring electricity instability and concerns around reliable service provision create a weak but tangible opening for recovery oriented thinking, especially where internal energy use is regarded as more feasible than external supply. WtE remains relevant not through strong strategic endorsement, but because ongoing waste and energy pressures prevent it from disappearing entirely from the conversation.

From a transition perspective, this is significant because it points to a pattern in which transition relevance in the South African context is produced less through stable long term coordination and more through immediate service pressures and institutional strain. WtE is kept in view by necessity rather than by coherent support. While this creates some space for recovery based thinking, that space remains narrow and indirect. The system therefore appears to face pressure toward change, while the conditions needed to translate that pressure into sustained implementation remain weakly developed.

A further observation is that stronger inducements often appear outside WtE incineration itself. Several consultants, government organisations, and experts pointed instead to pilots and projects using residues or outputs from other waste processes, for example tyres, pyrolysis, ETD, or other waste derived fractions, as inputs for industrial combustion, fuel production, or power generation. Recovery oriented activity is therefore present in the broader field, but the clearer inducements often sit in pathways other than incineration based WtE. Respondents also referred to examples outside South Africa, such as Indonesia, where support for WtE was tied more directly to electricity generation, illustrating that policy attention can favour different outputs and thereby shape inducement conditions in different ways.

4.3.4 Blocking Mechanism 1 – Institutional orientation toward destruction rather than energy recovery

A first major blocking mechanism concerns the institutional orientation of the HCRW system toward safe destruction rather than energy recovery. Regulation, permitting, and operational oversight are primarily organised around treatment, compliance, and risk control. This gives incineration a stable role for certain hazardous waste fractions, but it also narrows the space in which WtE can emerge as a legitimate and supported next step. In practice, plants are assessed mainly on whether they destroy waste safely and meet emissions requirements, while recovery remains institutionally secondary rather than actively encouraged.

This orientation is reinforced by the fact that incineration is mandatory only for specific HCRW fractions, including anatomical waste and some pharmaceutical waste. Respondents described alternatives for anatomical waste as incomplete and not yet ready, while the national incineration base remains very small. Institutional dependence on destruction is therefore reinforced by practical dependence on a small number of operating facilities, and the feedstock base available for a dedicated WtE application is already narrow from the outset. In the George case, the maximum theoretical annual capacity is estimated at approximately 8,000 tons under ideal operating conditions. Around 40,000 tons per year was suggested as preferable even to approach feasibility, while broader guidance suggests that WtE plants should generally not fall below 150,000 to 200,000 tons per year to be financially feasible. This places the scale of the HCRW case far below what is usually seen as an economically credible WtE application, and it aligns with the wider view that most HCRW incinerators are too small for effective energy recovery.

This mechanism affects the direction of search, legitimation, and market formation. Because institutional priorities remain centred on treatment, recovery becomes something additional that must fit within a system already structured by destruction and compliance demands. The blocking effect is not only normative; it also operates through a compliance environment described as costly, resource intensive, and unevenly implemented in practice. Plants had been stopped due to air emissions compliance, recommissioning required regulatory sign off, and substantial organisational effort was directed toward restoring compliance rather than advancing new recovery pathways. Inconsistent interpretation across municipalities and districts, including different oxygen correction requirements in emissions reporting, created uncertainty over what counted as compliance in the first place. Under such conditions, operators first need to establish or rebuild compliance credibility before any more advanced WtE pathway becomes plausible. As one respondent stated, "regulations must be in place for the design, financing, construction, operation and maintenance of WtE plants" (IO9), and developing countries should first work toward a more integrated waste management system before financing WtE facilities. The South African system is therefore not simply restrictive, but organised around treatment, while several of the institutional preconditions for WtE remain only weakly developed.

The transition observation here is that treatment and compliance priorities narrow the space for recovery oriented change, and that this constraint is intensified by fragmented and resource demanding regulatory implementation. The system does not reject WtE outright but contains it within an institutional framework where destruction remains the primary mission and where compliance absorbs managerial attention, technical effort, and financial resources. This reduces the ability of WtE to gain stronger strategic direction, broader legitimacy, or clearer market recognition. In a Global South transitions context, where public health protection, regulatory enforcement, and operational continuity carry weight, this helps explain why WtE remains an adjunct possibility rather than an institutional priority.

4.3.5 Blocking Mechanism 2 – Weak market formation for electricity from HCRW incineration

A second blocking mechanism relates to the absence of a stable and credible market for electricity or other recoverable energy from HCRW incineration. WtE remains constrained by grid barriers, uncertain offtake arrangements, low willingness to pay, and limited scale. Revenue conditions are tied mainly to gate fees and treatment economics, while electricity sales and formal commercial models remain weakly developed.

This mechanism affects market formation, resource mobilisation, and experimentation. Investment incentives are weak because actors cannot rely on a stable business model that justifies the additional cost and complexity of WtE. Even internal electricity use, often described as more realistic than grid export, remains financially uncertain because fixed grid related charges and limited energy savings reduce the upside. The HCRW stream itself is also relatively small, which makes it hard to create a high volume recovery model from HCRW alone.

The transition observation is that unstable market conditions undermine credible recovery based business models. This is especially important in a case where incineration is already a comparatively expensive treatment route relative to autoclaving or ETD for those waste fractions that do not require incineration. Since landfilling is not an option for HCRW, the relevant market comparison is not with landfill, but with lower cost treatment routes that reduce the volume entering incineration. Several HCRW fractions can be treated through incineration, autoclaving, or ETD, and respondents described ETD and autoclaving as the lower cost options for the high volume infectious and sharps stream. The volume entering incineration is therefore reduced by a competing treatment pathway within the existing system, which further weakens scale conditions for WtE and makes it harder to justify investment in recovery. The blocking effect is reinforced by the wider energy comparison. PV cells were described as a predictable technology, while WtE was described as more difficult because the nature of the waste is unpredictable, making the business case less predictable as well. WtE must therefore be assessed case by case and, broadly, will struggle to compete with other energy pathways that are already easier to justify (E1). In transition terms, technical recovery potential is present, but market demand, cost logic, and feedstock allocation do not currently align strongly enough to support durable implementation.

4.3.6 Blocking Mechanism 3 – Limited entrepreneurial experimentation and pilot projects

A third blocking mechanism concerns the combination of limited entrepreneurial experimentation and unstable operation. No pilot plant or demonstration project for WtE from HCRW incineration was identified in the case plants, and broader experimentation remains cautious and largely conceptual. At the same time, the existing plants do not operate under the stable conditions normally needed for credible testing and scaling. Repeated stoppages, downtime, manual work, daily cleaning shutdowns, and fragile continuity in operation were evident.

This mechanism affects experimentation, knowledge development, and legitimation. Technically demanding options cannot be evaluated properly when runtime is unstable and continuity is weak. A system characterised by manual feeding, repeated cleaning, and unstable throughput will therefore struggle to generate the operational evidence needed to support broader confidence in WtE. The benchmark visit to Renova's mature WtE facility further illustrates this contrast. At Renova, production stoppages occur at most once per year, with each boiler undergoing a planned maintenance period of approximately one month. While Renova is not directly comparable in scale, waste stream, or system maturity, the benchmark highlights how mature WtE operation depends on significantly higher continuity and operational stability than what is currently observed in George.

The transition observation here is that technically demanding options face high implementation thresholds under fragile operating conditions. This is not simply a matter of missing ambition. It reflects the fact that more advanced recovery options require a level of continuity, process control, and operational discipline that the current system does not yet consistently provide. In a Global South context where operational fragility is closely tied to infrastructure condition, labour constraints, and compliance pressure, this becomes a major reason why WtE remains exploratory rather than implementation oriented.

4.3.7 Blocking Mechanism 4 – Structural dependence on established waste management practices

A final blocking mechanism relates to the broader structural dependence of the waste system on established waste management and disposal practices. Cheap disposal, weak enforcement, and persistent accountability gaps continue to shape the wider waste economy. Municipalities and public facilities are often not held accountable for non-compliance to the same extent as private actors, which skews the economics of the system. Even though HCRW is treated under stricter conditions, the broader waste system still shapes expectations, cost logics, and the perceived attractiveness of more advanced alternatives.

This mechanism affects market formation, legitimation, and the direction of search. It reinforces the current system path by making recovery oriented alternatives appear less economically rational and less institutionally urgent. Where disposal remains cheaper and enforcement remains uneven, incentives to move toward more demanding and costly forms of value recovery remain weak.

The transition observation here is that existing disposal structures keep the system oriented towards established disposal practices, which makes recovery oriented alternatives harder to develop. The challenge is therefore not only inside the HCRW segment, but also produced by the wider waste system in which HCRW incineration is embedded. In that broader setting, established disposal practices continue to shape how alternatives are judged, which means that WtE has to push against a system whose dominant economic and institutional logic still favours cheaper established pathways over recovery oriented change.

5

Discussion

This chapter discusses the findings in relation to the theoretical framework and the study's three research questions. It begins by examining how the innovation system surrounding WtE incineration is configured and how it functions in South Africa. It then analyses the inducement and blocking mechanisms that shape the development of WtE within this system. Finally, it considers what these system dynamics reveal about the possibilities and limits of WtE as an energy transition pathway in a Global South context, including its justice dimensions.

5.1 A system structured around destruction, but weakly aligned for recovery

The central answer to RQ1 is that what we see in this case is not a recovery system that happens to include incineration. It is a treatment system built to destroy HCRW and keep that function going under difficult conditions. The basic conditions for a possible WtE pathway are not entirely absent. There are already plants, operators, routines, regulatory interfaces, and technical knowledge that could form part of such a development. However, these structures were built around destruction, public health protection, and continuity of treatment, not around the recovery of energy. That is why WtE remains visible in discussion while still struggling to become a real development path in practice.

Read through the TIS framework, the system is therefore structurally present but functionally misaligned. Actors, institutions, networks, and infrastructure are sufficiently developed to sustain destruction, compliance, and basic treatment continuity, but the same elements support HCRW destruction far more clearly than WtE development. As shown in Chapter 4, this misalignment runs through the system functions in a connected way. Knowledge exists but remains narrow, experimentation is limited, the direction of search is mixed, market formation is weak, legitimation is partial, resource mobilisation is constrained, and positive externalities are underdeveloped. The result is not an absent system, but a system whose configuration and functioning reproduce destruction more effectively than recovery (Bergek et al., 2008; Jacobsson & Bergek, 2011; Markard et al., 2015).

The wider waste context reinforces this orientation. WtE as a potential pathway would have to develop within a waste system still shaped by landfill dependence, informal disposal, open burning where collection does not reach, weak collection coverage, and uneven enforcement. The waste sector cannot be understood through simple market competition alone, where the technically or economically best option will automatically prevail. The state, municipalities, permitting authorities, and compliance systems all shape what waste handling costs, which actors are forced to carry those costs, and which routes remain cheaper in practice. Under those conditions, landfill can remain dominant even when it is environmentally inferior, which reinforces path dependence around disposal and makes more capital intensive and system dependent pathways such as WtE appear less credible and less attractive to invest in.

The HCRW stream itself adds a further constraint. The fractions tied to incineration, anatomical and pharmaceutical waste, are institutionally important but very small in volume, around 1 to 2 percent of total HCRW. Infectious waste and sharps, which together make up the overwhelming share of the HCRW stream, can often be directed to cheaper treatment routes such as ETD or autoclaving. The same system that keeps incineration in place for smaller high consequence fractions therefore directs much of the larger volume base away from the thermal segment. WtE would not build on a broad existing incineration base already oriented towards recovery. Instead, it would have to develop from a narrow and highly regulated destruction segment, where incineration persists mainly because certain waste fractions must be burned, while most other waste continues to go to landfill.

The site visit to George made it clear what this system looks like in practice. What we found was not a plant ready for upgrading, but a plant under strain, still trying to hold together its core treatment function. The facility is small, heavily manual, physically constrained, and old, with parts of the site exposed to weather and clear signs of damage and rust. It gave the impression of infrastructure being kept going rather than infrastructure being prepared for a next development step. The plant was not running during the visit, and the regulatory inspection observed at the same time made clear that there were unresolved Air Emission License (AEL) compliance problems serious enough to prevent operation. That changes the discussion about

WtE. It becomes difficult to talk seriously about upgrading when the plant is still struggling to meet the conditions required to run destruction. From a TIS perspective, this affects experimentation and resource mobilisation simultaneously, since the physical base does not support low risk testing while plant instability raises the perceived risk of committing new capital to recovery hardware.

The Renova benchmark is useful here, although only as a comparison. Renova should not be treated as a model that South Africa ought to copy, because the differences in waste stream, scale, institutional setting, and historical development are too large. The visit was analytically valuable because it made visible what mature WtE operation rests on. Higher continuity, stronger process control, greater automation, and an overall plant logic built around energy recovery are not extras that can be added to any incinerator. They are the operating environment that WtE depends on. The contrast with George therefore clarifies that the South African system does not primarily lack awareness of WtE. It lacks the combination of infrastructure quality, organisational routines, market credibility, and cumulative implementation experience that would allow the different system functions to reinforce one another.

Geography adds one further structural tension. The four operational HCRW incinerators are concentrated in two clusters, two near Johannesburg and two near Cape Town, around 1,400 km apart. When one part of the system is offline, waste has to be transported much further, which increases costs and shows how little backup capacity the system has. The obvious answer of spreading facilities out more evenly creates a new problem, because a more geographically distributed treatment system would mean smaller individual plants, and smaller plants weaken the scale case for WtE. The treatment system would benefit from greater geographical spread and resilience, while WtE would benefit from larger and more concentrated volumes. Those two logics do not combine easily in this case, which is why the spatial pattern matters both for infrastructure and for market formation.

Existing infrastructure therefore plays two roles. It keeps WtE conceivable as a retrofit option, but it also keeps the system tied to its current treatment role, which actors cannot easily risk interrupting. Effective recovery depends on getting close to the hottest parts of the process, but that becomes much more difficult in an old plant that was not designed for recovery in the first place, and a major retrofit changes flue gas conditions and downstream emissions treatment. In a plant such as George, where storage capacity is limited and revenue depends on continued intake, the cost of stopping for a major retrofit is not only technical but also operational and commercial. This is a clear example of path dependence, where existing assets do not only make WtE possible in principle but also tie operators to established routines, compliance requirements, and current revenue needs (Unruh, 2000; Markard et al., 2015).

Overall, the system around WtE incineration in South Africa is set up to destroy HCRW, meet regulatory requirements, and keep treatment running. WtE remains secondary because the wider waste system is still organised around other pressures. Incineration keeps its role because some waste must be burned, but those volumes are too small to support a strong recovery pathway on their own, while ETD and similar routes pull the larger fractions away. The treatment base is also fragile, with few plants, long transport distances, old infrastructure, and unresolved compliance problems. The answer to RQ1 is therefore a system whose structural components and system functions are misaligned with WtE development. The same elements that sustain destruction do not function as a strong inducement system for recovery, and that distinction sets up the inducement and blocking mechanism analysis in 5.2.

5.2 Weak inducement mechanisms and strong blocking mechanisms limit pathway development

If 5.1 showed that the system is organised around destruction, this section shows what that means for pathway development. WtE does not lack inducements altogether. The problem is that the inducements remain too weak and too disconnected to generate sustained experimentation, investment, and coordination, while the blocking mechanisms are reinforced by existing regulations, cost structures, operational routines, and disposal practices across the wider system. This section discusses the three inducement mechanisms and four blocking mechanisms identified in the findings and asks why they do not reinforce one another.

5.2.1 Why inducement mechanisms remain weak and fail to build momentum

The first inducement mechanism, existing incineration infrastructure and operational capability, does give WtE a starting point, since the pathway does not begin from zero but from an already existing structural base of plants, combustion routines, logistics arrangements, and accumulated experience in handling HCRW thermally. In TIS terms, this matters because infrastructure is not just background context. It is one of the structural conditions that can enable a new trajectory to emerge, but only if it supports the functions needed for that trajectory to grow (Bergek et al., 2008). In the present case, however, the same infrastructure that keeps WtE conceivable does not function as a strong inducement for pathway development. Instead, it remains tied to the existing treatment regime and to the practical need to maintain destruction under constrained conditions.

This is where the case becomes more specific. The HCRW incineration field is itself too limited in scale, volumes, and market size to support a dedicated WtE pathway. Against a national HCRW stream of around 55,000 tons annually, the volumes that the empirical material suggests would preferably be needed even to approach feasibility indicate how narrow the recovery margin may be. That margin becomes even narrower when a large share of the waste stream can be treated through cheaper alternatives such as ETD or autoclaving. Under those conditions, the issue is not just whether WtE is technically feasible, but whether it can be justified economically at all. Plants of this size make it difficult to justify the capital cost, the added staffing, and the extra operational complexity that WtE would require, especially when the underlying treatment business remains small and lower cost alternatives already absorb a large part of the waste stream.

The infrastructural base does not spill over into stronger functional development. It does not generate the kind of market formation, resource mobilisation, or entrepreneurial experimentation that would allow the pathway to build momentum over time. Rather than opening up a new innovation trajectory, the existing infrastructure mainly reproduces the current one. In that sense, the case supports the argument that structural components only become system building when they are linked to reinforcing functional dynamics, and it also shows more concretely what happens when that link remains weak. The incineration base keeps WtE visible, but it does not carry it forward (Bergek et al., 2008; Jacobsson & Bergek, 2011).

One way that the empirical material tried to think around this scale problem was co-incineration. The idea returned in different forms, suggesting that other waste streams could be added in order to lift throughput and improve the recovery case. In the material, however, this looked less like a real solution and more like the next problem. General waste cannot simply be treated as neutral extra volume. It comes with different gate fees, different handling logics, and different public associations. More importantly, it brings the pathway back to the same underlying challenge: as long as landfill remains so cheap, incineration will struggle to become a commercially viable option, even under optimal energy recovery conditions. Co-incineration would also change the social meaning of the pathway. The move from incinerating HCRW to incinerating broader waste streams is likely to trigger stronger resistance, not least because incineration of other streams is tied more closely to older images of black smoke, uncontrolled burning, and present-day open burning at municipal sites and in rural communities. In that sense, co-incineration does not simply solve the scale problem. It opens a new set of economic and legitimacy problems around who would pay for thermal treatment and why they would trust it.

The second inducement mechanism, technical knowledge and expert networks, is also already in place and does provide some support for pathway development. Engineers, researchers, consultants, technology suppliers, and plant actors can assess retrofit possibilities, identify constraints, and keep WtE visible as something technically conceivable. In the empirical material, this was often discussed in very concrete terms, such as corrosion, pressure drops, flow rate, internal electricity use, and possible ORC routes. That matters because it means WtE is not absent as a technical object. It can be discussed, estimated, and compared. A limitation is that much of this knowledge is international and shaped by technologies, infrastructures, and operating conditions more typical of Europe or other mature WtE settings. The wider material returns repeatedly to the point that South African conditions differ in important ways from those in which European reference projects were developed. The knowledge is relevant, but not fully transferable. It helps make WtE imaginable, but it does not automatically translate into implementation under South African conditions.

Feedstock uncertainty sharpens that problem further. Operators cannot reopen sealed healthcare containers after collection and therefore do not have full control over calorific value and composition. This is not unique to South Africa, but in the present case it becomes much more consequential because the system runs with lower margins, older equipment, more manual balancing, and much less room for testing and correction. In theory, knowledge development and knowledge diffusion are meant to reduce uncertainty and support experimentation over time (Hekkert et al., 2007; Bergek et al., 2008). The case shows a sharper limit. Here, uncertainty does not remain a temporary knowledge problem that can simply be worked away through learning. It becomes tied to the material and operational conditions of the system itself. Put differently, more knowledge does not automatically produce more experimentation if plant conditions are fragile and control over the waste stream remains limited. In that sense, the case confirms the broader TIS point that knowledge matters, but it also pushes the argument further by showing that knowledge only becomes productive when local operating conditions allow it to be translated into stable learning and practical improvement (Markard et al., 2015).

The most advanced WtE related project identified in the material illustrates this especially clearly. Even in a setting where licensing had already been secured after a long and complicated approval process, experimentation did not move into a pilot phase. A central reason was that the market was not seen as ready, while the project itself was not seen as financially feasible under current conditions. That tells us something important. The barrier does not lie in whether WtE can be imagined or formally authorised. The harder issue is whether experimentation can be made commercially and operationally defensible. Once spatial constraints, downtime, lost revenue, and the need for a new chamber are taken seriously, a pilot stops looking like a small next step. It starts to look like a major technical and financial commitment. This becomes even more significant in a system where treatment capacity is already thin. If anatomical and pharmaceutical fractions remain dependent on a very small number of incinerators, experimentation is not only an investment risk. It is also harder to justify because a failed retrofit or a prolonged shutdown can affect a treatment function on which the wider system still relies. Actors are therefore not experimenting from a position of surplus capacity, but from one of systemic constraint. This is also why high capital costs, uncertain returns, weak offtake structures, permit burdens, and dependence on external equipment and suppliers matter so much. In a capital-intensive pathway such as WtE, technical feasibility does not create investability on its own. A project can appear workable in technical terms and remain too uncertain if volumes, pricing, offtake, and contract duration cannot be secured over time. In the case, knowledge does not easily translate into experimentation when capital remains uncertain, just as policy relevance does not translate into implementation when projects are too costly to justify. The inducements remain present, but they do not lock together.

Another point that emerged is that when the analysis looked beyond WtE incineration itself, the stronger inducements often appeared elsewhere. The empirical material referred to pilots and projects that use residues from other processes, for example making fuel from old tyres or using outputs from ETD, pyrolysis, and other waste processes as inputs for industrial combustion or power generation. In that sense, inducement mechanisms seem clearer outside the incineration pathway than within it. Recovery is not absent from the broader field, but it often takes forms that avoid the most difficult parts of the incineration problem.

One useful contrast that came up in the material was Indonesia. The context is clearly different, not least because of population density and stronger space constraints, but the example still helps make a policy point. There, support for WtE has been tied more directly to electricity generation than to waste volume. That is interesting because it shifts the inducement logic. Instead of rewarding throughput, it rewards energy output. The value of that comparison is not that South Africa should copy it. The value is that it opens up a different way of thinking about inducement mechanisms. Policy can be designed to favour destruction, or to favour recovery, and those are not the same thing.

Taken together, this part of the analysis answers RQ2 by showing that the inducement mechanisms present in the system do keep WtE visible but remain too weak and narrow to generate cumulative momentum. Existing infrastructure does not provide a sufficient recovery base. Technical expertise remains concentrated and only partly transferable. At the same time, the very system that gives WtE some relevance is also one in which treatment capacity for certain hazardous fractions remains uncertain. That raises the cost of disruption and makes experimentation harder to justify. As a result, the inducements do not combine into reinforcing dynamics that could stabilise and expand the pathway over time.

5.2.2 Market formation, legitimation, and institutional inconsistency as key blocking mechanisms

The answer to RQ2 becomes clearer when the analysis turns to market formation, legitimation, and institutional inconsistency. These are not secondary issues that will be resolved once the technical side is in place. Rather, they help explain why technical possibilities remain difficult to translate into implementation. Without a credible market logic and sufficient legitimacy, even technically plausible options struggle to attract investment, experimentation, and sustained institutional support (Bergek et al., 2008; Markard et al., 2015).

This becomes visible first in relation to blocking mechanism 2, weak market formation. The empirical material is not uniform on this point, and the contrast itself is analytically useful. On the one hand, the value logic of HCRW incineration is described as overwhelmingly centred on treatment, with gate fees forming the main economic foundation and electricity treated largely as a possible side benefit. On the other hand, the material also indicates that electricity revenue can become meaningful where the wider regulatory and grid environment is supportive, and that decentralised generation is technically feasible and not impossible to authorise, even though the process is demanding. The two views are not necessarily contradictory. They reflect different vantage points, where one position speaks from a current treatment business with thin margins, while the other speaks from the position of what the technology could become under different conditions. Taken together, however, they still indicate that the commercial rationale for recovery is weak from the outset under present conditions. In TIS terms, this matters because market formation is not only about creating a buyer for a new output. It is also about whether the wider system creates conditions in which that output becomes worth pursuing in the first place (Bergek et al., 2008; Kivimaa & Kern, 2016). In the present case, that wider environment still favours older and cheaper arrangements. Lower cost treatment routes, particularly ETD and autoclaving, continue to absorb the larger share of the HCRW stream, and uneven enforcement helps keep established alternatives attractive in practice. Under such conditions, WtE is not only expected to prove its own value. It must also compete in a system that still works in favour of incumbent solutions.

Internal electricity use therefore appears more plausible than external sales in much of the material, because it can be justified in terms of operational resilience under electricity instability. The dominant pattern is that facilities are more likely to reduce their own consumption rather than feed back into the grid. Yet this should not be read in an overly optimistic way. The empirical material also raises doubts about whether self-sufficiency genuinely improves the financial position, given that the savings on the electricity bill could be offset by the higher labour costs, technical staffing, and maintenance demands associated with operating WtE equipment in addition to the existing incineration plant. On site generation also does not fully free the plant from the wider electricity regime, since shutdowns, maintenance periods, and moments of insufficient generation still require external supply or generator backup. Grid related fixed charges also remain, because the connection must still be maintained even when part of the demand is covered internally, with ongoing discussions about line fees that would apply regardless of consumption. Internal use may therefore reduce exposure, but it does not remove dependence. The two readings coexist in the material. The optimistic reading sees self-consumption as a workable first step toward decentralised generation, while the more cautious reading treats it as a hedge that does not justify the capital, operational, and staffing demands of WtE.

What also became clear is that self-use alone is unlikely to be sufficient. These plants do not consume electricity on a scale that would, by itself, justify major recovery investments. That means that some form of external value capture becomes important if the economics are to improve meaningfully, whether through electricity sales, heat use, or another offtake arrangement. Yet this is exactly where the perspectives in the material diverge most clearly. One position is that grid feedback is demanding but achievable, supported by the experience of generating facilities that have managed to obtain authorisation under difficult conditions. The other position treats electricity export as too uncertain to include in financial modelling at all, with even the strongest WtE related project identified in the material excluding any electricity revenue from its business case. Tariffs, export conditions, and broader contractual arrangements remain uncertain, and the dominant logic of grid development still points more clearly toward solar and wind. The contrast suggests that the question is less whether grid sales are technically possible and more whether they are bankable, since investors and lenders need predictable revenue streams rather than conditional pathways (Bergek et al., 2008; Kivimaa & Kern, 2016).

This also needs to be understood in relation to the wider South African energy transition. WtE is not entering an empty energy space, but a system where other technologies already enjoy stronger policy alignment, greater predictability, and lower perceived implementation risk. Solar PV appears more institutionalised and commercially derisked, partly because actors at multiple levels are now familiar with the established electricity utility and with PV combined with battery storage, while less established alternatives are met with caution among decision makers. At the same time, the comparison should not be overstated. WtE does not solve the same problem as solar or wind, since it is tied not only to energy generation but also to the mandatory treatment of certain waste streams. The empirical material is consistent on the point that incineration is the only currently accepted route for some hazardous fractions, that alternatives lack complete downstream solutions, and that A-Thermal policy is therefore retained as a deliberate institutional choice even were civil society voices express scepticism. The issue is therefore not simply that solar and wind are better. It is that they are easier to justify within current energy planning, whereas WtE would need to create value across both the waste and energy domains at the same time. This sets a higher threshold for implementation (Bergek et al., 2008; Markard et al., 2015).

The most advanced WtE related project identified in the material shows how this tension plays out in practice, and it is useful precisely because it does not fit a single narrative. On the one hand, it is one of the strongest cases in the country, in that it managed to secure a WtE license after a multi-year approval process and is technically positioned to move forward. On the other hand, once the license was obtained, the pilot did not move forward because the market was still not seen as ready, landfill based and lower cost treatment alternatives remained cheaper, and electricity export was considered too uncertain to include in the investment case. What this demonstrates, then, is not that WtE is technically infeasible or that the regulatory route is closed. It is that even where the technical and regulatory hurdles can be cleared, market formation, legitimation, and resource mobilisation may still fail to align strongly enough to turn technical potential into credible implementation (Hekkert et al., 2007; Bergek et al., 2008).

There is also an important discussion in the material about how actors understand waste as an energy source, and the views here run in two directions. Waste was described as too variable for reliable energy production, especially in a context where the grid is already unstable, with operational experience of frequent stops and feedstock variability cited as evidence that reliability is hard to guarantee. Other parts of the material, and the wider literature, counter that a well-run WtE plant can deliver stable performance, and that volume reduction together with energy recovery is precisely what makes the technology attractive in many contexts when operating conditions, scale, and emissions controls are sufficient (Chisholm et al., 2021; Olaniyi et al., 2018). The disagreement is therefore not really about the technical possibility, but about local credibility under current conditions. What matters here is not only technical truth but perceived credibility. In the present case, WtE still lacks the operating record, reference projects, and local pilot evidence that would make that credibility easier to build. This is important because legitimation in TIS is not only about formal acceptance. It is also about whether influential actors come to see a pathway as sufficiently familiar, appropriate, and dependable to support (Bergek et al., 2008; Markard et al., 2015).

The market discussion also links to a broader normative concern that is itself contested in the material. On one side, parts of the policy and civil society debate remain critical of incineration-based recovery, arguing that creating continued demand for residual waste sits uneasily with ambitions around waste minimisation, reuse, and recycling. On the other side, regulatory and operator positions argue that, in the absence of complete downstream solutions for certain hazardous fractions, incineration is the best available environmental response, and A-Thermal policy is therefore retained as a deliberate institutional choice. The concern about contradiction with the waste hierarchy is real, and it should remain part of the analysis. At the same time, the present case is not one of an already well functioning circular system being displaced by incineration. It is a case in which large residual streams already exist, landfill still dominates, and treatment capacity for hazardous fractions remains nationally significant. The relevant question is therefore not whether WtE displaces an ideal circular economy in theory, but how it fits into a system where substantial residual volumes are likely to remain for the foreseeable future.

A further issue is time horizon, and this is a point where the operator and intermediary positions in the material largely converge, although for slightly different reasons. From the operator perspective, the difficulty of securing long term contracts in a political environment shaped by five-year cycles and regular reelection pressures is a recurring concern, with municipalities described as reluctant to enter the kind of long contracts that WtE projects would require. From an intermediary and expert perspective, the same problem appears from a different angle, since long contracts are exactly what WtE requires, given that plant investments are large and normally depreciated over long periods. The convergence between these perspectives strengthens, rather than weakens, the conclusion that the surrounding environment does not easily support the durable commitments that would make investment more credible.

Landfill and cheaper treatment routes still shape the economic conditions against which WtE is judged, since disposal and lower cost treatment remain attractive in practice and continue to favour established waste practices over recovery. At the same time, two opposing dynamics need to be held together. On one side, there are signs that the established regime may tighten, with growing pressure on landfill airspace, stronger provincial attention in some regions, restrictions on organics to landfill by 2027, and discussions around higher disposal costs and other mechanisms that could raise the cost of established routes over time. On the other side, more cautious accounts emphasise that even if such mechanisms come into force, infrastructure alternatives cannot be built overnight, and that international guidance recommends developing countries first work toward a more integrated waste management system before financing WtE facilities. Rising pressure on landfill may therefore increase interest in WtE without resolving the investment, coordination, and credibility barriers that currently constrain it. The two views suggest that landfill economics are neither fixed nor immediately decisive for WtE, but rather a slowly shifting condition that will interact with, rather than substitute for, the deeper functional weaknesses of the system.

A similar pattern of contrasting views appears around blocking mechanism 1, namely institutional orientation toward destruction rather than energy recovery, and the legitimation problems that follow from it. Here the material contains a clear split. One position treats incineration with continued skepticism, drawing on older associations with pollution, black smoke, and earlier experiences of poor operation. The other position frames incineration as a necessary and currently irreplaceable treatment route for certain hazardous fractions, and HCRW incineration is widely accepted as a public health necessity. What this split implies is that legitimacy in the field is not absent, but narrow and conditional. Incineration is accepted where it is tied to the destruction of specific high consequence fractions and contested where it is associated with broader thermal treatment of general waste. The technology may therefore be accepted as a necessary treatment route while remaining much less secure as an energy pathway.

This is where the case adds something important to the TIS discussion. In TIS, legitimation is usually treated as the process through which a technology becomes appropriate and socially acceptable, often strengthening over time through governance support and system build up (Hekkert et al., 2007; Bergek et al., 2008; Markard et al., 2015). The present case suggests a more limited dynamic. Legitimacy does not travel smoothly from destruction to recovery, even when the technological base is similar. Instead, it remains tied to a particular system purpose. Acceptance of incineration as necessary destruction does not automatically create acceptance of incineration as value recovery. This helps explain why a pathway may remain technically feasible while still struggling to become institutionally credible. The point is reinforced when WtE is compared with technologies already perceived as legible, such as established utility electricity and PV with battery storage, where decision makers feel they understand the technology and the risks.

The licensing process strengthens that point further, although the material here also contains divergent assessments. From the regulatory side, the licensing process is described as proportionate, structured around environmental impact assessment, public participation, and compliance history, and as a route through which legitimate WtE projects can be approved when the underlying facility is compliant. From the operator and intermediary side, the same process is described as long, costly, and uncertain, at times to the point that a firm could run out of resources before securing the necessary approvals. Both assessments can be true at the same time. The process is intended to protect environmental and health interests, and it does include avenues for legitimate projects to advance, but its duration and unpredictability also act as a barrier in practice. In that sense, legitimacy is not only a matter of public opinion. It is also built into the practical ability to move through the state and secure permission to act. When that process is too slow or too unpredictable, it can weaken legitimacy rather than building it.

Institutional inconsistency intensifies these problems and operates in two related ways. South Africa has extensive legislation, permits, and compliance processes, and the country is described as having some of the strongest environmental and waste legislation on the continent. The issue is not the absence of rules, but the unevenness of their application. The material describes a clear double standard, in which formal private operators are subject to demanding approval and emissions requirements, regular inspections, and meaningful penalties through environmental enforcement, while municipal facilities and public sector generators face weaker accountability under cooperative governance arrangements. The wider potential of a circular economy is described as difficult to unlock if non-compliance is allowed to operate alongside the formal system, although the empirical material also includes structural explanations such as the constitutional difficulty of one sphere of government taking legal action against another and the limited resources of poorer provinces. Provincial variation reinforces this pattern. The four operating HCRW incinerators are not located in the same governance environment, which means that compliance expectations and practical implementation conditions differ across locations. The Western Cape is described as the most ambitious province in environmental terms, with the strongest enforcement orientation and clearest landfill diversion targets, while more rural provinces are described as having less financial and administrative capacity to enforce existing rules. From a TIS perspective, this connects directly to the function of legitimation, since institutional credibility depends not only on what is formally written, but on whether the rules are applied consistently enough for actors to plan around them (Bergek et al., 2008). Uneven enforcement is therefore a real and recurring concern, but it is also embedded in the wider governance architecture and cannot be resolved by simply tightening rules on private operators.

Taken together, the answer to RQ2 becomes more visible, and it does so precisely through the disagreements in the material rather than against them. WtE remains constrained not by one single blocking mechanism, but by the combined effect of weak market formation, segmented legitimacy, and uneven institutional support, all of which reinforce the broader institutional orientation toward destruction and the structural dependence on cheaper established routes. These blocking mechanisms prevent technical possibilities from becoming investable, credible, and cumulative. The fact that the material diverges in how strongly it expresses each barrier, with some indications pointing to genuine openings and others to severe constraints, is itself part of the system characteristic. It indicates a system in which WtE is neither institutionally rejected nor institutionally supported in any coordinated way. The result is that WtE remains present in the system as an imaginable option, but not as a pathway that gains enough momentum to move beyond selective interest, long approval processes, and isolated exploration (Bergek et al., 2008; Hekkert et al., 2007; Markard et al., 2015).

5.3 The limits and justice implications of WtE in a Global South context

This section moves beyond the internal system dynamics and asks what the findings mean in a broader energy transition context. More specifically, it examines what the case says about the possibilities and limits of WtE in a Global South setting, where transition pathways are shaped by uneven infrastructure, fragmented governance, and competing development priorities (Tomai et al., 2024; Wieczorek, 2018). Building on the analytical commitments established in 2.3, the section then reads the case through a justice lens, not as a separate framework standing alongside TIS, but as a way of reshaping how specific TIS functions are interpreted, particularly legitimation, market formation, resource mobilisation, and the direction of search.

5.3.1 WtE as a constrained energy transition pathway in a Global South context

What this case shows is that WtE becomes relevant in the South African energy transition debate because it appears to respond to two problems at the same time, namely pressure on the electricity system and pressure on the waste system. The empirical material shows, however, that relevance and viability are not the same thing. The same pressures that make WtE visible also leave the surrounding conditions too weak to carry it forward (Markard et al., 2012; Tomai et al., 2024). Whether the case is read as cautiously promising or as fundamentally constrained depends on which positions are foregrounded in the material, and the case contains both readings.

A multi-level perspective helps explain this by showing that broader landscape pressures may be present without necessarily generating the niche formation that transition theory might otherwise lead one to expect. South Africa faces electricity insecurity, landfill strain, environmental pressure, and broader service delivery problems, all of which could in principle open space for alternatives to grow (Geels, 2002). In the present case, however, WtE remains caught between two regimes that are not organised around it. The voices in the empirical material divide here. From an energy and intermediary perspective, the same landscape pressures are read as creating real openings for decentralised generation, particularly under conditions of grid instability. From a waste sector and regulatory perspective, those pressures are absorbed by other technologies before they ever reach WtE. Both readings can be supported from the material, but the latter appears stronger when account is taken of how policy attention, finance, and public discourse are actually distributed across the two regimes.

On the energy side, the system is moving more clearly toward solar and wind, which are easier to finance, easier to scale, and easier to fit into current energy planning. These technologies benefit from being more legible to both policymakers and investors. They are easier to benchmark, easier to model, and less dependent on uncertain fuel characteristics than waste based thermal recovery. In that sense, the competition is not only about cost, but also about predictability and institutional fit. WtE, by contrast, depends on waste composition, stable plant operation, permitting, and often uncertain electricity offtake arrangements. This means that the pathway enters the energy system with a credibility disadvantage, even before questions of technical feasibility are fully addressed. At the same time, there is an opposing position in the material that this is not the full story. Under specific conditions, particularly where solar would not be sufficient to cover heat dependent demand, incineration based recovery could in fact have an advantage if combined heat and power configurations are used and a nearby business or cluster of users can absorb the heat. The disagreement is therefore less about whether solar and wind are easier to finance, which appears uncontested, and more about whether WtE can find specific niches where its dual waste and energy logic gives it an advantage that single purpose technologies do not have. On the waste side, the system is still shaped by cheaper disposal routes and by more immediate service problems that pull attention elsewhere. What this means in practice is that WtE becomes visible without becoming established. The pathway can be seen, discussed, and even found interesting, but the wider system does not support it strongly enough for it to become an anchored pathway (Markard et al., 2012; Tomai et al., 2024).

Comparisons with Global North cases need to be handled carefully, and the empirical material itself supports this caution from two different angles. From the energy side, one of the strongest parts of the WtE logic in many Northern European settings is much weaker in South Africa. In several of those contexts, WtE became viable not mainly because electricity generation made sense on its own, but because heat could also be recovered and used in nearby industry, district heating systems, or buildings. The same point comes back from the operator side, where the South African situation is described as essentially the reverse of the European urban context, with limited bulk use for steam outside of a turbine because plants are typically not situated within chemical complexes or district heating networks. In Sweden and Denmark, where district heating is widely developed, WtE is often understood first as a heat production facility. The convergence between these perspectives, one drawn from international expertise and one from a South African operating context, strengthens the conclusion that the heat side of WtE in many Northern European settings does not transfer easily to the South African case.

At the same time, this should not be read to mean that heat has no relevance at all in the South African case. Combined heat and power could be commercially defensible where the project is sited near a heat intensive business or cluster of users that can absorb the energy. What this points to is not the complete absence of possible heat use, but rather the absence of a sufficiently stable and proximate heat sink. Once that part falls away, electricity only WtE becomes a less attractive proposition than combined heat and power, and that is one of the clearest reasons why WtE cannot be transferred too easily from mature Global North settings to the South African case. The implication is that the strongest rationale for WtE would likely need to be tied to specific local demand conditions, such as internal process heat or nearby industrial users, rather than to a broad district heating logic of the kind seen in Northern Europe.

The case also adds something important to the discussion on environmental goals and trade offs, and this is a point on which the material is clearly two sided. WtE can look attractive because it promises both less landfill and more electricity, but that can make the pathway seem more environmentally straightforward than it really is. If WtE moves beyond its treatment role, it may also create a continued need for residual waste and make it harder to keep materials in circulation over time (Unruh, 2000; D'Alisa & Demaria, 2024). The lock in concern is articulated very directly in the empirical material, with the argument that once large investments are made in such facilities, they create a structural dependence on continued waste flows and become difficult to phase out later. At the same time, the material does not support the opposite simplification either, namely that South Africa can simply bypass incineration and move straight to more circular solutions. The persistent reality of substantial residual streams, weak collection systems, and limited sorting infrastructure is described as a condition that more circular pathways would themselves need to function.

This is where leapfrogging becomes interesting, and the empirical material contains a particularly clear disagreement on this question. From one international perspective referenced in the material, the gap between current waste system conditions and a more circular system is described as too wide to bridge through leapfrogging in this context. From a domestic perspective, that view is openly contested, drawing on the precedent of leapfrogging in telecommunications and on the strong informal sector demand for reuse, repair, and recycling, while also expressing caution that a large scale rollout of incineration for municipal waste would lock the system into a path that contradicts longer term circularity ambitions. The contrast is analytically useful precisely because both positions are present in the material. Our reading sits between them. The case does not reject leapfrogging, but it does reject the easy version of it, since more circular pathways still depend on collection systems, sorting infrastructure, enforcement, and downstream markets that remain uneven in practice (Tomai et al., 2024; Wieczorek, 2018).

It makes good sense to argue that South Africa should avoid repeating the same waste path as many Global North countries, and the empirical material supports treating this as an important warning. What the findings challenge is the assumption that a better pathway will appear simply because the older one is criticised. Leapfrogging only becomes real when the alternative is organised and institutionally supported, which means that infrastructure, coordination, enforcement, and investment conditions all still matter in very concrete ways (Tomai et al., 2024; Wieczorek, 2018). Without those conditions, leapfrogging remains more of an ambition than an actual transition pathway. In that sense, the case does not suggest that South Africa should copy the Global North, but it does suggest that no pathway, whether thermal or more circular, can work without the wider system conditions that allow it to function. A related concern that should not be lost in this discussion is the worry that the country has struggled to manage landfill sites consistently, which raises the question of whether thermal treatment at scale could be managed any more reliably without the underlying governance capacity. This is a substantive concern, and it sits in tension with operator and intermediary accounts that frame technical capability in some parts of the system as more advanced than this critique implies. Both views can be true at the same time. Capability exists in some private operators while remaining absent or fragile elsewhere in the system, which strengthens the argument that pathway viability depends on system conditions rather than on the technology in isolation.

Taken together, the conclusion that emerges from these contrasting positions is more measured than either an optimistic or a dismissive reading of WtE in South Africa would allow. WtE in the South African context should not be understood as an obvious energy transition pathway that only waits for the right technology to unlock it, but neither should it be understood as an option that the system has already rejected. It is better understood as a constrained and conditional option that becomes visible under system pressure, but does not stabilise because the niche remains weak, the surrounding regimes are not aligned around it, and the wider transition environment supports other solutions more strongly. That is the main limit revealed by the case, and it is also the main reason why technical feasibility is not enough. The real barrier is that WtE would need a much stronger fit with the wider energy, waste, and investment system than is currently visible in the case (Markard et al., 2012; Tomai et al., 2024).

5.3.2 Justice dimensions and the conditions of a more responsible pathway

A just energy transitions perspective matters here because it forces a more difficult question than whether WtE can be made to work technically. It makes one ask who would benefit from this pathway, who would carry the costs, and whose concerns would matter if it moved forward (Jenkins et al., 2016; McCauley & Heffron, 2018). In line with the framing established in 2.3, this lens is not used here as a separate analytical framework, but as a way of reshaping how specific TIS functions are read. The analysis that follows therefore returns repeatedly to four functions in particular, namely legitimation, market formation, resource mobilisation, and the direction of search, and asks how each looks different when read through distributional, procedural, and recognition justice rather than through a function only TIS reading. Justice in this sense does not produce new analytical categories alongside the seven TIS functions, but sharpens what is at stake in how those functions are currently fulfilled in the South African case.

Before applying this lens to the empirical material, however, an important reflexive point should be made. The case is constructed primarily from the perspective of an established private operator, technology suppliers, intermediary experts, and regulators. These are the actors who shape WtE as a possible upgrading pathway, but they are not the only actors whose realities are at stake. Civil society organisations, public health practitioners, social development officials, informal waste workers, and households with limited or no formal waste service were not part of the interview base. This shapes what the case can see, and it shapes what it tends to overlook. The justice discussion that follows should therefore be read as a discussion grounded in a particular vantage point, not as a complete account of how this pathway looks from every position in the system. Where civil society or community voices would likely have framed the problem differently, this is flagged explicitly.

When the case is examined through that lens, there is no basis for claiming that WtE develops just simply because it recovers energy. That framing would be too neat for a case like this. What matters is how the pathway is introduced, who is expected to pay for it, what burdens it adds to an already fragile system, and whose problems it fails to reach.

What stands out first is that the gains are quite concentrated, while the extra demands would be spread more widely across a system that is already under pressure. A WtE upgrade could make plant operation less exposed to grid instability, help some operators keep treatment going more reliably, and reduce part of their electricity bill. Those are real advantages, especially in a field where stoppages matter and where treatment continuity is already a serious issue. Still, those benefits would mainly sit with the operator and the plant itself, whereas the costs would be much harder to contain. The empirical material adds nuance here. From the corporate-level, capital is described as in principle available for large investments, while plant-level accounts are more sceptical that the savings on the electricity bill would justify the additional staffing and maintenance demands of operating WtE equipment. The two accounts coexist and do not fully resolve. The financial logic looks more attractive at the corporate level than at the plant-level, which itself is part of the distributional pattern, even before the question of communities and households is brought in.

Moving upward in the waste hierarchy often means that the actor closest to the waste must do more and pay more, while the wider environmental gain is shared more broadly across society. That logic is very visible here. WtE may look better from a wider system perspective, but that does not change the fact that someone still must carry the added cost in practice. This also strengthens the point already made in the TIS discussion, because market formation is not only about whether a new option exists. It also depends on whether the wider selection environment still protects older and cheaper routes that remain easier to justify in practice (Bergek et al., 2008; Kivimaa & Kern, 2016). The justice question, however, goes one step further than the TIS reading, because it asks not only who benefits and who pays, but also whose framing of the problem is treated as authoritative.

This becomes even harder once the wider South African waste system is brought back in, and here the language used in the empirical material itself becomes part of the justice question. The material indicates that only around half of South African households have access to formal waste collection services, and the binding constraint at the bottom of the system is identified not as technology but as basic service coverage, alongside what is described in the interviews as illegal dumping and open burning. The terminology matters here. From an operator and regulator vantage point, dumping outside formal sites and burning waste in the open are non-compliant practices that breach national legislation. Read from a household vantage point, however, they may be the only practical option available where collection services do not reach, where transport to a formal site is not feasible, and where airspace at landfill sites is itself constrained. A more careful reading would therefore distinguish between intentional non-compliance by actors who do have access to alternatives, and what might more accurately be described as informal disposal driven by structural service gaps (Newell & Mulvaney, 2013; Tomai et al., 2024). Holding both readings together is important, because the case is unlikely to be either a pure compliance problem or a pure infrastructure problem. It is both, and the way it is named has implications for who is held responsible and what kinds of interventions appear legitimate.

The same point applies to the wider language of non-compliance in the case. Where private operators are described as struggling with stringent emissions standards, the response in the material is largely framed around technical upgrading, capital investment, and engineering judgement. Where municipal facilities and public sector generators are described in some cases as non-compliant, the material itself signals more structural causes, including limited financial capacity in poorer provinces, the constitutional difficulty of one sphere of government taking legal action against another, and a thin technical and managerial base in many municipal contexts. The same word, non-compliance, therefore, covers very different situations, and a justice sensitive reading should resist treating them as equivalent. This also has implications for how recommendations from this case should be read, since calls to tighten enforcement can have very different effects depending on which actors are most exposed to that enforcement and what alternatives they actually have.

In that setting, moving away from landfill and toward more expensive treatment routes would mean higher gate fees, higher collection costs, or both. The problem is therefore not only that landfill is cheaper. It is also that there is no clear and socially credible answer to who should pay for a more expensive system in a country where service coverage is uneven and the public revenue base is narrow. What makes the Global North and Global South contrast even clearer here is that only a small share of the population carries the formal tax base. Around one third of the population has a formal income, and only a smaller share of that group earns enough to pay income tax, which means that the burden of financing more advanced public services falls on a limited group. This makes the question more than a technical or environmental one. It becomes a political question about how waste services should be financed, by whom, and under what conditions a more expensive pathway can be made socially legitimate (Jenkins et al., 2016; McCauley & Heffron, 2018). It is also a question this case can only partially answer, because the actors who would carry these costs most directly, lower income households and under resourced municipalities, were not part of the interview base. What this thesis can do is point to the question and signal that any pathway forward must engage actors that the present case did not reach.

There is also a second contradiction here that matters, and the empirical material is unusually direct about it. As soon as actors start recovering value from waste, whether through recycling, material recovery, or electricity generation, it sends a signal that waste is no longer only a cost but also something from which value can be extracted. From the outside, that can be hard to accept if households, firms, or municipalities are at the same time being asked to pay more for waste handling. Put simply, people are told that their waste now has value and that someone can make money from it, while their own waste bill still goes up. The material reads this dynamic in different ways. From a policy and regulatory perspective, value recovery is seen as a positive development that creates an incentive for high product recovery away from landfill, with the state working through Extended Producer Responsibility schemes and the recently introduced waste picker levy to redistribute some of the value back into the system. From an operator perspective, the same dynamic appears as creating mixed signals to households, where municipalities at times encourage informal collection of recyclables on a free of charge basis, which is in turn seen as undermining private sector incentives and pushing occupational risks onto workers without proper protective equipment. These two readings are not entirely contradictory. They suggest that value recovery can be redistributive when accompanied by appropriate institutional design, and extractive when it is not. Notably, both readings are still framed primarily from the perspective of those who organise, regulate, or compete with informal recovery. The voices of waste workers themselves, and of households that are both source and consumer of waste services, would likely add a further layer to this account that this case does not capture (Jenkins et al., 2016; McCauley et al., 2013).

The same tension appears in a more familiar form in countries further up the waste hierarchy, where households are expected to sort more fractions, follow more rules, and often still pay more for collection and treatment. The individual does more and pays more, while the benefit lies mainly at the level of the environment and society. The same pattern is visible here, but more sharply. In South Africa, where landfill remains cheap and where much of the wider waste system still struggles with basic collection and compliance, the step upward in the hierarchy becomes even harder to justify to the actor closest to the waste. That does not make the step less necessary from an environmental point of view, but it does make the politics and the economics of that step much harder to stabilise.

WtE should not be presented as some broader justice answer to South Africa's waste problem. The HCRW field is far too limited for that, and the material does not support that kind of claim. Even if energy recovery were added successfully, the deeper inequalities in the wider waste system would remain, including uneven collection, informal disposal driven by service gaps, and burning of waste in places where alternatives are not available. This is exactly why the just transition lens is useful. It stops one from overstating what one bounded pathway can do. WtE may improve one limited part of the system, but it does not solve the wider waste crisis, and it does not remove the unequal conditions through which that crisis is lived (Jenkins et al., 2016; McCauley & Heffron, 2018; Tomai et al., 2024).

This justice question also appears on the recovery side itself, and the material is again two sided. On one side, waste pickers keep value in circulation by recovering cans, cardboard, plastics, and other materials that would otherwise be lost. The empirical material describes this contribution as substantial, with the country's relatively low export of recyclables to international processors during earlier decades described as having been possible largely because a large informal sector performed collection on a low cost basis. On the other side, the same material makes clear that the role of waste pickers should not be read as evidence that the recovery side of the system is already working well. It shows instead that recovery still relies heavily on informal and precarious labour arrangements, with uneven access to value, weak protection, and limited formal responsibility. The material also recognises that integrating informal waste pickers into a formal waste management system is not seen as desirable from a health, safety, or dignity perspective, but that as long as unemployment and poverty remain at current levels, informal recovery will continue to be a structural feature of the system. This holds two views together. Recognition is being formalised through extended producer responsibility schemes and the waste picker levy, alongside academic work on guidelines for integration, but the underlying dependence on precarious labour persists. Importantly, this part of the analysis is once again based on how waste pickers are spoken about rather than on how they describe their own situation. From a justice perspective, this is not only a question of efficiency. It is also a question of recognition, of who is allowed to speak for their own conditions, and of who carries the burden of making recovery happen in practice (Jenkins et al., 2016; McCauley et al., 2013; Newell & Mulvaney, 2013).

The labour dimension makes the case more distinctive, and again the material contains two readings that need to be held together. What was observed at plant-level was not an environment built around automation, stable routines, and strong operating buffers, but a treatment system that still depends heavily on manual work, everyday improvisation, and minimum wage labour. Staffing could also vary from one day to the next, since some workers were hired on a daily basis. From one perspective, expressed in the wider waste sector discussion, this kind of cheap labour is described as economically essential and as something close to a free input that allows recovery to happen at all in current South African conditions. From the operator perspective, however, the same labour model appears as a source of fragility, management accounts describe it with absenteeism, alcohol related dismissals, and difficulty building a stable workforce described as recurring operational problems. The two readings do not fully resolve, and once again neither is articulated by workers themselves. The labour model that helps the wider system absorb costs also sits uneasily with what WtE requires, namely a more stable plant rhythm, tighter process control, fewer interruptions, and a higher level of repeatability. Labour is therefore not a side issue here, but part of why the pathway remains weak in practice and part of why the distributional question cannot be settled within an operator centred frame.

This is where one of the main contradictions in the case becomes visible. The current system survives partly because it is built around cheap labour and manual handling, and in one sense that can look like an advantage because it allows operators to keep treatment going at lower labour costs than in many Global North settings, where more of the process is automated and labour is more expensive. But the same feature that helps the system survive also works against continuity, standardisation, and scale economies. As soon as recovery becomes part of the process, safety, monitoring, and repeatability matter more, which pushes the system in the opposite direction, toward more automation, more formal skills, and more disciplined operation. In other words, the same labour model that helps the system compete today starts to lose its value as soon as a safer and more recovery oriented process becomes necessary. This is one of the clearest differences between the present case and many Global North cases, where much more of that operating stability is already built into the plant, the infrastructure, and the wider institutional setting (Tomai et al., 2024; Wieczorek, 2018).

It is not only a question of plant design, because the wider social conditions show up directly inside plant operations, and here the empirical material requires especially careful interpretation. Unstable attendance, weak safety discipline, and the difficulty of building a workforce that management feels it can fully rely on over time are described in unusually direct terms. Some accounts are blunter and link these problems to alcohol related incidents, short term coping strategies, and fragile living conditions. These observations need to be handled with particular care, because they are articulated from a management perspective and not from the perspective of the workers concerned, and because reading such accounts at face value risks reproducing the kind of individualised explanation that a justice oriented reading should resist. The more important point, and one that is consistent with the wider just transitions literature, is that wider insecurity and social pressure do not stay outside the plant gate. They enter operations and become part of the production problem (Newell & Mulvaney, 2013; Tomai et al., 2024). What looks from one angle like unreliability looks from another like the visible trace of poverty, precarious housing, long travel distances, and weak public services. Both readings are present in the material, and the case cannot fully resolve between them without engaging the workers themselves.

It is easy to assume that a country with very high unemployment, especially among young people, should have no problem securing labour, but that is not what the case shows. The real issue is not labour supply in the abstract. The real issue is stable, reliable, and suitably skilled labour under difficult operating conditions. Poverty, long travel distances, low wage conditions, subcontracting, insecurity, and weak employment stability all shape whether workers can show up consistently and whether operators can build the disciplined production base that WtE would require. In the case, labour was described as operating close to minimum wage conditions, with parts of the workforce also characterised by short term and unstable employment. A similar tension appears around labour law and race, and here the views in the material run in opposite directions. From the operator side, recruitment is described as something shaped not only by skill shortages and wider poverty, but also by labour regulation and race based transformation requirements. From a wider policy perspective, those same regulations are part of a deliberate institutional response to historical exclusion, and South Africa's labour market cannot be separated from its racial history (Newell & Mulvaney, 2013; Gather et al., 2025). Both points are present in the material, and neither should be reduced to the other. Some firms clearly experience a tension between the need for stable technical staffing and the constraints of a labour market that is both highly regulated and historically shaped, and for a pathway like WtE, which would require more formal capability rather than less, that tension matters.

Procedural justice also has to be understood in that same grounded way, and again the empirical material is more nuanced than a single voice would suggest. From the regulatory side, formal procedures for licensing, objections, and participation are described as substantive, with the public participation process treated as an avenue through which affected parties can object and where compliance history is taken seriously in decision making. From the wider literature and from intermediary perspectives, the same procedures are described as risking becoming formal rather than substantive in contexts where technical complexity is high and trust uneven (Jenkins et al., 2016; McCauley et al., 2013). Both views can be held together. Procedures on paper exist and matter, but a procedure on paper is not the same thing as meaningful influence in practice. What matters more is whose knowledge shapes how the pathway is judged, whose risks are taken seriously, and whose realities count when decisions are made. In the present case, the empirical base itself reflects this uneven distribution of voice, since plant owners, regulators, and intermediary experts are well represented, while workers, affected communities, and civil society organisations are not. That is a limit of the case, and it is also part of what a procedural justice reading would identify as a wider system characteristic. Future work that engaged these actors directly would not necessarily reach different conclusions about WtE, but it would almost certainly reach a different judgement about which problems matter most and which costs are tolerable.

The case material does not support an outright rejection of WtE in this context, but it also does not support presenting WtE as an obvious transition solution. There are circumstances in which WtE may be justified, especially where incineration must happen anyway, where environmental control improves, and where some value can be recovered from a treatment process that is already necessary. This view is articulated in the material through the argument that recovery is environmentally defensible where waste must be incinerated and where the residual ash can be put to use, provided that the plant is properly managed and at appropriate scale. The same material, however, is sceptical that such conditions would be met if WtE were rolled out broadly into the municipal waste stream, given the wider concerns about lock in, governance capacity, and the cost burden falling on already stretched households and municipalities. Holding these views together, WtE is only defensible under fairly strict conditions, where it improves labour conditions rather than leaning harder on already stretched workers, where it operates in an enforcement environment that is calibrated to the very different positions of formal operators, small scale operators, and under resourced municipalities rather than applied uniformly without regard to capacity, where it adds environmental credibility instead of just another technical layer, and where it forms part of a wider waste transition that does not hide deeper structural failures behind one promising technology.

That last condition is also where the limits of this thesis as a justice contribution become clearest. Strengthening enforcement, expanding formal infrastructure, and tightening compliance can all sound straightforward from an operator and regulator vantage point, but the same measures can fall hardest on actors with the least capacity to absorb them. Tightening landfill rules without first expanding collection coverage shifts cost onto households that already lack service. Tightening emissions enforcement uniformly across formal and informal operators, or across well resourced and poorly resourced municipalities, can reproduce the same selection environment that the present case has identified as uneven. The thesis cannot resolve these tensions, and it does not try to. What it can do is signal that the recommendations developed from a TIS reading of this case should not be taken as a single coherent programme.

They point in different directions, and where they touch the actors least represented in the empirical material, they should be read with caution.

The broader theoretical point, then, is not simply that WtE in the Global South is difficult. It is that it must be judged through the whole sociotechnical system that would have to carry it, including labour conditions, governance unevenness, waste system pressures, and the everyday realities of plant operation, and that any such judgement is also shaped by which actors are part of the conversation that produces it. Put differently, it is not enough to ask whether energy can be recovered. The more useful question is what kind of system would be needed to recover that energy responsibly, and whose voices would have to be present for that judgement to be credible. That is where this case says something important, both about WtE and about how transition pathways should be judged in Global South settings. The disagreements between the positions that are present in the material, across operators, intermediaries, regulators, and policy actors, are part of the answer. The voices that are not present, including civil society, workers, affected communities, and households, are part of it too. Holding those competing perspectives together, including the ones the case can only point toward rather than fully include, is what a justice sensitive reading of WtE in this context requires (McCauley & Heffron, 2018; Newell & Mulvaney, 2013; Tomai et al., 2024; Wieczorek, 2018).

6

Recommendations

The final step of the TIS analysis is to present recommendations for policymakers and managers. These recommendations build on the main issues identified in the study and aim to strengthen the few inducement mechanisms that do exist, while reducing the blocking mechanisms that keep WtE weak in practice. At the same time, our findings point to a wider problem. The limits around WtE are not only about one technology. They reflect deeper weaknesses in waste governance, uneven enforcement, fragile treatment capacity, and poor alignment between the waste and energy systems. For that reason, the recommendations below do not treat WtE as the solution to South Africa's waste problem. They focus instead on what would need to change for the system to work more credibly, and for WtE, as well as other treatment and recovery pathways, to be assessed on more realistic terms.

6.1 Key policy recommendations

Recommendation 1: Tighten enforcement before expanding new WtE ambitions

Policy should strengthen compliance with existing waste, landfill, and emissions rules, but enforcement must be sequenced and accompanied by support so that vulnerable groups are not disproportionately burdened. Enforcement should primarily target actors that systematically avoid environmental obligations, while under resourced municipalities, informal workers, and affected communities should be supported through capacity building, affordable alternatives, and inclusive planning. If non-compliant disposal remains common and landfill continue to be the easier option, WtE will struggle to become a credible pathway. However, stricter enforcement should reduce environmental externalisation without shifting costs onto households, informal waste workers, or communities with limited alternatives. This is important because uneven enforcement weakens both market formation and legitimacy, while poorly designed enforcement could create new distributional injustices.

Recommendation 2: Prioritise waste prevention before recovery

Policy should ensure that WtE is not treated as a substitute for waste prevention, reduction, reuse, and recycling. Although HCRW includes waste fractions that require secure treatment, the broader waste system should still prioritise reducing waste generation at source and questioning production and consumption patterns that create residual waste in the first place. This is important because recovery pathways can only address downstream symptoms of the waste problem, while prevention targets the material flows and resource use that generate environmental burdens over time.

Recommendation 3: Create clearer rules for when WtE is appropriate

National and provincial policy should define more clearly where WtE fits within the wider waste hierarchy, especially in relation to hazardous waste, non-recyclable residues, and other recovery options. Clearer criteria are needed not only to reduce uncertainty, but also to ensure that WtE is used where it can be publicly justified rather than where it merely appears attractive under system pressure. This means that policy should specify under what conditions WtE supports public value, when other pathways should take priority, and how environmental risks, costs, and benefits are assessed, communicated, and distributed across affected groups. In this way, justice becomes part of how appropriateness is judged, rather than something considered only after the pathway has already been selected.

Recommendation 4: Support pilot projects across several recovery pathways, not only incineration based WtE

Public support should be directed to carefully selected pilot and demonstration projects that test different ways of recovering value from difficult waste streams. This includes WtE where relevant, but also other options such as tyre derived fuel, ETD related recovery routes, pyrolysis linked pathways, and industrial use of residues. A broader pilot strategy is important because it reduces the risk of prematurely privileging one pathway before its wider system effects are understood. Public support should therefore be tied to transparent learning, open evaluation, and clear assessment of who captures value, who carries implementation risk, and whether the pathway strengthens or weakens more circular alternatives over time. Pilot support should also be designed so that experimentation does not shift technical, financial, or environmental risks onto workers, municipalities, or communities with limited capacity to absorb them.

Recommendation 5: Improve the institutional conditions for energy recovery projects.

Government should reduce uncertainty around licensing, grid connection, tariffs, and electricity use or sale, while maintaining credible environmental safeguards and public oversight. Without clearer institutional conditions, even technically viable projects are unlikely to move forward. At the same time, improving these conditions should not mean making recovery easier at any cost. Institutional reform should also ensure procedural transparency, credible oversight, and accountability for environmental performance, so that the benefits of energy recovery are not pursued while operational risks, public monitoring burdens, or compliance failures are shifted elsewhere in the system. A more credible pathway therefore depends on both investability and accountability being strengthened together.

Recommendation 6: Build a more integrated waste system before expecting large scale WtE growth

Policy should prioritise better collection, separation, treatment coordination, and municipal capacity across the waste system. Such integration should not be understood as excluding informal or smaller actors, but as creating clearer responsibilities, safer working conditions, and more reliable infrastructure across the system. WtE cannot develop in a stable way if the wider system remains highly landfill based and operationally uneven. More fundamentally, a fragmented waste system makes it difficult to distribute responsibilities, costs, and benefits fairly, since actors closest to the waste often face the greatest burdens while the wider gains remain uncertain or diffuse. Building a more integrated waste system is therefore a precondition not only for technical reliability, but also for a more just and publicly defensible transition pathway.

6.2 Key Managerial Recommendations

Recommendation 1: Focus first on operational stability at plant-level

Managers should prioritise reliable combustion, staffing continuity, maintenance, and compliance performance before pursuing recovery investments. A plant that struggles to operate consistently is not a strong base for WtE. In this case, operational instability is not only a technical constraint. It also increases the likelihood that environmental, safety, and organisational burdens are absorbed by workers and surrounding communities through more fragile day to day operation. Improving stability is therefore a precondition for any more responsible upgrading pathway.

Recommendation 2: Improve waste characterisation and feedstock control

Operators should strengthen routines for understanding waste composition, calorific value, and moisture content. Better knowledge of the waste stream is necessary for assessing whether any recovery option is technically and economically realistic. It is also important for ensuring that uncertainty around emissions, combustion quality, and handling risks is not simply passed on to operators, inspectors, or nearby communities. Better feedstock knowledge therefore supports both feasibility assessment and more credible environmental responsibility.

Recommendation 3: Start with small and practical recovery options

Where recovery is explored, firms should begin with limited and site-specific options such as own use of electricity or heat, rather than assuming export to the grid. This would lower risk and better match the current institutional setting. It would also reduce the likelihood of pursuing large and uncertain investments whose gains remain narrow while the financial and operational consequences are spread across the organisation. A smaller starting point is therefore not only more realistic under current system conditions, but also more proportionate in relation to how risk and responsibility are distributed.

Recommendation 4: Build partnerships beyond the waste operator itself

Managers should work more closely with technology suppliers, industrial users, energy actors, public agencies, and affected stakeholders early in the process. Recovery projects depend on coordination across several parts of the system and cannot be developed by one actor alone. If WtE is to become more legitimate in practice, these partnerships must also help widen who is included in decision making and whose concerns are recognised in project development. In that sense, coordination is not only a matter of technical delivery, but also of building a pathway that is seen as credible, accountable, and aligned with broader public concerns.

Recommendation 5: Treat labour conditions as a strategic issue, not just an HR issue

Plant managers should invest in workforce stability, safety routines, supervision, and training. In this case, labour is not a background factor. It is one of the conditions that determines whether operations can remain stable enough for any upgrading pathway. If recovery ambitions are added without improving workforce support and protection, the pathway risks increasing demands on workers without improving the conditions under which they carry that responsibility.

7

Conclusion

The following section brings together the main findings of the study and reflects on their overall significance. It begins by addressing the research questions, before outlining the theoretical contributions of the study and discussing its limitations and implications for future research.

7.1 Main conclusions

The main conclusion of this study is that WtE incineration in South Africa remains a constrained possibility rather than an emerging transition pathway. Energy recovery from HCRW incineration is technically conceivable, but the surrounding system is not configured to support it in a strong, coordinated, or consistent way. What exists is a treatment system organised around destruction, compliance, and continuity of hazardous waste management. Recovery is visible in discussions and may appear attractive under conditions of electricity instability and landfill pressure, but it remains secondary to the core function of safe destruction. WtE is therefore not absent from the system, but it is also not developing into a credible pathway in practice.

RQ1: How is the innovation system surrounding WtE incineration configured, and how does it function in South Africa?

The innovation system surrounding WtE incineration is configured as a narrow and uneven system that is shaped primarily by HCRW treatment rather than energy recovery. Structurally, the actor base is small and concentrated around waste operators, regulators, technical consultants, and a few technology suppliers, while energy actors, financiers, municipalities, and electricity offtakers remain peripheral. Formal institutions give incineration a clear role as a treatment technology for specific HCRW fractions but provide weaker direction for energy recovery, and weak enforcement in the wider waste system keeps cheaper disposal routes attractive. Networks and infrastructure are present but oriented toward waste handling and compliance rather than coordinated WtE development, and the existing plants are old, manual, compliance sensitive, and not designed for stable recovery operation.

Functionally, the system performs unevenly across the seven TIS functions. Knowledge is concentrated in a small expert network and has not developed into broader implementation capability. Experimentation is weak, since few pilots or concrete WtE projects have been pursued. Direction of search is also weak, since WtE is not clearly prioritised by policy, firms, or the wider energy system. Market formation is one of the weakest functions because revenue models, tariffs, grid access, and internal use cases all remain uncertain. Legitimation is present but mainly attached to incineration as a necessary treatment route rather than to WtE as an energy transition solution. Resource mobilisation is constrained by high capital costs, uncertain payback, and limited specialist skills, while positive externalities remain limited because there is little cumulative learning, few demonstration effects, and no strong supplier ecosystem developing around HCRW WtE.

Taken together, the system is structurally configured around destruction, compliance, and treatment continuity, and functionally it performs mainly to maintain this existing treatment regime. WtE is present as a possible extension, but the structural components and system functions do not yet support it as a coherent or credible recovery pathway.

RQ2: Which inducement and blocking mechanisms enable or constrain the development of WtE within this system?

WtE development is enabled by a limited set of inducement mechanisms but constrained by stronger blocking mechanisms. The main inducements are existing incineration infrastructure and operational capability, technical knowledge and expert networks, and broader policy attention to waste and energy transitions. These conditions matter because WtE does not have to start from nothing. There are already plants, operators, regulatory interfaces, and technical discussions that make energy recovery imaginable. However, the infrastructure base is old and fragile, the knowledge base is narrow and partly international rather than locally embedded, and policy attention remains broad rather than translated into coordinated implementation support. As a result, WtE becomes visible as an idea but not investable or actionable as a pathway.

The blocking mechanisms are more decisive. The system remains institutionally oriented toward destruction rather than recovery. Market formation is weak because revenue models, tariffs, grid access, and offtake arrangements remain uncertain. Entrepreneurial experimentation is limited by operational instability, compliance risks, and cost uncertainty. Established waste management practices, including cheap landfill disposal and uneven enforcement, continue to favour established routes and reduce the urgency of recovery oriented alternatives. The answer to RQ2 is therefore that WtE is enabled only weakly while being more strongly constrained by institutional, market, operational, and structural barriers, and these blocking mechanisms prevent technical possibility from becoming credible implementation.

RQ3: What do these system dynamics reveal about the possibilities, limits, and justice implications of WtE as an energy transition pathway in a Global South context?

The system dynamics reveal that WtE is transition relevant, but not yet transition viable, in the South African HCRW incineration context. Its main possibility lies in treatment settings where incineration is already required, particularly for hazardous healthcare waste fractions, and where energy recovery could strengthen plant resilience, reduce exposure to electricity insecurity, and support continuity in hazardous waste treatment. In this sense, WtE may create value as an incremental recovery pathway attached to an existing thermal treatment process. However, the findings show that this possibility should not be overstated. The pressures that make WtE visible, namely electricity insecurity and strain within the waste system, do not automatically create a viable transition pathway. Rather, they are embedded in a wider context of landfill dependence, uneven service provision, weak enforcement, fragmented governance, and competing development priorities.

The limits of WtE are therefore not primarily explained by technical impossibility, but by weak systemic alignment. Several TIS functions exist around HCRW incineration, including operational knowledge, regulatory structures, treatment capability, and limited market activity. Yet these functions mainly support destruction, compliance, and treatment continuity, rather than recovery oriented system transformation. The current system is therefore functional in one direction, but weak in another. This distinction is central to the answer to RQ3. WtE is constrained not because energy recovery is technically unthinkable, but because the surrounding system does not yet provide the institutional coherence, operational stability, financial credibility, or market formation required for recovery to become a stable development pathway.

This also changes how WtE should be interpreted in a Global South context. Mature WtE systems in many Global North settings have often depended on stable regulation, high landfill costs, strong enforcement, heat demand, and coordinated waste and energy infrastructures. These conditions cannot be assumed in South Africa. Transferring WtE as a general model from Global North settings therefore risks overlooking the unequal institutional, infrastructural, and material conditions under which the technology would have to operate. In this case, WtE may be relevant because it connects to real waste and energy pressures, but it is not yet viable as a broader energy transition pathway because the necessary institutional, operational, financial, and market conditions remain weakly developed.

The justice implications of WtE are inseparable from these system constraints. Energy recovery could create narrow benefits by improving plant resilience and supporting treatment continuity where HCRW incineration is already necessary. However, these benefits would likely be concentrated around the plant and the operator, while the burdens could be more widely distributed through higher capital requirements, tighter process control, greater skill demands, and more demanding labour and maintenance conditions. From a distributional justice perspective, this raises questions about who benefits from energy recovery and who carries the additional operational, financial, and environmental risks. From a procedural justice perspective, it raises questions about which actors are included in decisions about WtE development. From a recognition justice perspective, it raises questions about whether the vulnerabilities and capacities of workers, regulators, municipalities, and communities affected by waste infrastructure are sufficiently acknowledged.

The answer to RQ3 is therefore that WtE can only be defended under strict and narrow conditions. It may be justified where incineration is already necessary, where energy recovery strengthens treatment continuity, where environmental control is maintained or improved, and where the pathway does not shift additional burdens onto workers, communities, or actors already carrying disproportionate risks. WtE does not emerge as a central energy transition pathway in this case. Rather, it appears as a constrained and context dependent option that may have value in specific treatment settings, but only if it is embedded in a wider transition agenda that also addresses enforcement, labour conditions, participation, financing, and higher value waste recovery.

7.2 Theoretical contributions

This study contributes mainly to the TIS literature by showing that system functionality should be understood as both justice sensitive and context dependent. TIS is useful because it explains how actors, institutions, networks, infrastructures, and system functions shape the development of a technology. What this study adds is the argument that it is not enough to ask whether a system functions. It is also necessary to ask what the system functions for, who it functions for, and under what conditions it can support a new pathway. This is particularly important in Global South contexts, where technology development is often shaped by fragmented governance, uneven infrastructure provision, limited institutional capacity, and competing social and economic priorities.

The first contribution is to clarify that a system can be functional in one direction and weak in another. A system may have relevant actors, existing infrastructure, knowledge, permits, and routines, but these elements may still support the existing purpose of the system rather than a new transition pathway. In TIS terms, structural presence should not be confused with functional readiness, and existing structures may create a starting point for change without automatically creating the markets, incentives, legitimacy, experimentation, or resources needed for a new pathway to develop. This implies that TIS analysis should pay closer attention to system orientation. If a system is organised around one purpose, its functions may continue to reproduce that purpose even when a new technological option becomes technically possible. System performance should therefore not only be assessed by whether functions are present, but also by whether the functions are aligned with the direction of change being studied. In the case of WtE, this distinction is especially important because an incineration system may be operationally functional as a treatment and destruction system, while still being weakly aligned with energy recovery, circular economy objectives, and transition oriented development.

The second contribution concerns how justice can deepen TIS analysis. In many TIS studies, legitimation is treated as whether a technology becomes accepted, credible, or supported. A justice perspective adds that it also matters whose acceptance counts, whose concerns are recognised, and how risks and benefits are distributed. Justice is therefore not only an ethical addition after the TIS analysis. It can change how key TIS functions are interpreted. Legitimation, direction of search, market formation, and resource mobilisation are not neutral processes. They involve choices about which pathways receive support, who captures value, and who carries social, environmental, and operational risks. This is especially important for energy transitions in contexts marked by inequality, uneven service provision, and limited institutional capacity, where a pathway may gain support from firms, regulators, or investors while still raising justice concerns if affected workers, communities, or informal actors are weakly recognised. Justice therefore helps TIS move from asking whether a system can support a technology to asking whether the pathway being supported is socially legitimate and broadly defensible.

A third contribution relates to inducement and blocking mechanisms. The study supports the view that system functions should not be analysed as separate categories, but as connected processes that reinforce or weaken one another. Positive conditions do not automatically become strong inducement mechanisms. They only become strong when they connect across functions and create momentum over time. Blocking mechanisms similarly become more powerful when weaknesses in one function reinforce weaknesses in others. For TIS research, this highlights the importance of analysing how functions interact, rather than only identifying which functions are present or absent. In Global South contexts, this interaction may be particularly important because weaknesses across governance, finance, infrastructure, and implementation capacity can compound one another. A weak market signal may therefore not only constrain investment, but also weaken experimentation, reduce legitimacy, and limit resource mobilisation.

A fourth contribution is to highlight the importance of alignment between different systems. Some technologies are positioned between several sectors and cannot develop through one system alone. They may depend on waste regulation, energy markets, infrastructure, finance, and public legitimacy at the same time. In such cases, weak system development may not only come from problems inside the focal TIS, but also from poor alignment between neighbouring systems. This suggests that TIS research should pay closer attention to technologies that sit between established regimes, where development depends on coordination across several institutional and market settings. WtE illustrates this point clearly, since it is neither only a waste management technology nor only an energy technology. Its development depends on whether waste treatment rules, electricity market conditions, permitting processes, and infrastructure systems jointly create a credible pathway for implementation.

The study also contributes to broader energy transitions theory by showing the difference between transition relevance and transition viability. A technology may appear relevant because it responds to visible problems or policy pressures, but relevance does not mean that it becomes a viable pathway. For a pathway to become viable, the surrounding system must support implementation, learning, investment, legitimacy, and long term operation. This is particularly important in Global South contexts, where urgent needs can make certain technologies appear attractive while fragmented governance, limited resources, and competing priorities prevent them from developing. The study therefore shows that WtE cannot be understood as a simple transfer of a pathway that has emerged in more mature waste and energy systems. Instead, it must be analysed as a context dependent transition option whose viability depends on local institutional alignment, operational capability, market formation, and social legitimacy.

Overall, the theoretical contribution of this thesis is to suggest that TIS analysis should be more attentive to orientation, justice, alignment, and context. Systems can be functional but still misaligned with a new transition pathway. Justice can change how TIS functions are understood, especially legitimation, direction of search, market formation, and resource mobilisation. Positive conditions only become meaningful inducement mechanisms when they create reinforcing dynamics across the system. In Global South contexts, these dynamics are shaped by broader conditions of uneven infrastructure, institutional fragmentation, constrained resources, and competing development priorities. This does not replace the TIS framework, but strengthens its usefulness for analysing complex energy transitions where technical feasibility alone cannot explain whether a pathway develops.

7.3 Limitations and future research

Three limitations should be acknowledged when interpreting the findings. The first is the embedded single case research design. The focal case is Averda’s South African HCRW treatment activities, with George and Klerksdorp as the primary plant settings. The empirical material extends beyond the focal company and includes A-Thermal as an additional operator perspective and BCL as an indirect comparative reference, alongside regulators, technology suppliers, consultants, experts, and industry actors. These external sources contextualise and triangulate the focal case rather than establish separate organisational cases. In line with the logic of single case research, the findings should not be interpreted as statistically generalisable. Their relevance lies in theoretical transferability and analytical generalisation to contexts with comparable institutional, infrastructural, and socio economic conditions, rather than across all national settings or all Global South contexts.

The second limitation concerns the composition of the empirical material. The study is anchored in a firm centred entry point and provides particularly strong insight into how WtE feasibility is understood from the standpoint of operators, technical experts, regulators, and institutional actors. Other perspectives, including those of workers, informal actors, municipalities, and affected communities, are less directly represented. As a result, certain dynamics, particularly those related to justice, labour conditions, informal waste practices, and lived experience, are interpreted indirectly rather than through extensive first hand accounts. This matters especially for the justice related parts of the analysis. The study does not claim to define what a just pathway should be for all affected actors, but offers a situated analysis of how justice related issues become visible when a firm centred WtE pathway is examined in relation to broader system conditions. The justice conclusions should therefore be understood as indicative and analytical rather than definitive.

The third limitation concerns analytical scope. The study focuses on WtE through incineration in the HCRW context, with existing plants and possible retrofit pathways as the main empirical entry point. It does not evaluate the full range of alternative waste and energy pathways that may prove more viable in South Africa, nor does it provide a complete technical design or full financial feasibility assessment for any specific project. Technical and economic issues are examined only to the extent that they help explain broader system conditions and implementation constraints. The findings should therefore be understood primarily as an analysis of systemic feasibility and contextual alignment, rather than as a definitive investment assessment.

These limitations point to four directions for future research. Comparative studies across different national settings could examine whether similar system dynamics are present beyond South Africa and across other Global South contexts, and could clarify which findings are more specific to the South African setting and which reflect broader patterns. Broadening the empirical scope beyond incineration based WtE could compare WtE with other treatment and resource recovery options that may be more viable, more scalable, or more appropriate under South African conditions. Engaging more directly with workers, municipalities, informal waste actors, and communities affected by waste management practices would deepen the justice analysis by allowing distributional, procedural, and recognition dimensions to be examined through the lived experience of those who carry the costs. Finally, more detailed techno economic and operational studies, including plant-level data on waste composition, downtime, emissions performance, retrofit costs, and electricity use, could test under what specific conditions limited forms of energy recovery may become viable in practice.

References

Averda. (n.d.a). *About us*. https://www.averda.com/about-us

Averda. (n.d.b). *Thermal treatment facilities*. https://www.averda.com/rsa/our-technology/thermal-treatment-facilities

Bell, E., Bryman, A., & Harley, B. (2022). *Business Research Methods* (6th ed.). Oxford University Press.

Bergek, A., Hekkert, M., Jacobsson, S., Markard, J., Sandén, B., & Truffer, B. (2015). Technological innovation systems in contexts: Conceptualizing contextual structures and interaction dynamics. *Environmental Innovation and Societal Transitions, 16*, 51–64. https://doi.org/10.1016/j.eist.2015.07.003

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research. Policy*, *37*(3), 407–429. https://doi.org/10.1016/j.respol.2007.12.003

Borup, M., Brown, N., Konrad, K., & Van Lente, H. (2006). The sociology of expectations in science and technology. *Technology Analysis & Strategic Management, 18*(3–4), 285–298. https://doi.org/10.1080/09537320600777002

Brinkmann, S., & Kvale, S. (2015). *InterViews: Learning the craft of qualitative research interviewing* (3rd ed.). SAGE Publications.

Braun, V., & Clarke, V. (2006). *Using thematic analysis in psychology*. Qualitative Research in Psychology, 3(2), 77–101.

Bryman, A. (2018). *Samhällsvetenskapliga metoder.* Stockholm*:* Liber AB.

Burnard, P. (1991). *A method of analysing interview transcripts in qualitative research*. Nurse Education Today, 11(6), 461–466. https://doi.org/10.1016/0260-6917(91)90009-Y

Carlsson, B., & Stankiewicz, R. (1991). On the nature, function and composition of technological systems. *Journal of Evolutionary Economics*, *1*(2), 93–118. https://doi.org/10.1007/bf01224915

Centre for Research on Energy and Clean Air. (2023). *Health impacts of Eskom's non-compliance with minimum emissions standards*. https://cer.org.za/wp-content/uploads/2023/02/Health-impacts-of-Eskoms-non-compliance-with-minimum-emissions-standards-Google-Docs.pdf

Chisholm, J. M., Zamani, R., Negm, A. M., Said, N., Abdel daiem, M. M., Dibaj, M., & Akrami, M. (2021). Sustainable waste management of medical waste in African developing countries: A narrative review. *Waste Management & Research, 39*(9), 1149–1163. https://doi.org/10.1177/0734242X211029175

Corvellec, H., Zapata Campos, M. J., & Zapata, P. (2013). Infrastructures, lock-in, and sustainable urban development: The case of waste incineration in the Göteborg Metropolitan Area. *Journal of Cleaner Production, 50*(1), 32–39. https://doi.org/10.1016/j.jclepro.2012.12.009

Dalén, M. (2015). *Intervju som metod.* Malmö: Gleerups Utbildning AB.

D'Alisa, G., & Demaria, F. (2024). *Accumulation by contamination: Worldwide cost-shifting strategies of capital in waste management*. World Development**.** https://doi.org/10.1016/j.worlddev.2024.106495

de Oliveira, L. G. S., Lacerda, J. S., & Negro, S. O. (2020). A mechanism-based explanation for blocking mechanisms in technological innovation systems. *Environmental Innovation and Societal Transitions, 37*, 18 38. https://doi.org/10.1016/j.eist.2020.07.006

Department of Forestry, Fisheries and the Environment (DFFE). (2025, March 18). *Overview by the Department of Forestry, Fisheries and the Environment on waste management including the compliance status of municipal landfill sites in South Africa* [PowerPoint presentation]. Portfolio Committee on Forestry, Fisheries and the Environment.

Edquist, C. (2005). Systems of innovation: Perspectives and challenges. In J. Fagerberg, D. C. Mowery, & R. R. Nelson (Eds.), *The Oxford handbook of innovation* (pp. 181–208). Oxford University Press.

Emerson, R. M., Fretz, R. I., & Shaw, L. L. (2011). *Writing ethnographic fieldnotes* (2nd ed.). University of Chicago Press.

Fernandez, A. de J., & Watson, J. (2022). Mexico's renewable energy innovation system: Geothermal and solar photovoltaics case study. Environmental Innovation and Societal Transitions, 43, 200–219. https://doi.org/10.1016/j.eist.2022.04.004

Gather, J., Prowse, M., & Seussler, D. (2025). Pathways towards just transitions in the Global South. *Energy Research & Social Science, 127*, 104293. https://doi.org/10.1016/j.erss.2025.104293

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy, 31*(8–9), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

George, T. (2021). A guide to exploratory research. [online] Scribbr. Available at: https://www.scribbr.com/methodology/exploratory-research/

Granovetter, M. (1985). Economic action and social structure: The problem of embeddedness. *American Journal of Sociology, 91*(3), 481–510. https://doi.org/10.1086/228311

Gustafsson, J. (2017). Single case studies vs. multiple case studies: A comparative study.

Hekkert, M. P., Suurs, R. A. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. H. M. (2007). Functions of innovation systems: A new approach for analysing technological change. *Technological Forecasting and Social Change, 74*(4), 413–432. https://doi.org/10.1016/j.techfore.2006.03.002

Hughes, T. P. (1987). The evolution of large technological systems. In W. E. Bijker, T. P. Hughes, & T. Pinch (Eds.), *The social construction of technological systems: New directions in the sociology and history of technology* (pp. 51–82). MIT Press.

IEA Bioenergy. (2023). *Review of waste to energy policies in South Africa and international comparisons*. https://www.ieabioenergy.com/wp-content/uploads/2023/05/Task-36-Waste-to-Energy-Policy-Review_2023final-2.pdf

Intergovernmental Panel on Climate Change. (2023). Climate Change 2023: Synthesis Report. https://doi.org/10.59327/IPCC/AR6-9789291691647

International Solid Waste Association. (2023). *ISWA white book on Energy-from-Waste (EfW) technologies*. International Solid Waste Association.

IPCC. (2023). *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee & J. Romero (Eds.)]. Intergovernmental Panel on Climate Change. https://doi.org/10.59327/IPCC/AR6-9789291691647.001

Jacobsson, S., & Bergek, A. (2011). Innovation system analyses and sustainability transitions: Contributions and suggestions for research. *Environmental Innovation and Societal Transitions, 1*(1), 41–57. https://doi.org/10.1016/j.eist.2011.04.006

Jacobsson, S., & Lauber, V. (2006). The politics and policy of energy system transformation: Explaining the German diffusion of renewable energy technology. *Energy Policy, 34*(3), 256–276. https://doi.org/10.1016/j.enpol.2004.08.029

Jenkins, K., McCauley, D., Heffron, R., Stephan, H., & Rehner, R. (2016). Energy justice: A conceptual review. *Energy Research & Social Science, 11*, 174–182. https://doi.org/10.1016/j.erss.2015.10.004

Johnson, A., & Jacobsson, S. (2001). Inducement and blocking mechanisms in the development of a new industry: The case of renewable energy technology in Sweden. In R. Coombs, K. Green, V. Walsh, & A. Richards (Eds.), *Technology and the market: Demand, users and innovation* (pp. 89–111). Edward Elgar Publishing. https://doi.org/10.4337/9781843762867.00012

Kaza, S., Yao, L. C., Bhada-Tata, P., Van Woerden, F., & Levine, D. (2018). *What a waste 2.0: A global snapshot of solid waste management to 2050*. World Bank. https://doi.org/10.1596/978-1-4648-1329-0

Kemp, R., Schot, J., & Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. *Technology Analysis & Strategic Management, 10*(2), 175–198. https://doi.org/10.1080/09537329808524310

Kennedy, M. M. (1979). Generalizing from single case studies. Evaluation Quarterly, 3(4):661–678. https://doi.org/10.1177/0193841X7900300408.

Kivimaa, P., Bergek, A., Matschoss, K. and van Lente, H. (2020) *Intermediaries in accelerating transitions: Introduction to the special issue*. Environmental Innovation and Societal Transitions, 36, 372–377. https://doi.org/10.1016/j.eist.2020.03.004

Kivimaa, P., & Kern, F. (2016). Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. *Research Policy, 45*(1), 205–217. https://doi.org/10.1016/j.respol.2015.09.008

Köhler, J., Geels, F. W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Fünfschilling, L., Hess, D. J., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., McMeekin, A., Mühlemeier, M. S., ... Wells, P. (2019). An agenda for sustainability transitions research: State of the art and future directions. Environmental Innovation and Societal Transitions, 31, 1–32. https://doi.org/10.1016/j.eist.2019.01.004

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. SAGE.

Makarichi, L., Jutidamrongphan, W., & Techato, K. (2018). The evolution of waste-to-energy incineration: A review. Renewable and Sustainable Energy Reviews, 91, 812–821. https://doi.org/10.1016/j.rser.2018.04.088

Markard, J., Hekkert, M., & Jacobsson, S. (2015). The technological innovation systems framework: Response to six criticisms. *Environmental Innovation and Societal Transitions, 16*, 76–86. https://doi.org/10.1016/j.eist.2015.07.006

Markard, J., Raven, R., & Truffer, B. (2012). *Sustainability transitions: An emerging field of research and its prospects*. https://doi.org/10.1016/j.respol.2012.02.013

Markard, J., & Truffer, B. (2008). Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research Policy, 37*(4), 596–615. https://doi.org/10.1016/j.respol.2008.01.004

Marshall, R. E., & Farahbakhsh, K. (2013). Systems approaches to integrated solid waste management in developing countries. *Waste Management, 33*(4), 988–1003. https://doi.org/10.1016/j.wasman.2012.12.023

McCauley, D. M., & Heffron, R. (2018). Just transition: Integrating climate, energy and environmental justice. *Energy Policy, 119*, 1–7. https://doi.org/10.1016/j.enpol.2018.04.014

McCauley, D., Heffron, R., Stephan, H., & Jenkins, K. E. H. (2013). Advancing energy justice: The triumvirate of tenets and systems thinking. *International Energy Law Review, 32*(3), 107–116.

Merriam, S. B., & Tisdell, E. J. (2016). *Qualitative research: A guide to design and implementation* (4th ed.). Jossey-Bass.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). *Qualitative data analysis: A methods sourcebook* (3rd ed.). SAGE.

Newell, P., & Mulvaney, D. (2013). The political economy of the "just transition". *The Geographical Journal, 179*(2), 132–140. https://doi.org/10.1111/geoj.12008

Nordic Council of Ministers. (2024). *Current status of the waste incineration sector in the Nordics*. Nordic Council of Ministers.

North, D. C. (1990). *Institutions, institutional change and economic performance*. Cambridge University Press.

Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic analysis: Striving to meet the trustworthiness criteria. *International Journal of Qualitative Methods, 16*, 1–13. https://doi.org/10.1177/1609406917733847

OECD (2025), *Environmental Outlook on the Triple Planetary Crisis: Stakes, Evolution and Policy Linkages*, OECD Environmental Outlook, OECD Publishing, Paris, https://doi.org/10.1787/257ffbb6-en.

Olaniyi, F. C., Ogola, J. S., & Tshitangano, T. G. (2018). *A review of medical waste management in South Africa*. Open Environmental Sciences, 10, 34–45. https://doi.org/10.2174/1876325101810010034

Powell, W. W., Koput, K. W., & Smith-Doerr, L. (1996). Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. *Administrative Science Quarterly, 41*(1), 116–145. https://doi.org/10.2307/2393988

Ramos-Mejía, M., Franco-Garcia, M. L., & Jauregui-Becker, J. M. (2018). Sustainability transitions in the developing world: Challenges of socio-technical transformations unfolding in contexts of poverty. *Environmental Science & Policy, 84*, 217–223. https://doi.org/10.1016/j.envsci.2017.03.010

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.

Rogge, K. S., & Reichardt, K. (2016). Policy mixes for sustainability transitions: An extended concept and framework for analysis. *Research Policy, 45*(8), 1620–1635. https://doi.org/10.1016/j.respol.2016.04.004

Scott, W. R. (2014). *Institutions and organizations: Ideas, interests, and identities* (4th ed.). SAGE Publications.

Shenton, A. K. (2004). Strategies for ensuring trustworthiness in qualitative research projects. *Education for Information, 22*(2), 63–75. https://doi.org/10.3233/EFI-2004-22201

Suurs, R. A. A., & Hekkert, M. P. (2009). Cumulative causation in the formation of a technological innovation system: The case of biofuels in the Netherlands. *Technological Forecasting and Social Change, 76*(8), 1003–1020. https://doi.org/10.1016/j.techfore.2009.03.002

Tobiasen, L., Kamuk, B. (2012). Waste-to-Energy for District Heating . In: Meyers, R.A. (eds) Encyclopedia of Sustainability Science and Technology. Springer, New York, NY. https://doi.org/10.1007/978-1-4419-0851-3_401

Tomai, M., Papachristos, G., & Ramani, S. V. (2024). The dynamics of change towards sustainability in developing countries: Evidence from Ghana's Waste-to-Energy transition. Environmental Innovation and Societal Transitions, 53, 100928. https://doi.org/10.1016/j.eist.2024.100928

Ulmanen, J., & Bergek, A. (2021). Influences of technological and sectoral contexts on technological innovation systems. *Environmental Innovation and Societal Transitions, 40*, 20–39. https://doi.org/10.1016/j.eist.2021.04.007

United Nations Environment Programme, International Resource Panel, United Nations Statistics Division, European Commission, & Organisation for Economic Co-operation and Development. (2021). *The use of natural resources in the economy: A global manual on economy-wide material flow accounting*. UNEP. https://seea.un.org/sites/seea.un.org/files/unre_0.pdf

United Nations Environment Programme, & International Solid Waste Association. (2024). *Global waste management outlook 2024: Beyond an age of waste—Turning rubbish into a resource*. https://doi.org/10.59117/20.500.11822/44939

Unruh, G. C. (2000). Understanding carbon lock-in. *Energy Policy, 28*(12), 817–830. https://doi.org/10.1016/S0301-4215(00)00070-7

Vetenskapsrådet. (2024). *God forskningssed 2024* [Good research practice 2024]. Vetenskapsrådet. https://www.vr.se/analys/rapporter/vara-rapporter/2024-10-02-god-forskningssed-2024.html

Weckowska, D., Weiss, D., Schwäbe, C., & Dreher, C. (2025). Technological innovation system analyses and sustainability transitions: A literature review. *Environmental Innovation and Societal Transitions, 54*, 100935. https://doi.org/10.1016/j.eist.2024.100935

Wieczorek, A. J. (2018). Sustainability transitions in developing countries: Major insights and their implications for research and policy. *Environmental Science & Policy, 84*, 204–216. https://doi.org/10.1016/j.envsci.2017.08.008

Wieczorek, A. J., & Hekkert, M. P. (2012). Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. *Science and Public Policy, 39*(1), 74–87. https://doi.org/10.1093/scipol/scr008

World Health Organization. (2014). *Safe management of wastes from health-care activities* (2nd ed.). World Health Organization.

World Health Organization. (2019). *Overview of technologies for the treatment of infectious and sharp waste from health care facilities*. World Health Organization.

World Health Organization. (2024). *Health-care waste*. https://www.who.int/news-room/fact-sheets/detail/health-care-waste

Yang, Y., Xia, S., Huang, P., & Qian, J. (2024). Energy transition Connotations, mechanisms and effects. *Energy Strategy Reviews, 52*, 101320. https://doi.org/10.1016/j.esr.2024.101320

Yin, R.K. (2003) Case Study Research: Design and Methods. 3rd Edition, Sage, Thousand Oaks.

Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). SAGE Publications.

Zikhathile, T., Atagana, H. I., Bwapwa, J., & Sawtell, D. (2022). *A review of the impact that healthcare risk waste treatment technologies have on the environment*. International Journal of Environmental Research and Public Health, 19(19), 11967. https://doi.org/10.3390/ijerph191911967

DEPARTMENT OF TECHNOLOGY
MANAGEMENT AND ECONOMICS

CHALMERS UNIVERSITY OF TECHNOLOGY

CHALMERS
UNIVERSITY OF TECHNOLOGY