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ASSESSMENT OF POTENTIAL WASTE-TO-ENERGY TECHNOLOGY OPTIONS FOR MUNICIPAL SOLID WASTE MANAGEMENT IN THE TAMALE METROPOLIS

ABDUL-WAHAB, TAHIRU

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ASSESSMENT OF POTENTIAL WASTE TO ENERGY TECHNOLOGY OPTIONS FOR MUNICIPAL SOLID WASTE MANAGEMENT IN THE TAMALE METROPOLIS

BY

ABDUL-WAHAB, TAHIRU (MPhil. Environmental Science)

(UDS/DES/0007/21)

THESIS SUBMITTED TO THE DEPARTMENT OF ENVIRONMENT AND SUSTAINABILITY SCIENCES, FACULTY OF NATURAL RESOURCES AND ENVIRONMENT, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A DOCTOR OF PHILOSOPHY DEGREE (PhD) IN ENVIRONMENTAL MANAGEMENT AND SUSTAINABILITY.

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DECLARATION

I hereby declare that, except for references to other people's work, which have been duly acknowledged, this thesis is the result of my own research work carried out in the Department of Environment and Sustainability Sciences under the supervision of Prof. Samuel Jerry Cobbina and Dr. Wilhemina Asare. It is further declared that this thesis has never been presented either in whole or in part for the award of any degree in this University or elsewhere.

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ABSTRACT

Tamale faces increasing challenges with the management of municipal solid waste. This study explored Waste-to-Energy (WtE) technologies as a viable solution, aiming to evaluate their suitability for implementation in the city. The study utilized a waste audit analysis, involving the physical and chemical characterization of solid waste sampled from various sources such as households, markets, hotels, and restaurants. Stakeholder preferences for four waste-to-energy (WtE) technologies (incineration, gasification, landfill gas recovery, and anaerobic digestion) were analyzed using the Analytic Hierarchy Process (AHP) of Multi Criteria Decision Making (MCDM). Quantitative research methods were employed to assess public perceptions and social acceptance of WtE technologies. Specifically, the study used ANOVA, T-tests, and multiple regression analysis on data collected from a survey of 395 residents in Tamale. Lastly, in-depth interviews and focus group discussions were held with key waste management stakeholders in Tamale to explore the challenges and opportunities for incorporating Waste-to-Energy (WtE) technologies into the current waste management framework. The study revealed that the Tamale metropolis produces 176 tons of Municipal Solid Waste (MSW) per day, with a per capita generation rate of 0.47 kg/day. Organic matter constituted the largest portion at 44.9%, followed by miscellaneous and plastic waste, each accounting for 20%. The hospitality sector contributed the highest organic waste content, making up 62.3% of its total waste. Gross calorific values found for waste sampled from the study area ranged from 7.8 MJ/kg to 28.8 MJ/kg, suggesting that MSW in the Tamale metropolis was suitable for energy generation. Stakeholder engagement identified Anaerobic Digestion (AD) as the preferred WtE technology due to its environmental benefits, social acceptability, and job creation potential. However, a sensitivity analysis showed that prioritizing economic factors could shift preference towards Landfill Gas Recovery (LFG) if economic weight exceeds 85% in the decision model. This suggests LFG as the second-most viable WtE option for Tamale. While acknowledging WtE benefits, a lack of technical understanding of WtE plants fuels anxieties about odor and health risks, manifesting as a "Not-In-My-Backyard" (NIMBY) syndrome. Age, education, and proximity to WtE plants influenced awareness and acceptance, with higher levels observed in urban residents, older age groups, and those closer to existing plants. This underscores the importance of focused public education and awareness initiatives. The study also identified key obstacles to the current Municipal Solid Waste Management System (MSWMS), including policy challenges, financial constraints, social issues, and institutional weaknesses. On the other hand, success factors for enhancing waste management and shifting towards a Waste-to-Energy (WtE) focused MSWM system included stakeholder collaboration, public education, and capacity building. Moreover, a new framework for integrating WtE into a comprehensive Integrated Solid Waste Management (ISWM) system is proposed. This study finds that anaerobic

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digestion, among waste-to-energy technologies, shows promise in addressing Tamale's growing municipal solid waste issue. This research provides crucial insights for policymakers and regulatory bodies, including the PURC, the Ministry of Energy, and local authorities, on integrating waste-to-energy (WtE) solutions into Ghana's waste management framework in alignment with SDGs 7, 11, and 12. It highlights the viability of waste valorization strategies, particularly anaerobic digestion (AD), as a sustainable and economically feasible option. Finally, it recommends a pilot implementation to assess feasibility.

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I equally want to thank all my research participants, especially the staff of the Tamale Metropolitan Assembly, Environmental Health Unit, Environmental Protection Agency, Energy Commission and Zoomlion Ghana Limited whose cooperation and support made my fieldwork a success.

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DEDICATION

This work is dedicated to my wife Abdul-Wahab Nawaratu, and our son (Dagimah Zayn Wurisibna).

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LIST OF ACRONYMS AND ABBREVIATIONS

AD	Anaerobic Digestion
AHP	Analytic Hierarchy Process
ASTM	American Society for Testing and Materials
CE	Circular Economy
CPCB	Central Pollution Control Board
EEA	European Environment Agency
EPA	Environmental Protection Agency
EPI	Environmental Performance Index
EU	European Union
FGDs	Focus Group Discussions
GCV	Gross calorific value
GHG	Green House Gases
ISWM	Integrated Solid Waste Management
LFG	Landfill Gas
MCDM	Multicriteria Decision-making Model
MENA	The Middle East and North Africa Region
MSW	Municipal Solid Waste
NGOs	Non-Governmental Organizations
OECD	Organization for Economic Co-operation and Development
PB	Perceived Benefits
PPPs	Public-Private Partnerships
PR	Perceived Risks

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PWS	Private Waste Service
RAT	Residents attitude
RAU	Recognition, Awareness, and Understanding
RDF	Refuse Derived Fuel
RWS	Resources and Waste Strategy
SDGs	Sustainable Development Goals
SWM	Solid Waste management
TaMA	Tamale Metropolitan Assembly
TQW	Total Quantity of Waste
UK	United Kingdom
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
WtE	Waste to Energy

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CHAPTER ONE

INTRODUCTION

1.1 Background

Increasing energy consumption per capita and waste generation are two of the world's most pressing issues today (Afriyie et al., 2023). These issues are exacerbated by global population growth, urbanization, and improved living standards. In 2016, urban areas produced approximately 2 billion tons of MSW (Dlamini et al., 2019). This number is forecast to increase by 70%, thus reaching 4.2 billion tons by 2050 (Dlamini et al., 2019).

According to Ferronato and Torretta. (2019), in developing countries, over 90% of waste is frequently dumped in uncontrolled landfills or burned in the open. Mismanaged waste poses health risks to residents, wreaks havoc on the environment, and stunts a nation's economic development (Woon et al., 2021). If the current policy and technological trends continue, global energy consumption will grow by nearly 50% between 2020 and 2050 (Geelani et al., 2020). Of the five main sources of greenhouse gases (GHG), fossil fuels account for more than 80% of global energy consumption (Geelani et al., 2020). Avoiding the worst effects of climate change requires keeping most of the world's remaining fossil fuels underground by 2050, scientists have warned (Qazi et al., 2018).

As one of sub-Saharan Africa's rapidly urbanizing nations, Ghana has experienced a surge in energy consumption and waste production in recent years (Afriyie et al., 2023; Tahiru et al., 2023). Much of Ghana's municipal solid waste (MSW) is currently dumped illegally in the open or burned, releasing toxic organic compounds, unpleasant

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odors, and greenhouse gas emissions into the environment (Afriyie et al., 2023 ; Tahiru et al., 2024a). The country lacks adequate waste management systems and infrastructure to properly manage the increasing volumes of waste generated (Asare et al., 2020). Also problematic is the fact that electricity is not always consistently available throughout the whole country (Korzhenevych & Owusu, 2021). Power plants in the country rely heavily on fossil fuel imports to produce electricity (Korzhenevych & Owusu, 2021). Accordingly, over 90% of primary electricity generation plants in Ghana are currently powered by crude oil, diesel, and natural gas (Abban & Awopone, 2021). To help cover the increasing cost of production and distribution network operations for the improvement of service and reliable delivery of electricity, the Electricity Company of Ghana proposed a 148% increase in electricity tariff for the year 2022 and with 7.6% upward adjustments bWtEeen the periods of 2023-2026 (Electricity Company of Ghana, 2021). This is evidence that Ghana's reliance on fossil fuels is not going to help it achieve sustainable economic growth (Gyimah et al., 2021). Ghana aims to increase the share of renewable energy in its total energy mix from 1.1% to 10% by 2030 (International Renewable Energy Agency, 2021). However, as of 2021, renewable energy accounted for only 1.7% of total energy consumption (IEA, 2021), indicating that the country is falling significantly behind its target and requiring accelerated policy interventions to bridge the gap.

Against this backdrop, Ghana government may want to consider waste-to-energy generation (WtE) (Opoku et al., 2022). In the United States, policymakers are actively pursuing the recognition of waste-to-energy (WtE) as a source of renewable energy to reduce the country's reliance on fossil fuels (Alqattan et al., 2018). In this way, WtE

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can aid in the attainment of SDG goals 7, 11, 12 and 13. Sustainable Development Agenda Goal 7 aims to raise the use of renewable energy in the world's energy blend, which in turn helps to achieve Goal 12 and Goal 13 of the SDGs, which is to mainstream sustainable consumption and production and take immediate action to address climate change, respectively. Moreover, implementing Waste-to-Energy (WtE) will support Ghana in achieving Sustainable Development Goal 11, which aims to create inclusive, safe, resilient, and sustainable cities. This will be accomplished by reducing the negative environmental impact of cities on a per capita basis by 2030, with a particular emphasis on improving air quality, managing municipal solid waste, and addressing other key aspects of waste management (Gulluscio et al., 2020 ; Tahiru et al., 2024d). Even though waste-to-energy technologies are well-developed in some advanced economies, these facilities cannot simply be transposed to developing countries (Khan et al., 2022). The efficiency of these technologies is determined by a variety of factors, not the least of which is the chemical composition of the feedstock (Khan et al., 2022; Roy et al., 2022). Several waste-to-energy technologies have been developed to help reduce waste (Mukherjee et al., 2020; Tahiru et al., 2024c).

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Many studies have been conducted in recent years to assess the viability, acceptability, and public opinion of various energy technologies (Aloa et al., 2021; Dlamini et al., 2019). This is due in partly to the widespread belief that WtE technologies are prohibitively expensive. To address this, existing waste treatment technologies have been modified, and new treatment technologies are being developed to cater to even small communities to solve the waste disposal problem and extract valuable energy (Doaemo et al., 2021; Das et al., 2019). Sustainable urban development relies heavily

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on the management of municipal solid waste (Kombiok & Naa Jaaga, 2023). Waste management encompasses all the steps taken to reduce waste's negative impact on the environment, including waste sorting, storing, collecting, transporting, treating and finally disposal (Seshie et al., 2020). According to Hu et al (2022), we can classify the conversion of waste to energy as either biochemical or thermochemical. Thermochemical processes include incineration technologies, gasification, pyrolysis (Hu et al., 2022). Biochemical processes include landfill gas and anaerobic digestion systems for producing biogas (Leckner et al., 2015). Today, new tools are being developed to assess the possible energy retrieval from waste, and existing methods are being refined. Despite this, selecting an appropriate WtE technology is no simple feat, as the volume and quality of solid waste generated vary with the seasons and the socioeconomic status of both producers and/or consumers (Miezah et al., 2015 ; Tahiru et al., 2024e;). A dependable tool of choice for selecting an appropriate WtE technology must consider inputs such as waste quality and quantity, composition assessment, environmental friendliness, social acceptance, and economics (Khan and Kabir, 2020).

In literature, there have been a plethora of studies investigating the technical and economic potentials of WtE technologies in different parts of the world (Batista et al., 2021). In Ghana, only two studies have been conducted so far on WtE assessment using the multicriteria decision-making model (MCDM) over the years. The two studies have been conducted to select a preferred WtE technology for adoption using only an expert survey as a tool for their respective recommendations (Afrane et al., 2022; Agbejule et al., 2021). Moreover, these studies employed a "top-down

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approach," disregarding the perception-based participatory input from stakeholders. Consequently, it was crucial to conduct a comprehensive investigation that considers equally significant factors, such as feedstock compositional analysis, waste volume, technological, economic, environmental, and social considerations, including stakeholder-centered perception-based participatory approaches (a combined approach), when evaluating all feasible WtE technologies. This approach is more reliable in the identification of the most sustainable WtE technology. Shahnazari et al. (2020) discovered that in situations where multiple incomparable factors need to be considered while selecting the most suitable WtE technology for a particular municipality, several researchers rely on the analytic hierarchy process (AHP) due to its dependability. From the literature there is a dearth of studies that aim to evaluate the adoption and sustainable implementation of WtE in Ghana with the majority of the available studies on WtE focusing on Accra and the nation at large (Afrane et al., 2022; Agbejule et al., 2021). For the reliability of data and customization of interventions to ensure sustainability, Ahmad et al. (2021) argue that a local-level assessment of WtE is necessary. In the last few years, Tamale has recorded an increase in MSW due to the rise in urban population growth (Asare et al., 2020). Therefore, examining the environment-techno-socio-economic feasibility of various WtE technologies and the challenges of WtE adoption in the Metropolis is critical to ensure effective management of solid waste in Tamale and subsequently influence efficient solid waste management in Ghana.

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1.2 Problem statement

Energy generation and Ghana's persistent energy crisis, marked by frequent blackouts and supply disruptions, underscores the urgent need for alternative and sustainable energy solutions (Osei-Appiah & Dioha, 2019). The nation has struggled with severe power rationing across multiple periods—1983–1984, 1997–1998, 2003–2004, 2006–2007, and 2011–2016—resulting in economic losses estimated at $2.1 million per day (Osei-Appiah & Dioha, 2019). Overreliance on fossil fuels (which accounted for 69% of electricity generation in 2020) and hydroelectricity (29.9%) has led to high transmission losses, increased carbon emissions, and an unsustainable power sector (Energy Commission Ghana, 2021). Despite national targets for renewable energy expansion, solar, wind, and biomass together contribute only 1.1% to Ghana's energy mix, largely due to their intermittent nature (Energy Commission Ghana, 2021). This highlights the need for stable, cost-effective, and scalable renewable energy sources, particularly waste-to-energy (WtE) technologies, which can generate continuous energy output while addressing environmental concerns (Ayodele et al., 2018).

Parallel to this energy crisis, Ghana faces a waste management dilemma, particularly in rapidly urbanizing cities like Tamale. With an annual solid waste generation of 4.64 million tonnes (Lissah et al., 2021), an estimated two-thirds of this waste is either openly burned or indiscriminately dumped, leading to groundwater contamination, greenhouse gas (GHG) emissions, and public health hazards (Lissah et al., 2021). Tamale alone generates 150 tonnes of waste daily, yet city authorities collect only 7.5 tonnes, leaving a backlog of 142.5 tonnes per day (Issahaku et al., 2014). The financial burden of ineffective waste collection is immense—GHC1.44 million annually for

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waste transport alone—straining municipal budgets (Tamale Metropolitan Waste Management Department, 2017). With landfills prematurely closing due to overuse and lack of GHG capture infrastructure, waste management in Ghana is at a critical juncture (Agbejule et al., 2021).

From literature, Tamale presents strong potential for WtE infrastructure development, given its high organic waste fraction, which makes WtE options viable for energy recovery (Lissah et al., 2021). The successful integration of WtE could simultaneously mitigate waste accumulation and enhance energy security, aligning with Ghana's Energy Sector Recovery Programme (2019) and the National Renewable Energy Action Plan (2016), which emphasize the development of alternative energy sources, including biomass and WtE technologies. However, lessons from previous WtE initiatives in Ghana and Africa suggest that technical, social, and policy-related barriers must be carefully assessed before large-scale implementation (Asare et al., 2020).

Despite the history of WtE dating back to the 2010s, its application in sub-Saharan Africa remains limited, often hindered by inadequate feasibility assessments, poor stakeholder engagement, and policy misalignment (Agbejule et al., 2021). By systematically comparing WtE options through an evidence-based decision-making framework and expirements, this research contributes to both policy formulation and practical implementation strategies, ensuring that Ghana's WtE transition is socially acceptable, economically viable, and environmentally sustainable.

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1.3 Objectives of the Study

1.3.1 General Objective:

The aim of this study was to explore the potential of municipal solid waste for WtE in Tamale-Ghana.

1.3.2 The Specific Objectives:

1. Examine the characteristics and quantities of solid waste for possible WtE conversion in Tamale.
2. To assess the most suitable WtE technology for Tamale based upon available feedstock using MCDM
3. To analyze Public Perceptions towards WtE as a Waste Management tool in Tamale.
4. To Assess the nexus between waste management systems and WtE adoption and implementation in the Tamale metropolis

1.3.3 Research Questions

1. What is the composition of MSW, and its physico-chemical composition in Tamale?

2. What is the best WtE technology for Tamale according to expert analysis and feedstock quality?

3. What is the appropriate WtE technology for acceptance in Tamale ?

4. What is the nexus between the prevailing waste management system and waste to energy in Tamale?

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1.3.4 Significance of the Study

This study is significant in multiple dimensions, encompassing policy development, environmental sustainability, energy security, waste management efficiency, and socio-economic impact. By providing an evidence-based framework for WtE adoption in Ghana, this research offers practical, policy-relevant insights for addressing the country's dual challenges of waste mismanagement and energy insecurity.

1. Contribution to Sustainable Waste Management in Ghana

- The study provides empirical data on the composition, calorific value, and potential energy recovery from municipal solid waste (MSW) in Tamale, filling a critical data gap in Ghana's waste management sector.
- By identifying the most suitable WtE option, this research guides decision-makers on viable and sustainable waste valorization pathways.
- It contributes to reducing landfill dependence and environmental pollution, aligning with Ghana's National Sanitation Policy and international Sustainable Development Goals (SDGs 11 & 12).

2. Strengthening Energy Security and Renewable Energy Transition

- By demonstrating that WtE can serve as a reliable and continuous renewable energy source, this study supports Ghana's Energy Sector Recovery Programme (2019) and the National Renewable Energy Action Plan (2016).
- The research highlights how WtE can complement solar and wind energy, which are intermittent, thereby enhancing grid stability and diversifying Ghana's energy mix.

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- The study provides an economic justification for WtE investments, showing how public-private partnerships (PPPs) and feed-in tariff mechanisms can attract investors.

3. Advancing Policy and Governance in WtE Adoption

- This research provides a framework for integrating WtE into Ghana's existing MSW landscape, ensuring alignment with the Environmental Protection Agency (EPA) guidelines and climate mitigation policies.
- The findings serve as a reference for future WtE feasibility studies and policy discussions, ensuring evidence-based planning for urban waste management.

4. Socio-Economic Impact: Job Creation and Community Well-being

- The research underscores how WtE adoption can create green jobs across waste collection, processing, energy generation, and technology maintenance, contributing to local economic development.
- By addressing public concerns regarding WtE, this study informs awareness campaigns and policy interventions to enhance social acceptance and stakeholder engagement.
- Finally, the study highlights the health and environmental benefits of diverting organic waste from open burning and indiscriminate dumping, thereby improving air quality and public health outcomes.

1.4 Justification

Following the commissioning of Ghana's first 400 kW/h hybrid waste-to-energy (WtE) plant in Gyankoba, Ashanti region, in May 2022, and the government's subsequent commitment to replicate this model across the remaining 15 regions,

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efforts to reduce dependence on imported fossil fuels, eliminate waste, lower greenhouse gas emissions, and promote a circular economy have gained momentum (MESTI, 2023). In support of this agenda, it is critical to conduct a technical, and environmental sustainability evaluation of WtE options in Ghana to come up with regional specific waste-to-energy technology options for adoption in order to avoid the risk of poor implementation and premature closures.

Few studies have been carried out on WtE in Accra-Ghana, including those by Opoku et al. (2022) and Agbejule et al. (2021), which utilized the MCDM model to select a preferred WtE technology for adoption in Accra. However, these studies failed to conduct sensitivity analyses on their respective preferences to ascertain their robustness and stability to support prudent decisions on waste-to-energy. Moreover, both studies relied solely on expert inputs to choose a WtE technology for implementation and adoption in Accra, Ghana, without considering the chemical composition of the available feedstock (waste) as well as the social acceptability of the populace. A recent study conducted by Afrane et al. (2022) also, utilized the MCDM-TOPSIS model to identify a suitable WtE technology for Ghana. However, like Agbejule et al. (2021), this study also relied solely on expert surveys to decide on the preferred waste-to-energy option for Ghana, which limits the openness of the decision-making process.

From the foregoing literature it is clear that previous studies in selecting WtE technologies in the scheme of Ghana follow a “top-down” approach, ignoring “local” stakeholder perspectives and participation, and chemical composition of feedstock. However, Vazquez-Peraita, (2022) asserted that direct and indirect stakeholders’

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experts and non-experts involved in decision-making, may perceive value and interests differently. Therefore, the inclusion of many stakeholder members in choosing the required WtE technologies is key to efficient implementation. Furthermore, feedstock quantity and composition are critical factors to consider when selecting the most suitable waste-to-energy technology for adoption (Khan et al., 2022). Since waste composition and characteristics are influenced by geographical location and other factors such as weather, purchasing power, culture among others.

By understanding the feedstock composition, researchers can be sure that they are selecting the technology that will deliver the highest efficiency sustainably. Moreover, there has been limited research in Ghana on WtE technology selection that, factored the characteristics of the available feedstock i.e., moisture content, energy potential, physical characteristics, ash content inter alia. Again, no detailed study has been done to determine the energy potential of MSW and suitable WtE technologies in the context of northern Ghana specifically in Tamale Metropolis. There is therefore a research gap in the viability of available MSW for WtE and the most suitable WtE technology for specific locations as in Tamale Metropolis. As such, it is critical that sound research be available to assist in providing insight and to educate the decision-making process on the adoption of WtE in Tamale and in Ghana.

Further, limited studies in Ghana have evaluated the perceptions of the public that influences WtE adoption. Therefore, this research addresses the existing knowledge gaps by using a holistic approach i.e., laboratory experiment, surveys and interviews together with MCDM-AHP for the selection of the most suitable WtE technology for adoption in the Tamale metropolis.

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The determination of the potential for WtE conversion is foundational for technological selection. Understanding the specific waste profile, generation rates, and energy content in Tamale is essential to ensure the selected technology can efficiently handle the local waste characteristics, leading to more sustainable and efficient energy production. Directly linked to the regional adaptation strategy, is to evaluate various technologies through a robust decision-making framework to ensure that the chosen technology aligns with local feedstock characteristics and operational realities. This is crucial to avoid the implementation pitfalls noted in other regions.

Public acceptance is vital for the success of any environmental initiative. This is to gauge community support and identify potential resistance or concerns regarding WtE strategies in Tamale. Incorporating public opinion can enhance social legitimacy and acceptance of the implemented technology.

The appreciation of how existing waste management practices can include the integration of successful WtE implementation is vital for ensuring that the WtE systems are not only technically feasible but also practical within the existing infrastructural and management frameworks. Each of the studies objectives are integral to ensuring that the selected WtE solutions are not only scientifically sound and technically feasible but also socially acceptable and aligned with local waste management practices. The outcome of the research may be useful in other areas with few or no alteration to the affirmation of the adoption of waste-to-energy technologies for sustainable solid waste management.

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1.5 Organization of the study

The organization of the study is in 5 chapters. The breakdown of the chapters is as follows: Chapter one represents the introduction of the research with subsections under it. Chapter two showcases a review of related literature to the research topic and discusses the theoretical approach for the study.

Chapter three centres on the method employed in the study in collecting and assessing data. It presents then research design, research instruments, sampling procedure, data collection and analysis for the study.

Chapter four expresses the research findings and discussions in the scheme of the topic. Chapter five, the last section, presents a summary, conclusions, implication and recommendation based on the study results.

1.6 Definition of Key Concepts

Waste-to-energy (WtE) is a process that transfers waste materials into usable forms of energy, like electricity or heat.

Municipal solid waste (MSW), also popularly called trash or garbage, refers to the daily items we discard after consumption.

A circular economy refers to a model where production and application directs to maintain resources in consumption for as long as possible.

Household size refers to the number of individuals in a family. Averagely, the size of a family for the study area is 6 people per household.

Solid waste management: actions and processes needed to manage waste from its generation point till it reaches the final disposal.

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Integrated solid waste management (ISWM): is an all-encompassing and detailed framework that acknowledges the full developmental waste system and its effects

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CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

In rapidly growing urban areas with increasing economic development, effective solid waste management practices become crucial (Tahiru et al., 2024). These practices aim to enhance resource recovery and waste recycling, reduce landfill pressure, and lower disposal costs (Asare et al., 2020). To achieve these, it is essential to explore waste-to-energy (WtE) options for harnessing energy from waste. This approach not only addresses waste management challenges but also offers environmental and economic benefits.

2.1 Definition of Waste

The definition of waste is somewhat subjective since something regarded as waste by someone could be a resource that generates goods or revenue for another. For example, most developing countries re-use and recycle discarded materials considered as waste by developed countries. The dynamic nature of the concept of waste has led to different definitions found in the literature. Seshie et al., (2020) define waste as any unwanted material that is intentionally thrown away for disposal. These are made up of wastes brought from residential, commercial, industrial, institutional, construction, demolition and municipal services. "Wastes are substances disposed of or are intended to be disposed of or are required to be disposed of by provision of national law - *Basel Convention, 1997"* (Krueger, J. 2017). Pongrácz (2002) defines waste based on the concept of ownership thus "a man-made thing that is, in the given time and place, in its actual structure and state, not useful to its owner". This definition was based on the

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classification of waste using the 'purpose, structure, state, and performance" as a tool. 1) Purpose - unwanted things, created but not intended or not avoided, with no purpose. 2) Structure - Things that were given a finite purpose thus, destined to become useless after fulfilling their purpose 3) State - Things with a well-defined purpose but their performance ceased being acceptable 4) Performance - Things with a well-defined purpose and acceptable performance, but their users failed to use them for their intended purpose.

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2.2 Municipal Solid Waste

Municipal solid waste (MSW) is generally defined as solid waste collected by municipalities or other local authorities (Kombiok & Naa Jaaga, 2023). Typically, MSW includes household waste; garden (yard) and park wastes; streets sweepings; and non-hazardous commercial/institutional waste (Miezah et al., 2015). Similarly, Bowan et al., (2020) posit that MSW consists mainly of waste from households (60–90%), though similar wastes from other sources such as commerce or public institutions are also included. Medical waste, which needs special handling and management is regarded as MSW in some locations, whilst municipal construction and demolition wastes are mostly excluded from MSW. Relatedly, other researchers and institutions describe MSW as a term usually applied to a heterogeneous collection of wastes produced in urban areas, the nature of which varies from region to region (Hoornweg & Bhada-Tata, 2012). The variants in wastes between regions or within the same region are because the characteristics, quantity and quality of solid waste generated in a region are not only a function of the living standard and lifestyle of the region's inhabitants, but also of the abundance and type of the region's natural

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resources. From the preceding definitions of MSW, it can be deduced that the definition of MSW is based on either the source or composition of waste or both. Therefore, this study defines MSW as solid waste arising from streets, domestic, commercial, and institutional activities, in an urban area that enter and/or leave the municipal waste stream. Municipal authorities or other government authorities in developing countries are solely responsible for the management of MSW (Asare et al., 2020). Because of this, MSW should include only waste that does not need special handling. Other waste such as clinical and construction/demolition wastes when included in MSW will further exacerbate the MSWM problem confronting many developing countries.

2.3 Integrated Solid Waste Management

Integrated Solid Waste Management (ISWM) is a holistic and comprehensive framework that recognise the entire life cycle of a waste system and its impacts. Reike et al. (2018) define Integrated Solid Waste Management as: The combination of waste streams, waste collection, treatment and disposal into a practical waste management system that aims to provide environmental sustainability, economic feasibility, and social acceptance for any specific region. This can be achieved by combining a range of treatment options, including waste reduction, re-use, recycle (waste hierarchy), composting, bio-gasification, thermal treatment, and landfilling (Winans et al., 2017).

ISWM systems are highly dependent on local conditions Batista et al. (2021). A system used by one municipality, which incorporates recycling and landfilling, might be different from another municipality which uses composting and incineration. It must be noted that there is no one universal 'best' system that can be applied to all

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cases (Roy and Gosh, 2019). A study by Addaney and Oppong (2015) in Ghana discovered that even though stakeholders in solid waste management were committed to achieving sustainable solid waste management, they are limited by low technical and financial capacity and the absence of a coordinative framework. Therefore, they argued that achieving sustainable integrated solid waste management may depend mainly on an effective and relevant legal framework, institutional strengthening and capacity building for the private sector, and implementation of cost recovery regimes. They again specified that it would require the development of sound partnerships with the private sector, waste reduction education and mainstreaming of recycling activities as well as enforcement of environmental sanitation regulations and byelaws.

Samwine *et al*. (2017) reported high cost of management, limited modern technologies, inadequate technical staff, and lack of proper planning for waste management services as challenges of ISWM. They also observed that the limiting factors to ensure effective resource recovery and solid waste management hinge more on irregular collection services, inadequate equipment to support waste storage, collection, and disposal, low collection coverage, inadequate funds as well as increasing volumes of waste. The others include lack of proper planning, poor attitude among the citizens, and lack of public participation in waste management. Despite these, the lack of sufficient engineered landfills with gas capture for disposal is a huge challenge to effective management (Roy, 2019). Most likely, when these factors are considered, it may lead to a move from the traditional way of municipal solid waste management (MSWM) that relies on collection and disposal to more sustainable ways of management to reduce the cost associated with the management of solid waste.

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The level of integration within any ISWM system is heavily dependent on the location in which it is used. Again, it is crucial to remember that the single foremost objective of the ISWM is to find the most environmentally friendly, economically effective, and socially accepted waste management scheme for a specific region, city, or community (UNEP, 2005). There are many different policy principles and options created which use ISWM. These Policy options have been based on either the circular economy, waste hierarchy or Zero waste to landfill. The options and goals can either be used separately or combined, depending on the needs of the waste system.

2.4 Theoretical Frameworks for Circular Economy and Waste-to-Energy (WtE)

While the Circular Economy (CE) provides a strong foundation for sustainable resource use and waste management, integrating additional theoretical perspectives can offer a more comprehensive and nuanced understanding of waste-to-energy (WtE) technologies and their role in sustainable development. This section expands on CE by incorporating Industrial Ecology (IE) and the Socio-Technical Transition (STT) Theory, comparing their applications to waste management and justifying the choice of CE and IE as the most suitable theoretical foundations for this study.

2.4.1 Circular Economy (CE) and Its Relevance

Circular economy is a concept that promotes sustainable resource use by minimizing waste and maximizing the value of materials (Ellen MacArthur Foundation, 2013). The CE framework aligns with the waste hierarchy, emphasizing prevention, reuse, recycling, and resource recovery (see Figure 2.1). This model reconfigures the traditional linear economy of extraction–production–consumption–disposal into a

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closed-loop system, where waste is transformed into valuable resources such as energy, fuels, and raw materials.

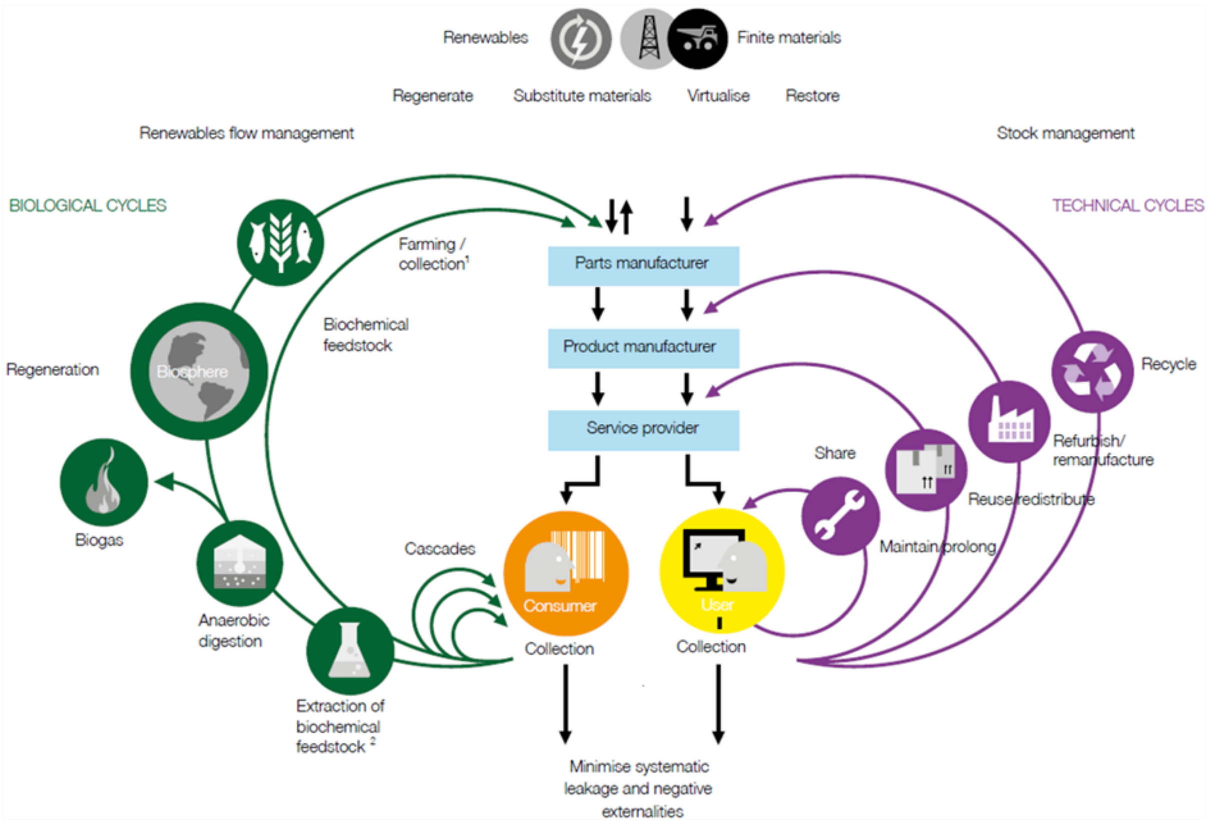

Figure 2. 1: Scheme of Circular Economy (MacArthur, 2013)

CE has gained global recognition, with the European Commission (Reike et al., 2018) and UK Government's Resources and Waste Strategy (Kępys & Jaszczura, 2020) advocating for its implementation. However, some NGOs and scholars argue that certain WtE technologies, particularly incineration-based energy recovery, contradict CE principles, as they rely on waste as a fuel source rather than fully eliminating waste (Cucchiella et al., 2016; Zero Waste Europe, 2016).

Despite these critiques, Hoornweg & Bhada-Tata (2012) highlight that WtE offers a more sustainable alternative to landfilling, reducing methane emissions and supporting

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energy security. Thus, CE provides a valuable framework for analyzing the integration of WtE technologies within sustainable waste management.

2.4.2 Industrial Ecology (IE) as a Complementary Framework

Industrial Ecology (IE) is a systems-based approach that views industrial systems as analogous to natural ecosystems, where waste from one process becomes input for another (Graedel & Allenby, 1995). It focuses on material and energy flows within industrial networks, advocating for closed-loop production cycles that minimize environmental impact.

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Applying IE to waste management aligns with CE principles, but it provides a more structured methodology for analyzing interconnections between industries, energy systems, and waste streams. In the context of WtE, IE can:

- Map material and energy flows within waste systems to optimize resource efficiency.
- Encourage symbiotic industrial relationships, where waste from one sector fuels energy generation in another.
- Assess life-cycle impacts of WtE processes to ensure sustainability.

IE strengthens the practical implementation of CE principles, offering a quantitative and systems-oriented approach to waste valorization and energy recovery.

2.4.3 Socio-Technical Transition (STT) Theory and Its Limitations

The Socio-Technical Transition (STT) Theory explores how new technologies and sustainable practices emerge within complex social, economic, and institutional systems (Geels, 2002). It emphasizes the role of policy, stakeholder engagement, and

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innovation adoption in transitioning from traditional waste disposal to advanced WtE solutions.

While STT offers insights into the barriers and drivers of adopting WtE technologies, it is less applicable to the core analytical framework of this study, which focuses on waste flows, energy recovery efficiency, and economic feasibility. However, elements of STT may be useful in policy recommendations and stakeholder engagement strategies.

2.4.4 Justification for Choosing CE and IE

Based on this comparative analysis, Circular Economy (CE) and Industrial Ecology (IE) are the most suitable theoretical frameworks for this study. Their selection is justified as follows:

1. CE provides a broad sustainability perspective, guiding the transition from a linear waste economy to a regenerative system.
2. IE enhances the technical and industrial feasibility of WtE by mapping energy and material flows and optimizing resource efficiency.
3. Both frameworks align with global best practices in waste management and Ghana's policy ambitions for a net-zero carbon economy by 2050 (Tahiru et al., 2024a; Tahiru et al., 2024b; Tahiru et al., 2024c).

By integrating these theories, this study enhances the existing understanding of waste management and WtE's role in sustainable development, contributing to a holistic and evidence-based framework for Ghana's transition towards a low-carbon, resource-efficient economy.

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2.5 The Global Perspective on Waste Generation and Composition

An essential part of contemporary life is waste generation, which is defined as the production of non-hazardous solid substances or objects, mostly in urban settings (Zambrano-Monserrate et al., 2021). Except for wastewater sludge, it includes a vast array of materials and objects. Although MSW has universally consistent basic components, production, density, and the relative amounts of different garbage streams differ greatly among nations (Sharma et al., 2020). Income, lifestyle, cultural norms, geography, and weather are some of the many elements that impact this variation (Chen, 2018; Havukainen et al., 2017; Saja et al., 2021). Access to accurate data regarding garbage production rates and garbage characteristics is crucial for effective waste management and resource recovery (Adenuga et al., 2020; Hameed et al., 2021; Iqbal et al., 2020). According to Asare et al., (2020), this data is crucial for the design and operation of waste management systems. While there are worrying trends in waste generation worldwide, developing countries have it especially bad when it comes to managing MSW. For example, many developing countries have a hard time getting their hands on complete and accurate data about MSW, which makes it hard for them to create effective waste management plans (Asare et al., 2020).

Due to regional differences in consumption habits, it is difficult to generalize about future patterns of MSW creation (Asare et al., 2020). Urban population and economic conditions are the primary determinants of MSW quantity, according to (Sharma & Jain, 2020). However, correctly estimating garbage production is a challenging undertaking, especially in developing countries' fast-growing metropolitan areas (Jain et al., 2022). Important data on things like demographic and economic indicators are

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hard to get by, which leads to the problem outlined before (Jain et al., 2022). As a result, inadequate data on MSW generation and characteristics hinder waste management strategy and activity planning and execution (He et al., 2022). There is cause for concern since the current pattern of MSW generation around the world shows an exponential rise. According to (Statista, 2016), the current annual global levels of MSW creation are around 1.3 billion metric tonnes. According to the projections (see Tables 2.1 and 2.2), this quantity is predicted to climb sharply, reaching almost 2.2 billion metric tonnes per year by 2025.

Table 2. 1: Disparities in Regional Waste Generation by Population

Region	Per Capita Waste Generation		
	Lower limit	Upper limit	Averag e
Africa (AFR)	0.09	3.01	0.65
Eastern Asia and the Pacific Region (EAP)	0.44	4.32	0.95
Region of Europe and Central Asia Region (ECA)	0.29	2.11	1.10
Region of Latin America and The Caribbean (LCR)	0.11	5.52	1.11
The Geographic Area Comprising the MENA States	0.16	5.71	1.12
Organisation for Economic Cooperation and Development (OECD)	1.10	3.70	2.23
Area of South Asia (SAR)	0.12	5.13	0.45

Source: Hoornweg & Bhada-Tata, 2012

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Table 2. 2: Waste generation projections for 2025 by regions.

Regin	Current status			Forecast for 2025			
	Total urban population (millions)	Urban waste generation		Projected population		Projected urban waste	
		Per capita (kg/capita/day)	Total (tons/day)	Total population (millions)	Urban population (millions)	Per capita (kg/ capita/ day)	Total (tons/day)
AFR	260	0.65	169,119	1,152	518	0.85	441,840
EAP	777	0.95	738958	2124	1229	1.50	1,865,379
ECA	227	1.10	254,389	339	239	1.50	354,810
LCR	399	1.11	437,545	681	466	1.62	728,392
MENA	162	1,12	173,545	379	257	1.43	369,320
OECD	729	2.23	1,566,286	1,031	842	2.11	1,742,417
SAR	426	0.45	192,410	1,938	734	0.77	567,545
Total	2980	1.09	3,532,252	7,644	4,285	1.39	6,069,703

Source: Hoornweg & Bhada-Tata, 2012

Within the next eight years, the growth should lead to a considerable spike in the rates of waste generation per capita, rising from 1.1 to 1.42 kilogrammes per individual per day. In emerging nations, waste management's complexity will increase only if appropriate measures are not put in place to address this expanding challenge. The reason behind this is the increasing tendency of people to move from rural areas to cities, as pointed out by (Porru et al., 2020). In terms of garbage generation per capita, (Noufal et al., 2020) found that high-income countries had significantly higher rates, whereas low-income countries had significantly lower rates. Variations in commercial and industrial operations leading to different rates of waste production are the primary cause of the observed discrepancy. Furthermore, there is a strong relationship between

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waste production and economic prosperity, as demonstrated in Table 2.3, which is based on the Gross Domestic Product (GDP) (Munir et al., 2021).

Table 2. 3: Income Levels and Their Impact on Per Capita Waste.

Level of Income	Quantity of waste generation per capita (kg/c/day)		
	Bottom limit	Top limit	Average
High	0.70	14	2.1
Upper middle	0.11	5.5	1.2
Lower middle	0.16	5.3	0.79
Lower	0.09	4.3	0.60

Source: Scarlat et al., (2019)

Effective decoupling of waste management from economic expansion is crucial for ensuring long-term survival. Scarlet et al., (2019) noted that some European nations have decreased their rates of MSW creation through implementing regulations like Directive 2008/98/CE on MSW. From 1995 to 2015, Table 2.4 shows that Bulgaria, Romania, Slovenia, and Norway all saw decreases ranging from 3% to 40%. However, during the same period, the output of MSW surged in several European countries, including Greece, Denmark, Latvia, and Malta. These cases show how the growth of the economy can be decoupled from garbage creation. There was disconnect between the increase in municipal garbage and economic growth in the OECD region, according to 2007 data from the European Environment Agency (EEA). Specifically, according to Komarnicka & Murawska's 2021 study, there was a surge of around 58% (2.5% per year) from 1980 to 2000, and then a subsequent decline to 4.6% (0.9% per year) from 2000 to 2005. The data provided above suggests that even with ongoing obstacles, it is possible to achieve more sustainable waste management via effective WtE techniques.

While several European nations have managed to lower their solid waste generation rates, emerging nations are facing a crisis because of fast industrialization and inadequate infrastructure, leading to an increase in garbage output (Dutta et al., 2021). Given this context, it is necessary to incorporate comprehensive solid waste management strategies into these nations' development plans (Doaemo et al., 2021). After exploring the global perspective on solid waste creation, it is critical to investigate the composition of MSW and the factors that influence its composition. The waste composition, on the other hand, is the breakdown of a stream's components by weight (Von Massow et al., 2019; Roosen et al., 2020). Similar to how factors, including but not limited to cultural norms and economic activities, affect the formation of MSW, they also have an impact on waste composition (Sebastian et al., 2020). Figure 2.2 shows that when cities expand and economies develop, inorganic resources like plastic and aluminum are used more frequently, while organic materials make up less of a share of the total (Alkarimiah et al., 2022). When comparing the massive amounts of organic waste created by emerging nations to the relatively small amounts of inorganic garbage produced by wealthy ones, the aforementioned pattern becomes readily apparent. So, according to (Hoang et al., 20220, there are primarily two types of MSW streams: organic waste and inorganic garbage.

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Table 2. 4. Annual municipal waste production for a number of European nations

EU Countries	Year basis (kg/capita)					
	1995	2000	2005	2010	2015	Percentage Change (%) 1995 – 2015
The nation Belgium	455	471	482	456	418	-8
The nation of Bulgaria	694	612	588	554	419	-40
The nation of Denmark	521	664	736		789	52
The nation of Estonia	371	453	433	305	359	-3
The nation of Greece	303	412	442	532	485	60
The nation of Malta	387	533	623	601	624	61
The nation of Netherlands	539	598	599	571	532	-3
The nation of Norway	624	613	426	469	421	-33
The nation of Romania	342	355	383	313	247	-28
The nation of Spain	505	653	588	510	434	-14
The nation of Slovenia	596	513	494	490	449	-25
The nation of Turkey	414	465	458	407	400	-9
United Kingdom	498	577	581	509	485	-3

Source: Starovoytova, (2018)

The percentage of organic matter in urban waste streams in low-income nations is often rather high, ranging from forty percent to eighty-five percent. Paper, plastic, glass, and metal are the main components of waste streams in high-income countries, as pointed out by (Alkarimiah et al., 2022). For instance, according to (Starovoytova, 2018), the OECD countries have the lowest percentage of organic waste at 27%, while the East Asia and Pacific Region has the greatest proportion at 62%. Ife-Adediran

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(2019) states that glass (7%), metals (6%), and paper (32%) make up the largest percentages of MSW in OECD countries. Compared to other regions, South Asia has the lowest percentages for paper (4%), glass (1%), and metals (1%). Sub-Saharan Africa, on the other hand, has a disproportionately high percentage of organic waste (57%) in its MSW (Debrah et al., 2022). Table 2.5 displays data on the composition and generation rates of MSW in specific African urban regions, illustrating the heterogeneity in waste content. Academics agree that whereas developed nations have a higher percentage of inorganic solid waste in their MSW streams, developing nations have a higher percentage of organic waste. The organic fraction is crucial because, if not controlled, it could have negative impacts on human health and the environment. In a study conducted by (Maurice et al., 2022), it was found that organic waste can be a food and shelter source for rodents and vector insects. kwun Omang et al., (2021) emphasized that improper solid waste disposal, especially at open dumps, can lead to the release of harmful gases, aesthetic damage, and the production of unpleasant odours. These issues are not confined to the disposal sites, but rather affect the entire area. As a result, waste-to-energy (WtE) solutions must be put into place to ensure the effective management and removal of organic waste. Planning, managing, and implementing sustainable waste-to-energy technology relies heavily on accurate predictions of MSW generation and composition (Kuznetsova et al., 2019). According to Sharma & Jain, (2020), the content and pace of waste generation have a major impact on the methods chosen for solid waste collection, recovery, processing, treatment, and subsequent disposal. Inadequate assessment and prediction of MSW production and composition pose significant challenges in a number of developing

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nations, including Ghana. Many factors contribute to the issues, including unreliable data, societal and economic effects, limited technical skill, regulatory limits, and institutional restraints.

Table 2. 5: MSW composition and generation in some selected cities in Africa

City	Country	Per capita GDP (US$) (World Bank, 2016)	Population of city (millions)	Generation rate kg/p/day	Organics (%)	Inorganics (%)	Inert (%)	Miscell a-neous (%)	Source
Cairo	Egypt	3.514.5	7.73	1.3	56	34.7	9.4	-	Zaki et al., (2023)
Cape town	South Africa	5,273.6	3,34	0.7 – 1.3	47	32	21	-	Baloyi et al., (2012)
Lagos	Nigeria	2,178.0	9.00	0.5	53	39	8	-	Ojo and Bowen (2014)
Nairobi	Kenya	1,455.4	2.75	0.6	65	21	14	-	Okot-okumu (2012)
Feetown	Sierra leone	496.0	0.80	0.56	59.2	10.2	19.9	-	Sankoh et al., (2012)
Accra	Ghana	1,513.5	1.96	0.74	65.8	25.7	5.2	4.1	Meiza te al., (2015)

2.6 The Nature and Quantity of Ghana's Solid Waste

The amount Insufficient and unreliable national statistics on solid waste composition and generation impede Ghana's efforts to plan effectively for waste management. The amount and composition of garbage produced within the country have been the subject of numerous studies. A generation rate of 0.47 kg/person/day was noted in a study carried out by (Miezah et al., 2015) in various cities within Ghana. That works out to over 4 million tons annually and 12,710 tons daily. Due to population expansion, this generation rate is expected to see an upward trend. Stafford. (2020) reports that in Accra, Ghana, people with higher incomes generated 0.6 kg more garbage per day than those with lower incomes. Those in the medium income bracket produced 0.4 kg of

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garbage per capita per day, while those in the lowest income bracket produced only 0.3 kg. Vittin is a high-income neighborhood in the Tamale Metropolis, and according to (Denteh et al., 2018), its residents generate 0.33 kg of waste per day. Analyses of garbage from several municipalities in Ghana have shown that organic materials make up a sizable portion of the solid waste. Also, as shown in Figure 4, research carried out in certain regions of Ghana by (Miezah et al., 2015) found that organic materials made up about 61% of the total solid waste produced in the country. Owusu-Nimo et a., (2019) performed waste characterization tests at the Kumasi Metropolitan Assembly's (KMA) ultimate disposal site and found that organic waste made up about 40.32 percent of the total garbage. Gyimah et al., (2021) found that organic garbage made up 54.4% of the total household waste in the senior and junior staff residential area of Cape Coast University (UCC). With percentages ranging from 1.1% to 31.4%, other waste kinds, such as plastics, paper, textiles, metals, and glass, made up smaller shares. Municipal solid waste was characterized and quantified in studies carried out in the Takoradi Sub-Metro. Biodegradable materials made up 60.0% of the solid waste, plastics 11.5%, inert materials 8.0%, paper and cardboard 7.1%, miscellaneous materials 5.0%, textiles 2.9%, metals 2.4%, glassware 1.5%, and leather and rubber 1.2%, according to the findings (Seshie et al., 2020). Otoo. (2022) found that in three communities within the Eiisu-Juaben municipality in Ghana, the amount of organic waste was more than 30%.

Researchers examined the make-up of solid waste that washed up on the beaches of Ghanaian coastal lagoons (Nukpezah et al., 2022). The results showed a somewhat different distribution of litter categories, with plastic making up half of the solid waste,

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organics coming in at 20%, paper at 10%, textiles at 10%, and other random stuff at 10%. Previous studies have shown that there is no statistically significant relationship between seasonal changes and the make-up and amount of household garbage. However, there are seasonal changes that impact the amount of outdoor garbage, particularly yard waste; one important factor is the rate of pruning (Addae et al., 2021). In addition, multiple studies have shown that different socio-economic classes in rural and urban locations generate solid waste at varied rates. The daily waste generation rates in high-class, middle-class, and low-income districts were 0.56 kg, 0.49 kg, and 0.47 kg, respectively, according to (Miezah et al., 2015). Safo-Adu et al., (2023) found that different socioeconomic strata in the Kumasi metropolitan region generated different amounts of rubbish on a daily average. Values for low-class areas were 0.47 kg/day, 0.49 kg/day for middle-class areas, and 0.56 kg/day for high-class areas. According to Asare et al., (2021), solid waste management techniques are implemented based on the diversity of waste and volumes. The logical conclusion is that methods of waste management that work in one setting might not work in another. Since different types of waste have different properties and are generated in different ways, it is crucial to consider these factors when choosing methods for solid waste management, such as alternatives to waste-to-energy (WtE) technology.

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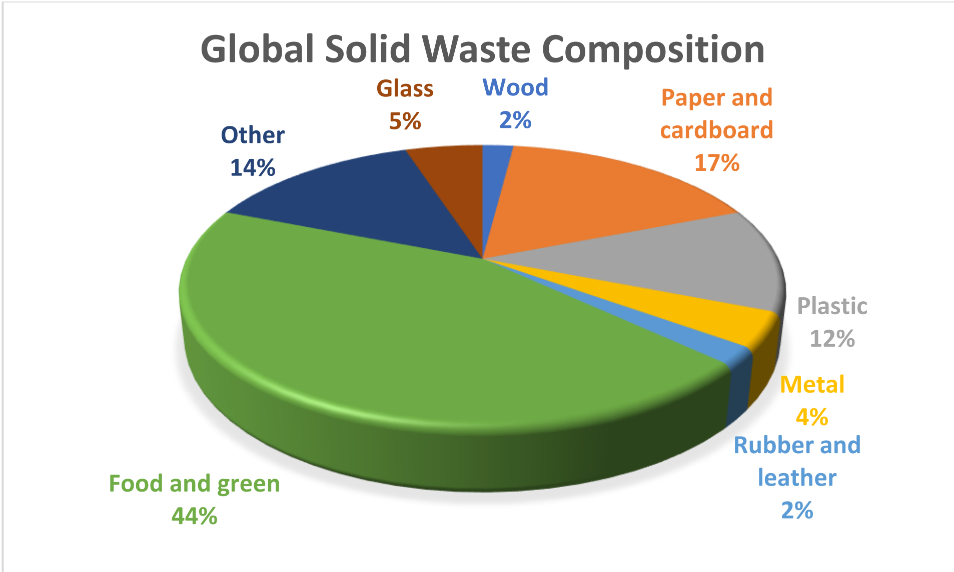

Figure 2. 2: Global solid waste composition

(source: Authors construct, data from Kaza et al., 2018)

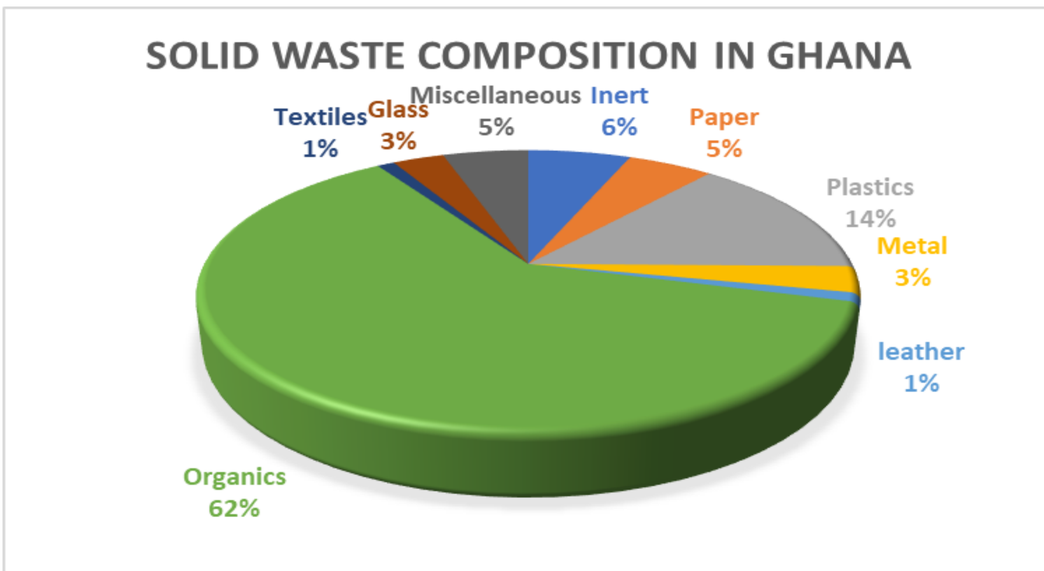

Figure 2. 3: Solid waste composition in Ghana

(source: Authors construct, data from Meizah et al., 2015)

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2.7 Solid Waste Management in Tamale

The current municipal solid waste (MSW) management in the Tamale Metropolis is characterized by several challenges. Indiscriminate disposal, insufficient waste collection and transportation, and open dumping are the main practices, with most waste being openly dumped without pre-treatment (Asare et al., 2021). Additionally, the waste management bodies in Tamale collect only 7.5 tonnes of MSW per day, leaving a backlog of 142.5 tonnes per day (Issahaku et al., 2014). There is minimal provision of MSW disposal infrastructures and communal collection containers (Bowan et al., 2020). Furthermore, a major challenge to effective MSW disposal in Ghana and other developing countries is the non-segregation of wastes at the various generation sources and throughout the waste management chain (Adedara et al., 2023; Zhang et al., 2022; Kassah, 2020). This is despite the significant stake of recyclable materials in the waste composition, which comprises both hazardous and non-hazardous waste.

As an illustration, in Tamale, mixed municipal solid waste (MSW) is often stored in single bins, improperly disposed of (e.g., burned, buried, or dumped in bushes), or collected through door-to-door services and communal containers before being openly dumped at an unregulated landfill site (Ramli et al., 2021; Asare et al., 2021). This system has detrimental environmental and public health consequences, including pollution of natural resources, ecological damage, and long-term health complications (Alabi et al., 2019; Chu, 2019; Akoto-Bamfo, 2020). While informal material recovery by scavengers and metal waste merchants partially mitigates the impact and provides livelihoods (Singh, 2021), there is no formal waste recovery or recycling system in

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place. As in many developing countries, informal recovery diverts some materials from the municipal waste stream (Khan et al., 2022; Cole et al., 2019). Therefore, implementing formal waste segregation, recovery, and recycling programs could significantly reduce the amount of MSW requiring disposal, thereby mitigating the adverse effects of current practices. Given these challenges, Tamale urgently needs to expand and invest in innovative waste management strategies, such as waste-to-energy (WtE) technologies.

2.8 Resource recovery

While waste prevention and waste reduction are important and are prioritised before resource recovery in the waste hierarchy (Tahiru et al., 2024), this current research addresses resource recovery and in particular energy recovery as necessary steps for sustainable management of the waste that has been generated. A change in paradigm regarding waste as a resource, and not just something to be disposed of, is the key to sustainable waste management practice (Wilts et al 2016). Resource recovery includes material and energy recovery. In less economically developed communities and developing countries recycling may be done informally by householders separating certain valuable components of mixed waste, such as glass and plastic bottles and metal cans, to sell to recyclate buyers; or by scavengers collecting from the streets and dumpsites. In more economically developed communities and developed countries recycling is more formalised, and materials are collected by systems with varying degrees of householder participation in source segregation and advanced technology in waste segregation facilities, such as materials recovery facilities (MRF). Energy recovery practices are generally more prevalent in more economically developed

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communities and in communities in colder climates as heat and electricity are produced. For instance, in Thailand in 2011, 3.39 million tonnes or 21.21 % of MSW was recycled, 0.12 million tonnes or 0.75 % of MSW utilised in electricity generation or as fuel alternative, and 0.59 million tonnes or 3.69 % composted or used in biogas generation (Pollution Control Department, 2012). In England in 2011/12, 43 % of MSW was recycled or composted, 14 % of MSW incinerated with energy recovery (Powell et al., 2012). In the USA in 2011, 34.7 % of MSW i

was recycled or composted, and 11.7 of MSW % incinerated with energy recovery (Cho et al., 2020). In the EU in 2009, 59 million tonnes or 23.5 % of MSW is recycled, 45 million tonnes or 17.9 % composted and 51 million tonnes or 20.3 % of MSW incinerated with energy recovery. Sweden, an EU member state with advanced environmental technology and the political will to implement good practice, as demonstrated by a ban on the landfilling of combustible waste, has a high rate of 49% energy recovery from MSW in 2009 (Nugent et al., 2019).

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2.8.1 Energy from Waste

With policies to reduce waste entering landfills and to increase renewable energy sources, local authorities in many nations are turning toward waste-to-energy (WtE) conversion technologies. The current commercially available WtE conversion technologies include thermal processes such as incineration, pyrolysis, gasification; and biological processes such as anaerobic digestion and landfill gas recovery. Mechanical biological treatment (MBT) and mechanical-heat treatment (MHT) are pre-treatment methods that separate the MSW to reduce the volume of waste entering the landfill (Geelani et al., 2020) as well as to separate the waste residue for refuse

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derived fuel (RDF) or solid recovered fuel (SRF) production for thermal processing. Historically, incineration or mass burn of MSW is the most common method of energy recovery and is widely used in Western Europe, the USA, China, and Japan. In 2016, the number of WtE facilities for MSW reached 1618 plants worldwide, including 512 plants in Europe, 822 plants in Japan, 88 in the United States and 166 in China (Smol et al., 2020). The United States generated 258 million tonnes of MSW in 2014, of which 136 million tonnes were landfilled, 89 million tonnes were recycled and composted, and 33 million were burned with energy recovery. The installed WtE capacity in that year reached the total of 2.5 GW and resulted in a production of 14,310.2 GWh of electricity (Leckner et al., 2015). Landfilling in the United States is a more viable option due to the lowest economic cost compared to other MSW facilities. On the other hand, incineration is predominant in Japan due to the land (e.g., availability of land areas) and environmental constraints (e.g., pressure for decreasing landfilling waste volume) as well as for energy production.

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Waste incineration technology was introduced in China in the late 1980s, and the number of incineration plants has increased significantly since then. Between 2013 and 2014, the WtE total capacity reached 46 million tonnes a year (Alao et al., 2020) and the power generation 18.7 billion kWh, accounting for 1.2% of total RE production. However, most of the household waste is still deposited in landfills (105 million tonnes annually) or incinerated (46 million tonnes annually) without energy recovery. In Europa, Germany, France, and UK are the leading countries on energy recovery from MSW resources.

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In terms of specific applications, Defra, in the UK, set up the New Technologies Demonstrator Programme (NTDP) in 2003 to encourage development of new technologies for reducing biodegradable waste entering the landfill and for resource recovery. The aim of the programme was to help local authorities implement these technologies to divert waste from landfills by establishing pilot plants (Brooks and Powrie, 2007). Among these pilot plants, two plants with energy recovery which continued operation after the trial were the Waste Gas Technology UK Limited in Isle of Wight using gasification and the Biocycle South Shropshire Biowaste Digester in Ludlow, Shropshire using anaerobic digestion (Brooks and Powrie, 2007). The gasification plant on the Isle of Wight using Energos technology was completed in 2008. The plant has a capacity of 30,000 tonnes/year of municipal waste and can generate 2.3 MW of electricity. In 2010 the emissions exceeded the dioxin standards and there was a temporary shutdown. It was discovered that the problem was due to contamination remaining in the system since the plant was retrofitted to an old incinerator and flue gas cleaning system. After modifications, the gasification plant is operating normally (Murrant et al., 2017). The anaerobic digestion plant at Ludlow can treat 5,000 tonnes/year of food waste. In the pilot period the plant received food waste from the local council's household waste collection service. In 2010 the contract ended due to the council changing to a fortnightly collection system. The plant continued to operate with food waste from other local councils and commercial sources. In September 2012 operation was suspended when the contracts ended. In August 2013 the Cwm Harry Land Trust, an environmental charity, announced plans to resume the operation of the anaerobic digestion plant (Tawatsin, 2014).

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2.9 Waste to Energy conversions

As outlined in the previous section, Ghana relies heavily on open dumping and landfilling as primary waste management methods. However, with waste generation steadily increasing across the country, there is an urgent need for municipal authorities to reassess and improve waste management strategies. Now is the time to explore waste-to-energy (WtE) solutions as a sustainable approach to addressing Ghana’s growing waste challenges. According to the (Energy commission, 2021), an estimated 152.34 gigawatt-hours (GWh) of electrical energy was projected to be generated from renewable energy sources in 2021. Additionally, fossil fuels primarily fuel electricity production in Ghana, providing energy for electricity-generating facilities such as thermal sources, which account for nearly 70% of power production in Ghana (Afful-Dadzie et al., 2020). Given this context, waste presents an immensely appealing alternative fuel source due to its relatively eco-friendly nature and local availability.

In the present investigation, we zeroed in on a few key biochemical and thermochemical processes: anaerobic digestion, incineration, gasification, and landfill gas. We chose these specific technologies because of how far along they are in their development and availability of data on them in the context of Ghana (see Figure 6). Furthermore, according to the literature (Miezah et al., 2015; Addae et al., 2021; Osei-Appiah, & Dioha, 2019; Amo-Asamoah et al, 2020), the physical and chemical features of Ghana's MSW permit the implementation of these WtE conversion procedures.

Broadly, there are two main routes to convert MSW to energy: the thermochemical processes (incineration, pyrolysis, and gasification) and the biochemical processes

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(anaerobic digestion and landfilling with biogas recovery) (see Figure 2.4). As shown, each technological process may yield different valuable products as summarized in figure 2.5. Thermochemical processes employ high temperatures to change the molecular structure of the waste materials to produce heat, gas or oil (Nixon et al., 2017). The main differences between the thermal processes considered are the amount of oxygen fed into the system; incineration requires excess oxygen, whereas gasification requires limited oxygen, pyrolysis, however, requires no oxygen. As such, the quantity of oxygen fed to the system determines the main products obtained from each process as shown in equation (2.1) to equation (2.3) (Leckner, 2015).

Incineration: Biomass+excess $O_2 \rightarrow O_2 + H_20$ (2.1)

Gasification: Biomass+limited $O_2 \rightarrow$Syngas ($CO+H_2$) (2.2)

Pyrolysis: Biomass+Heat →Charcoal, Bio-oil, gas (2.3)

Heat is the main useful product obtained from the incineration process, whereas the gasification process produces both heat and syngas (mainly carbon monoxide and hydrogen) which is a high value fuel gas. The main products obtained from pyrolysis are charcoal, bio-oil and gas. In this case, the percentage of each product depends on the operating conditions (Leckner, 2015). The biochemical or biological processes generate biogas from the decomposition of waste by microorganisms. The main products obtained from this type of process are biogas, which is composed of methane and hydrogen. There is also some ethanol and butanol obtained from the process (Nixon et al., 2017). Further details are Summarized in the Schematic Diagram below (Figure 2.5).

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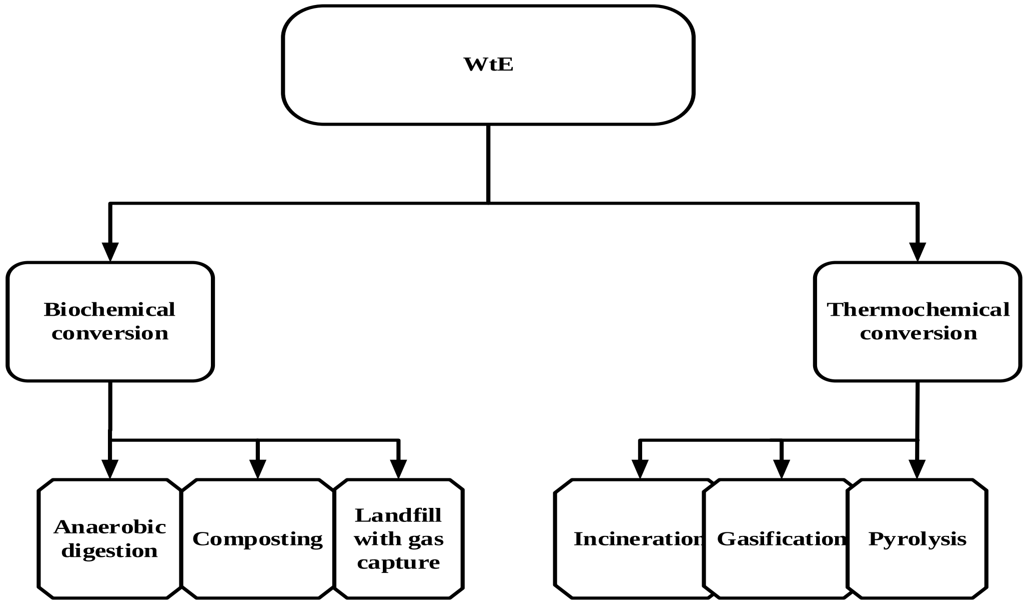

Figure 2. 4: waste-to-energy technologies (Leckner, 2015)

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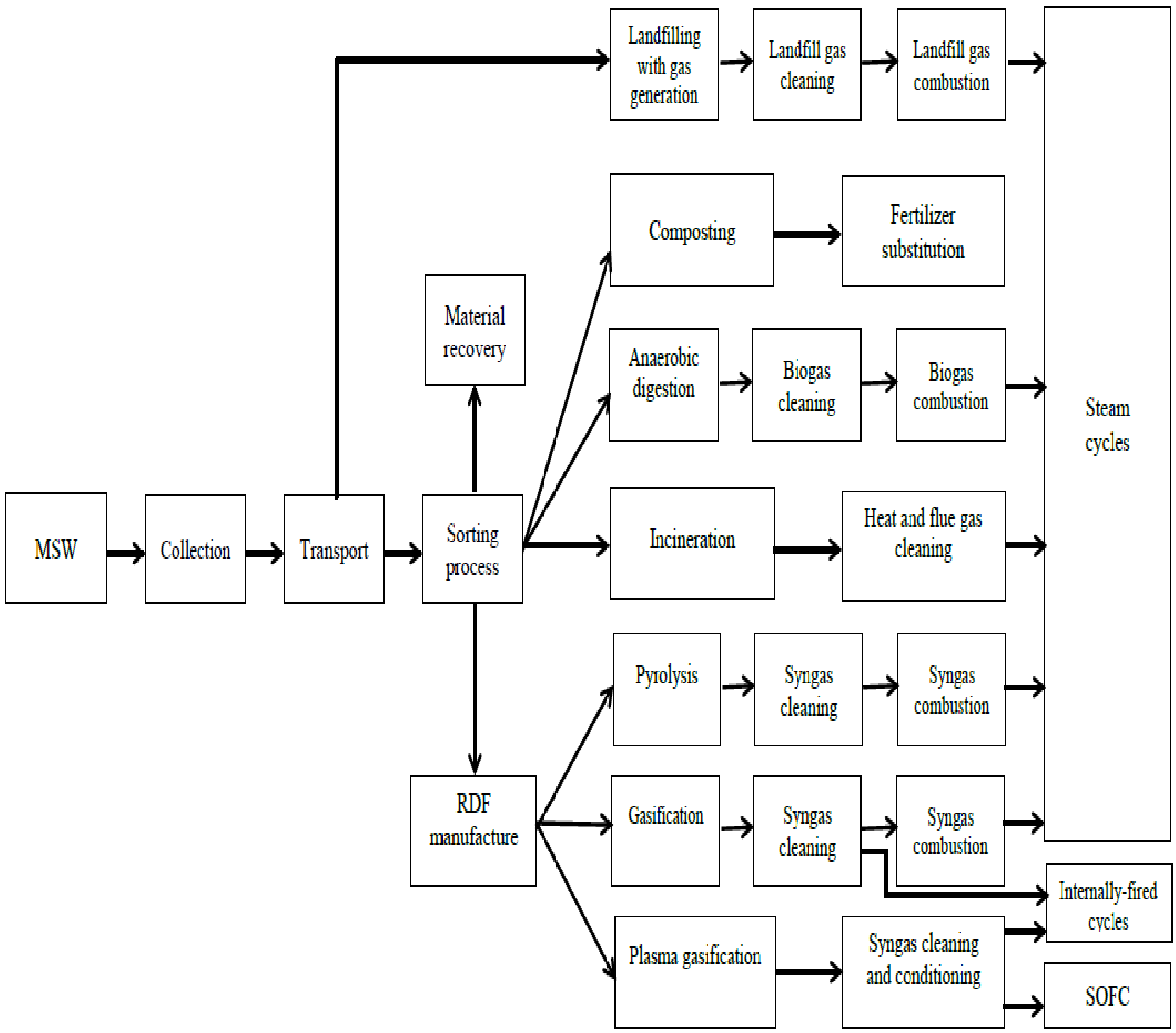

Figure 2. 5: A Summarized Schematic Diagram of Each WtE Process and Their Respective Products

(Source; Schafer et al., 2019)

2.10 Adoption and Implementation of WtE Technologies

2.10.1 Technical and environmental impact of WtE technologies

When compared to more traditional waste management practices, such as open burning or unregulated landfilling, WtE technologies significantly reduce emissions

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of greenhouse gases, including carbon dioxide, which contribute to climate change. Incinerating MSW in a thermal WtE plant reduces the release of around 1,010 kg of CO_2 per tonne of solid waste into the environment. This is especially true when biogenic carbon emissions from landfill methane gas are not considered. CO_2 emissions from incinerators stand at 1.188 kg of CO_2 per kWh, while gasification plants exhibit lower emissions, approximately 0.855 kg of CO_2 per kWh. Anaerobic digestion plants contribute around 0.05–0.5 pound of CO_2 per kWh of electricity generated, and landfill gas recovery systems release 0.6 pound of CO_2 per kWh (EPA. 2016). Among these WtE technologies, anaerobic digestion stands out as the most environmentally friendly. It is reported that gasification, pyrolysis, and anaerobic digestion are 33%, 65%, and 111% more environmentally sustainable, respectively, than direct combustion, according to findings by (Kabir & Khan, 2020).

Regarding the repurposing of byproducts, incinerators usually recycle bottom ash to recover important metals, and the remaining ash can be used to make aggregates for construction (Schafer et al., 2019). In the case of anaerobic digestion, the primary by-product is digestate, a nutrient-rich material suitable for use as a fertiliser (Aso, 2020). Gasification primarily results in ashes alongside the generated syngas. The by-products of landfill gas (LFG) can exhibit considerable variability based on several specific parameters employed in the process, including feedstock type, waste age, landfill age, oxygen levels, moisture content, and temperature. Primary by-products of LFG plants typically include bottom ash and digestate. Bottom ash can undergo recycling to extract valuable metals, and the remaining ash is a viable option for construction materials, notably aggregates. Digestate, on the other hand, serves as a

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nutrient-rich material suitable for use as a fertiliser (Duan et a., 2021). Saha & Singh. (2020) detail the usual capacity scales for each waste treatment method, as follows: As an example, (1) incinerating waste can treat 1500 metric tonnes per day; (2) gasifying waste can effectively manage 10 and 100 metric tonnes per day; (3) anaerobic digestion can handle approximately 500 metric tonnes per day; and (4) it is estimated that a typical African landfill can treat approximately 8 x10-4 tonnes of waste per day, which could be used for LFG production and utilisation. While plant size has a direct bearing on production capacity, these numbers give a rough idea of the global average for facilities that are currently available and functional. In terms of technological advancement, landfill gas and waste incineration are the most developed processes, followed by anaerobic digestion; gasification, however, is still in its nascent phase (Din et al., 2021).

The efficiency of energy production varies across technologies due to factors such as thermodynamic cycles, plant scale, feedstock type, and optimisation techniques (Roopnarain et al., 2021). Using steam turbines, traditional incinerators have an electrical efficiency range of 15–30% (Tugov, 2015). For heating purposes, incinerators can achieve efficiencies of up to 90%, while those for combined heat and power are closer to 40% (Tugov, 2015). Maximum efficiency for biogas production using anaerobic digestion is 28% (Beegle & Borole, 2018), and if the efficiency of a gas turbine is 30% to 40%, the overall efficiency range could increase by 8.4 to 11.2%. Depending on the type of turbine used, gasification technology can achieve efficiencies of 10–27%, or 30–40% for advanced gasification Roy et al., (2022). In most cases, a gas turbine can be used to convert landfill gas into electricity. Based on

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their findings, Ayodele et al., (2018) agree that landfill gas is rich in methane (40–60%) and thus has great potential for power generation (58%) and should be treated as a valuable resource. In terms of feedstock or waste types, incineration stands out for its ability to process a wide range of waste types. Gasification and pyrolysis plants also hold promise for treating diverse waste types with fewer environmental impacts and lower costs than incineration, but they are less advanced. On the contrary, landfill gas and anaerobic digestion are more limited, unable to handle non-biodegradable materials such as plastics (Kępys & Jaszczura, 2020). Notably, while WtE technologies boast positive impacts, they also leave some negative footprints. For instance, the process of incinerating waste releases pollutants such as dioxins, furan, ash, heavy metals, among others, jeopardizing land and air quality (Din et al., 2021). Landfills, linked to WtE through gas recovery, pose concerns for soil and groundwater contamination. Other WtE technologies like anaerobic digestion, which is scientifically proven to be a more environmentally benign technology, have their negative aspects, including but not limited to methane emissions and odorous releases into the atmosphere. Gasification, converting waste to syngas, reduces landfill waste but raises concerns about air pollution and methane emissions, akin to incineration (Abdul–Wahab and Takase, 2019; kwun Omang et al., 2021; Saha & Singh, 2020).

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2.10.2 Socio-economic impact of WtE technologies

The construction and operation of WtE plants can provide local communities with direct, indirect, temporary, and permanent employment opportunities (Kabir & Khan, 2020). Islam (2016) estimates that 100 people can be employed at a waste-to-energy generation plant of moderate capacity in a developing country.

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2.10.3 Environmental-health risks associated with existing solid waste management strategies

Ghana, a nation undergoing rapid urbanization and economic growth, faces a mounting challenge – the inadequate management of its solid waste. This seemingly mundane issue has far-reaching consequences, posing significant environmental and health risks to its citizens. The crux of the problem lies in outdated management practices. Waste collection systems struggle to keep pace with population growth, resulting in overflowing bins and open dumping. These dumpsites become breeding grounds for harmful bacteria and vectors, releasing a cocktail of pollutants into the air, soil and surrounding water sources (Tahiru et al., 2024). A 2019 study by the Ghana Water Company revealed that over 40% of water treatment plants exceeded safe levels of contaminants linked to improper waste disposal (Anyame et al., 2022). Air pollution is another threat. Open burning of waste releases harmful toxins like dioxins and particulates, contributing to respiratory illnesses like asthma and bronchitis (Lu et al., 2019).

The repercussions extend beyond the environment, directly impacting public health. For instance, The World Health Organization estimates that ambient air pollution alone claimed over 29,000 lives in Ghana in 2019 (WHO, 2020). A 2018 report by the Ghana Health Service indicated a worrying 20% increase in malaria cases linked to improper waste management in urban centers (Ghana health service, 2018). Furthermore, exposure to fecal matter due to open defecation and overflowing waste can cause skin infections and diarrhoeal diseases, particularly amongst children (Abubakari et al., 2021). A 2021 study by the Kintampo Health Research Centre found

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a direct correlation between poor waste management practices and a surge in childhood diarrhoeal diseases in the surrounding communities (Abubakari et al., 2021).

The story is especially grim in urban centers like Accra and Kumasi. Here, densely packed communities generate vast quantities of waste daily. With limited collection capacity, overflowing drains and streets choked with garbage have become a common sight. This festering waste not only creates a breeding ground for disease but also exacerbates flooding during the rainy season, further contaminating water sources. The World Bank estimates that improper waste management costs Ghana $420 million annually in healthcare and lost productivity (Maina et al., 2012).

Beyond the immediate health risks, Ghana's current waste management practices threaten the long-term health of its environment. Open burning, a common practice for waste disposal, releases harmful pollutants into the atmosphere, contributing to respiratory climate change. Leachate, the toxic liquid produced by decomposing waste in landfills, can seep into the soil and contaminate groundwater, rendering it unfit for drinking or irrigation. This impacts human health and disrupts agricultural productivity, a vital sector for Ghana's food security.

As part of recent efforts to address this crisis, Initiatives like the Urban Health Initiative (UHI) were launched to promote sustainable waste management practices, aiming to create a "greener" waste sector (Odoi & Kleiman, 2021). However, their success hinges on overcoming significant obstacles such as inadequate funding, paucity in infrastructure and waste management logistics. Furthermore, the informal

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waste collection sector, which plays a crucial role in waste management, remains largely unintegrated into formal systems. These "waste pickers" often lack proper safety equipment and work in hazardous conditions, further exacerbating the health risks associated with waste management.

The path forward requires a multi-pronged approach. Comprehensive strategies, effective policies, and community involvement are essential for mitigating pollution, protecting public health, and ensuring a sustainable environment for future generations. Investing in waste-to-energy plants, promoting waste reduction and recycling initiatives, and empowering communities to adopt responsible waste management practices are all essential pieces of the puzzle. By prioritizing a holistic approach, Ghana can transform this looming crisis into an opportunity for a cleaner, healthier future for all its citizens.

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2.11 Barriers to WtE Implementation in Developing Countries

Although WtE technologies have been effectively adopted and implemented in certain developed nations, their utilization in developing countries is impeded by considerable challenges. The barriers encompass various dimensions, including logistical, technical, financial, socio-environmental, and policy aspects (Sharma et al., 2021). In terms of logistics, inadequate waste collection infrastructure and a lack of source segregation are major logistical challenges in developing countries, including Ghana. Developing countries also have a scarcity of technical data on waste quantity and quality. Analysis of waste composition, including physical and chemical properties, is critical for determining calorific value and moisture content, among other important properties of MSW feedstock (Shi et al., 2016). It is important to note that waste

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characterization knowledge gaps can lead to mismatched equipment and WtE technology choices, wasting both resources and time (Singhal et al., 2022).

WtE projects present significant financial challenges for developing nations to overcome. Not only do such projects demand substantial upfront capital investments, but ongoing operational costs are also difficult to sustain. For example, in Malaysia, incinerator operations were halted due to high expenditures on fuel and maintenance (Mansor et al., 2014). Socio-environmental concerns also pose barriers, as public opposition stems from worries over pollution and land use (Palmer et al., 2016). On the policy front, waste-to-energy legislation in many developing countries remains inconsistent or lacking (EPA, 2016). To reap the benefits of waste-to-energy, nations must address obstacles in the waste management sector. For instance, establishing strict tipping fees similar to the ones in developed nations could maximise diversion from landfills and ensure stable waste feedstock supply to WtE plants. Also, encouraging source-separated waste will improve calorific value while reducing the operating expenses of waste-to-energy plants. Additionally, expanding the technical analysis of existing waste streams, addressing financial and public concerns, and strengthening complementary policies aid in completing the framework for effective and sustainable deployment of waste-to-energy. Only through holistic solutions across interlinked challenges can waste-to-energy fulfil its potential to sustainably manage waste as a resource. Substantial coordination is required.

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2.12 Application of WtE technologies as waste management options

Significant progress has been made on the application of WtE technologies as waste management options and methods for producing cleaner energy in developed and developing countries. As a result of this, a vast number of studies (research articles and review papers) have been published on the applicability of WtE technologies for waste management as well as renewable and sustainable energy generation methods. For instance, (Mukherjee et al., 2020) presented a review on WtE technologies adoption in USA including their unique challenges. It was concluded that only 13% of MSW is used for energy recovery via mass-burn and refuse-derived fuel technologies from 86 facilities; and 53% is landfilled. In the work of (Sinhg et al., 2020), a review is presented on the challenges and health related issues for waste management in India including possibilities of energy recovery from the wastes. In Bangladesh, (Alam and Qiao, 2020) reviewed the current status of MSW management, treatment and disposal but little emphasis was paid to energy recovery from the MSW. It was pointed out that about 23,688 tons/day of MSW was generated in Bangladesh which contains about 70% organic solid waste with average moisture content and collection efficiency of 50% and 56%, respectively. A study by (Dlamini et al., 2019) focused on reviewing WtE technologies and their implications on sustainable waste management with particular attention to the City of Johannesburg, South Africa. In the work of (Nanda and Berruti, 2021), a review of thermochemical and biological methods of WtE is conducted with a view to analyzing the potential for energy and material recovery. A review on the limiting factors for sustainable municipal solid waste management (MSWM) in the BRIC (Brazil, Russia, India and China) countries vis-a-

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vis the historical transition to a sustainable level in some high-income countries was conducted by (Batista et al., 2021). In the work of (Fodor and Klemes, 2012), a review on design of WtE technologies as an alternative to produce energy carriers was presented. It is important to note that waste-to-energy technologies are a sub-set of waste management. While examining many articles, it was observed that most of the literature focused on waste management concerns, encompassing waste-to-energy technologies, their current state and applications worldwide. However, an evident gap emerged in the existing body of literature, specifically regarding a comprehensive evaluation of the suitability of waste-to-energy technologies in Ghana. This void in literature is noteworthy considering the substantial emphasis placed on municipal solid waste management through the adoption of WtE technologies globally.

2.13 Feasibility study of WTE plant operations in Ghana

The four major factors that justify the feasibility of electricity or energy production from MSW are (1) the amount of MSW generated, (2) characteristic and quality of the wastes, (3) the type of technology used for the energy production and (4) economic conditions of the location of the WtE plant. For instance, in 2010, Ghana produced about 4.5 million tons of MSW which could produce about 2 GWh electricity/year by controlled incineration and 1.0–1.5 GWh electricity/year by landfilling according to the Ghanaian MSW characteristics.

2.14 Best Practice Models for Waste-to-Energy Systems in Developing Countries

The Tamale metropolis in Ghana could potentially learn from several successful was WtE systems implemented in other developing countries, which optimize waste management and generate electricity. Examples of these include:

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1. **Phuket, Thailand:** Phuket has implemented a WtE system where municipal solid waste is converted into electricity via an incineration plant. The facility has a capacity of 9.5 MW and processes about 600 tons of waste per day. The electricity produced is sold to the national grid, creating a revenue stream for the local government (Jitto and Nakbanpote, 2023).

2. **Lahore, Pakistan:** Lahore features a WtE plant with a capacity of 12 MW, processing approximately 3,000 tons of waste daily (Zafar et a., 2024). This project represents a public-private partnership, showcasing the potential for collaboration in WtE initiatives.

3. **Addis Ababa, Ethiopia:** The Reppie Project in Addis Ababa marks one of Africa's first WtE facility, with a capacity of 50 MW and processing around 1,400 tons of waste per day (Armoo et al., 2024). The project exemplifies effective governmental and private sector cooperation.

4. **Other African Initiatives:**

- **Kenya:** The Gorge Farm Anaerobic Digestion Power Plant in Naivasha, Kenya, processes vegetable and flower waste to generate 2.4 MW of power (Ddiba et al., 2022).

- **South Africa:** The Bronkhorstspruit Biogas Plant, operated by Bio2Watt Ltd, is the continent's first industrial-scale WtE facility, producing biogas from organic waste to generate electricity. Additionally, a state-of-the-art biogas plant is planned for 2025 to serve Cape Town (Manala et al., 2016).

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- **Zimbabwe:** Plans are underway for the Bulawayo Waste-to-Energy power plant to convert solid waste into biodiesel and biogas for electricity generation (Gunarathne et al., 2023).

5. **Ghana's Emerging Projects:** A notable project in Gyankobaa, Ghana is the Hybrid-PV-Biogas-Pyrolysis plant, the first in the nation, which aims to convert 12 tons of waste daily into bio-fertilizer and energy (Tahiru et al., 2024). This medium-scale power plant will combine solar energy, biogas, and pyrolysis of plastic waste to generate electricity.

These examples illustrate diverse approaches in the deployment of WtE technologies that efficiently manage waste while producing energy, offering valuable lessons for implementing similar systems in Tamale, Ghana.

2.15 Benefits of Waste Systems Centered on WtE

A waste management system centered on WtE technology offers numerous benefits. Firstly, it provides a sustainable solution to a city's growing waste problem by diverting waste from landfills and reducing the environmental impact of waste disposal. WtE plants can process non-recyclable waste, which would otherwise end up in landfills, and convert it into valuable energy resources. Secondly, WtE technology can generate renewable energy in the form of electricity and heat, contributing to Metropolis's energy security and reducing its reliance on fossil fuels. This can lead to lower energy costs for residents and businesses and a reduction in greenhouse gas emissions, mitigating the city's contribution to climate change.

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Thirdly, the implementation of a WtE plant can create jobs and stimulate economic growth. The construction and operation of the plant require skilled labor, providing employment opportunities for residents. Additionally, the sale of electricity and heat generated from the plant can generate revenue for a city. Fourthly, WtE technology can improve public health by reducing the amount of waste disposed of in open dumps and landfills. This can minimize the risk of disease transmission and create a cleaner and healthier environment for residents. Finally, the adoption of WtE technology can enhance a metropolis's reputation as a sustainable and forward-thinking city. It can attract investment, promote tourism, and contribute to the overall well-being of the community.

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2.16 Summary

Overall, the literature has shown that the impacts of the WtE sector extend far beyond techno-economic and environmental factors, and due recognition must be given to the full range of social, political, environmental, and techno-economic impacts in any assessment.

When considering opportunities and barriers identified in the literature, it is important to note that the development of some WtE options have been contested: there seems to be substantial support for development from some groups, such as those of the government departments and industry which are investing in the deployment of these technologies and developing policies for their implementation. However, others, such as Global alliance for incinerator alternatives (GAIA), seem to consider their impact to be environmentally and socially negative and believe, therefore, that further development should cease, this is partly due to differences between stakeholders'

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interests, technological advancements, values and priorities (Gunarathne et al., 2023). Given this context, realizing the full potential of WtE needs an all-inclusive appreciation of the perspectives of several stakeholders, from the initial design stages to the communities where these projects are implemented.

Moreover, recognizing the significant interplay between the waste management and Waste-to-Energy (WtE) sectors, addressing their challenges in isolation may result in unsustainable development and missed opportunities for efficient waste utilization. However, it is essential to accept a holistic approach that considers the interactions between these sectors and various factors. This enhanced understanding would facilitate the appreciation of WtE's impact in Ghana, guiding its sustainable development aligned with principles of the circular economy, energy retrieved from waste, and the transition to a low-carbon economy. Ultimately, such efforts add to the country's aim of realizing net zero emissions by 2050. The literature review strongly suggests that the selection of Waste-to-Energy (WtE) approaches for waste management is contingent upon the specific needs of decision-makers. Therefore, WtE technologies must be customized to align with the unique requirements of each area, such as the Tamale metropolis. Consequently, while WtE technologies implemented in one location may be suitable for another, some adjustments may be necessary. This underscores the importance of conducting location-specific analyses to inform local waste management planning, development, and efficient service delivery to communities.

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As a result, the research identified several knowledge gaps in municipal solid waste management, particularly in Tamale, Ghana, which it attempted to address. These include:

a) Data on the selection of a suitable WtE technology considering large-scale waste treatment and energy recovery is limited in Ghana
b) The application of waste management decision support tools in MSWM decision-making is very limited and rarely documented in Ghana
c) location-specific analysis (considering both experimental and modelling (MCDM-AHP) analysis) to support the adoption and implementation of WtE in the research area is limited
d) A holistic view considering the interrelation of the waste management sector and the WtE sector in addressing the issues of waste management is limited
e) Data on social, political, environmental, and techno-economic impacts in the deployment of WtE technologies assessment is limited
f) Data on the WtE perspective of residents and stakeholders from communities and WtE sector is limited
g) Available data on MSW generation and characteristics needs to be updated.

Hence, this study sought to add to the existing body of literature by addressing the identified gaps, including but not limited to challenges related to the adoption and implementation of WtE technologies, including their economic, environmental, and social effects. Additionally, the study examines the selection criteria and sustainability aspects of WtE technologies in the research area. With a focus on the most mature

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WtE technologies, the research seeks to offer solutions to the challenges of municipal solid waste (MSW) management while promoting effective and environmentally favorable methods of renewable energy production.

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CHAPTER THREE

MATERIALS AND METHODS

3.0. Chapter Overview

This section details the research methodology used in the study, as well as data collection and analytical tools. To provide context, a brief description of the study area is presented. The instruments used for data collection, research design, sampling procedures, pre-testing of questionnaires, and data analysis techniques are all outlined.

3.1. Study Area

Tamale Metropolis, the capital and economic hub of Ghana's Northern Region, is experiencing rapid urbanization with a population of approximately 485,000 and an annual growth rate of 3.5% (Asare et al., 2021). As the most urbanized district in the region, with a population density of 319 persons per square kilometer, Tamale faces significant waste management challenges driven by increasing economic activities, high population density, and limited infrastructure. The metropolis generates approximately 150 tonnes of municipal solid waste (MSW) daily, yet only 7.5 tonnes (5%) is formally collected, leaving a backlog of 142.5 tonnes per day (Issahaku et al., 2014).

Several factors contribute to the waste generation crisis, including rapid urban expansion, commercial activities, dietary patterns that result in high organic waste, inadequate waste collection infrastructure, and cultural practices such as open dumping and burning. The waste composition in Tamale is predominantly organic (60–65%), with smaller fractions of plastics, paper and textiles, and metals/glass (Tahiru et al., 2024). Tamale's current waste management system relies on household

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waste storage, limited collection by private contractors, and inefficient transport to open dumpsites managed by the Tamale Metropolitan Assembly. Due to inadequate funding and infrastructure, most waste is either dumped in unregulated sites or burned, leading to environmental hazards and greenhouse gas emissions (Agbejule et al., 2021). Recycling efforts remain informal and minimal, with only a few small-scale enterprises engaged in plastic and metal recovery. Given these challenges, transitioning to WtE solutions would offer a sustainable alternative, reducing landfill dependency, mitigating environmental risks, and contributing to Ghana's renewable energy goals.

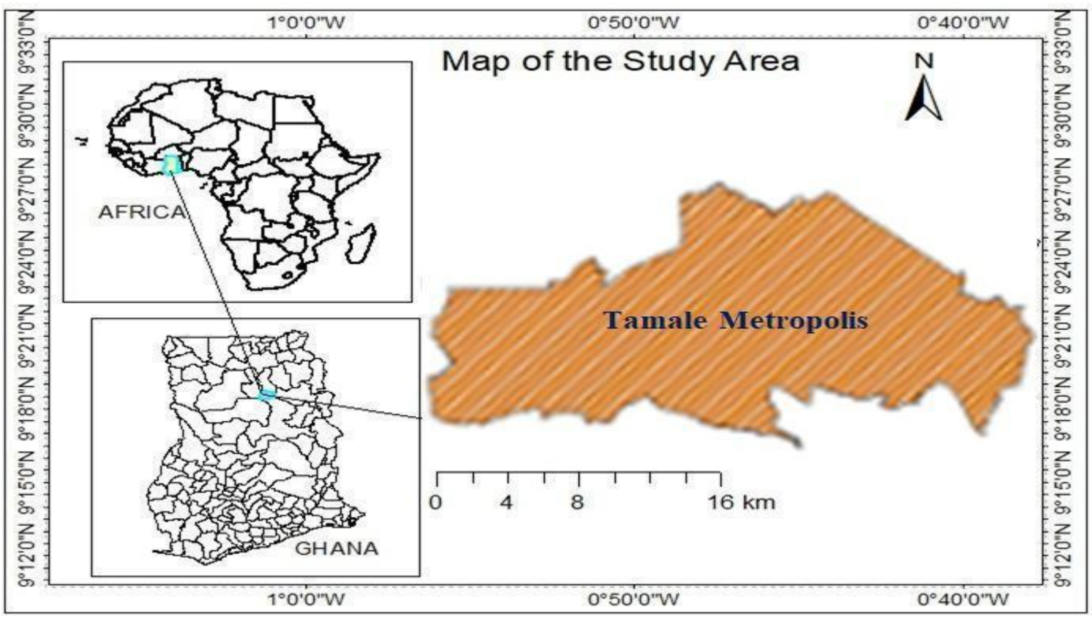

Figure 3. 1: Location map of Tamale in the Northern Region of Ghana (Source; Author's construct).

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3.2 Conceptual Framework of The Research

The proposed conceptual framework (see figure 3.2) provides a systematic and holistic approach for identifying, selecting, and integrating the most suitable WtE technology in Tamale, Ghana, prioritizing sustainable development and stakeholder engagement. It acknowledges that successful WtE implementation goes beyond technical aspects and requires a comprehensive understanding of the socio-environmental context.

The framework begins with a baseline assessment of current waste composition in Tamale, resource recovery potential, and establishing the foundation for WtE integration. It then proceeds with rigorous physical and chemical characterization of MSW streams to determine energy potential, composition, and suitability for various WtE technologies. This data-driven approach ensures that technology selection aligns with the specific characteristics of Tamale's waste.

In making sure a transparent and representative decision-making process, the framework uses the Analytic Hierarchy Process (AHP) within a Multi-Criteria Decision Analysis (MCDA) framework to systematically evaluate potential WtE technologies based on weighted scores on the technical, economic, environmental, and social criteria.

Recognizing the intricate interplay between technological and social factors in WtE adoption and implementation, the framework underscores the importance of assessing public perceptions, knowledge, and understanding towards WtE. This assessment helps ascertain the level of social acceptance and guides the development of targeted

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education or awareness-creation initiatives where needed, thereby enhancing the likelihood of successful WtE integration.

Lastly, a thorough analysis of the existing institutional and regulatory landscape is also crucial for identifying potential barriers and enablers for WtE integration, outlining necessary policy adjustments or incentives to facilitate successful project implementation and long-term sustainability. This exercise provides valuable insights that can inform a holistic implementation plan, ultimately leading to the formulation of a comprehensive pathway that outlines a roadmap for a seamless fussing of WtE into Tamale's existing waste management system.

Overall, this conceptual framework provides a robust and adaptable blueprint for exploring the potential of municipal solid waste for WtE applications in Tamale, Ghana. By emphasizing the integration of technical, economic, environmental, and social factors, it sets the stage for the development of sustainable and effective WtE solutions that can contribute to the overall improvement of solid waste management in the city.

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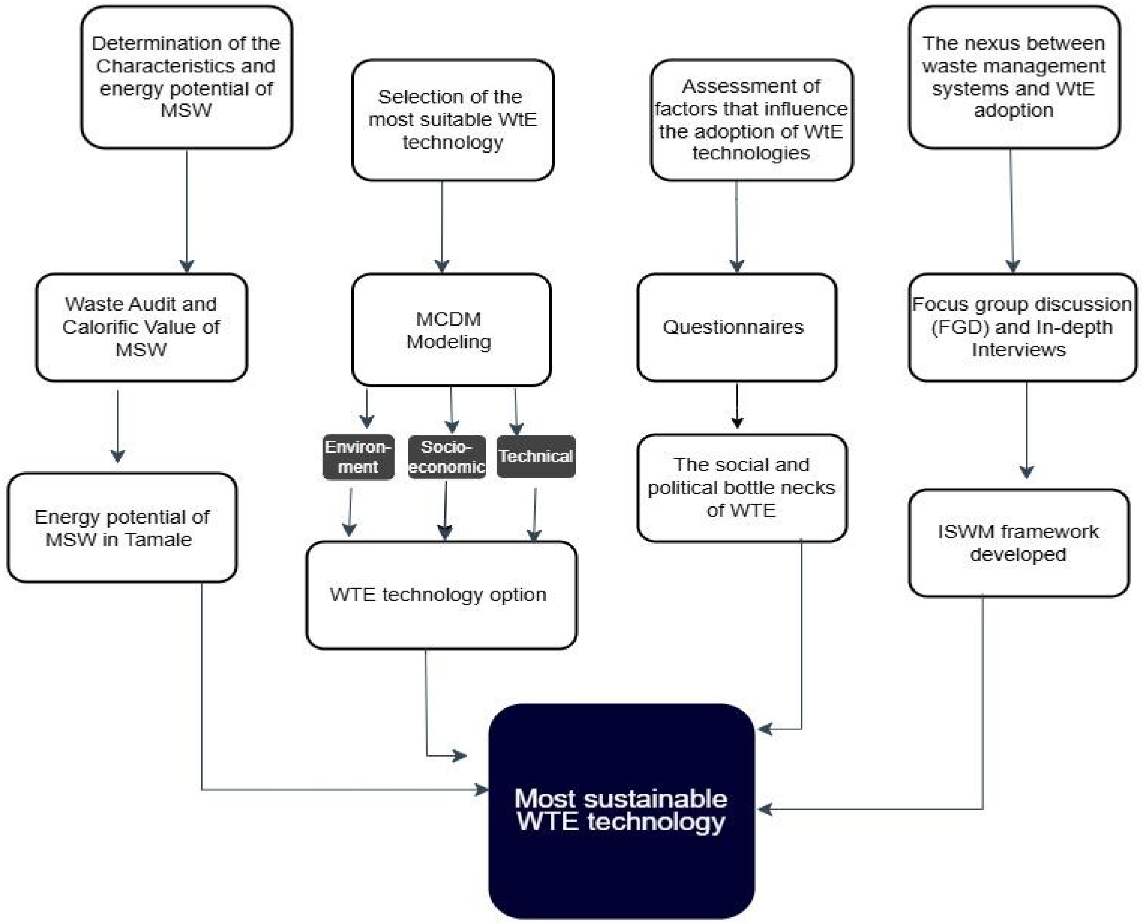

Figure 3. 2: The conceptual framework of the research (Source: Author's contruct, 2023).

3.3 Research Philosophy

The research adopts pragmatist epistemology, emphasizing the practical implications and usefulness of knowledge (Cherryholmes, 1992). This approach focuses on generating knowledge directly applicable to solving real-world problems, particularly in waste management and sustainable energy solutions in Tamale. The pragmatist stance is crucial for this study in that: the research aims to provide insights that inform decision-making processes related to WtE implementation, including identifying suitable technologies, addressing public concerns, and integrating WtE into the

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existing waste management system. Pragmatism acknowledges that knowledge is context-specific (Johnson & Onwuegbuzie, 2004). The research generate knowledge relevant to the unique challenges and opportunities presented by Tamale's environment and community engaging with stakeholders, including residents, waste management professionals, policymakers, and WtE experts, and ensured that the research addresses the needs and concerns of those most affected by WtE implementation (Stringer et al., 2014).

The study also assumes ontologically that reality is dynamic and constantly evolving, shaped by social, economic, and environmental factors (Stringer et al., 2014). This understanding necessitates a holistic approach, considering the interconnectedness of factors influencing waste management and WtE adoption in Tamale, such as social attitudes, economic constraints, and environmental impacts and regulations. It also recognizes the unique challenges and opportunities of Tamale's local environment, community demographics, and existing waste management infrastructure. Lastly, the study aims to generate solutions adaptable to changes in waste composition, energy demand, and public perception over time (Nanayakkara, 2019).

By adopting pragmatic epistemology, this research emphasizes practical outcomes and flexibility in addressing the complex, real-world challenges of waste management in Tamale. The dynamic nature of municipal solid waste generation, driven by factors such as population growth, urbanization, and climate change, demands a research approach that is both adaptable and solution focused. Pragmatism allows for the integration of diverse methods and perspectives, facilitating a comprehensive

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assessment of WtE potential, and ensuring the findings are directly applicable to the city's waste management needs.

This focus on practical, context-specific solutions aligns with the research objectives of generating actionable and sustainable waste management strategies. Moreover, pragmatism accommodates the iterative and evolving nature of the waste sector and the local policy environment, making it a well-justified and appropriate philosophical choice for this study.

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3.4 Research Design

This study employed a mixed-method research design, the study combined laboratory analysis of MSW samples with quantitative and qualitative surveys. This comprehensive data served as the foundation for designing a framework for an integrated solid waste management system centered around WtE technology in Tamale. The research design is further illustrated in Figure 3.3.

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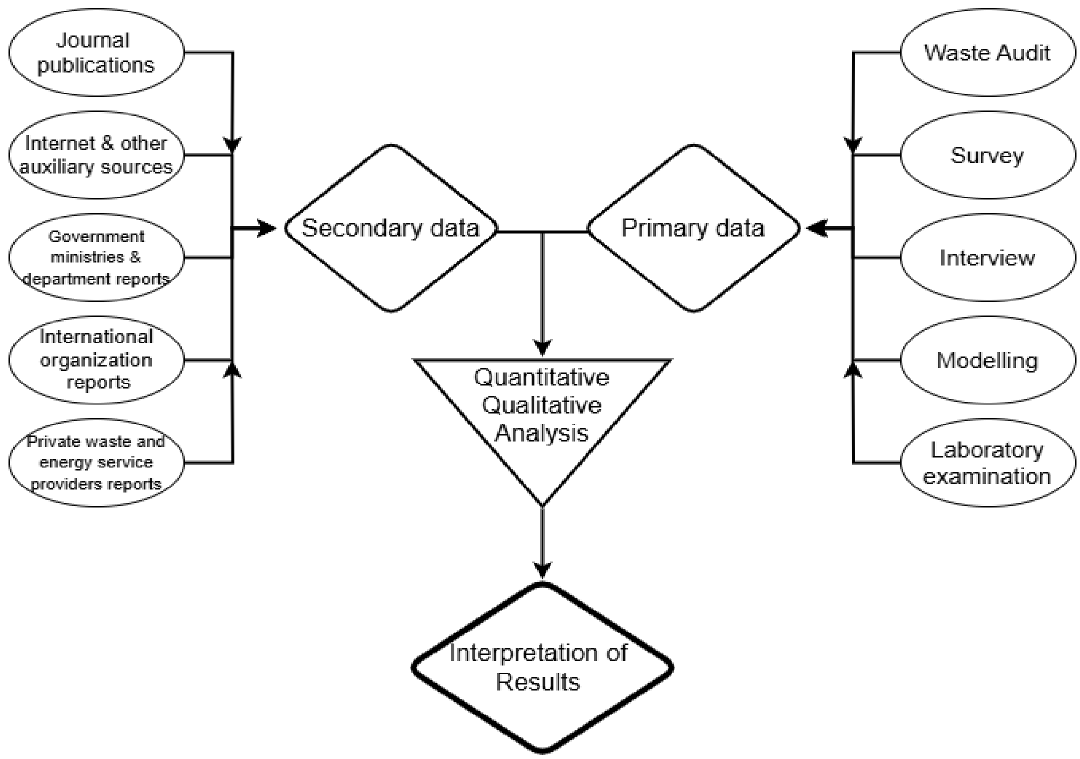

Figure 3. 3 Research design framework (Source: Field, 2024)

3.5 Sample Size and Sampling Procedure

In this research, sample size was determined by utilizing the formula of sampling for continuous variable measurements reported by Cochran (1977) which has been widely applied by other researchers including Oribhabor & Anyanwu (2019), Sullivan et al. (2020) and Godoy et al. (2019). The formular as in Eq. (1), was used to estimate the representative waste sample for analysis.

$$\mathrm{N} = Z * Z \left[\frac{P*P}{D*D}\right] \quad \textbf{(1)}$$

where N represents the sample size, Z is the value for a selected alpha level of each tail (1.96 for an alpha level of 0.05., P is the estimate of the standard deviation in the

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population, and D is the acceptable margin of error for the mean being estimated. Based on the estimation, the number of households selected in each service area in the Metropolis ranged between 24 and 60, except for the hotels and market centers, as supported by previous literature (Sullivan et al. 2020; Okoe Bosomprh, 2019; Seshie et al., 2020).

The study employs a multistage sampling technique, characterized by a series of sequential sampling operations. In the initial stage, zones for the research were selected using a cluster sampling technique, as outlined in the section on socioeconomic zone stratification. The communities, hotels, and market centers for the study were chosen using both purposive and random sampling in the second stage. Finally, in the third stage, a random sampling technique was once again employed to select household members as well as market and hostel managers who served as focal persons for the exercise. The selection process was contingent upon their willingness to participate in the study.

3.6 Materials for Waste Audit

The materials and instruments that were used during the study included a Scale (Maximum weight: 50 kg) for weighing the waste, Bomb calorimeter with model IKA calorimeter C-4000 adiabatic, Crucibles, Digital Camera, VECSTAR furnace up to 1200 0C, CARBOLTE furnace up to 1400 0C, oven up to 110 0C, plastic sheets, Thread, Chromium wire, Thermometer stopwatch, and EA1112 thermo flash gas analyzer. A 70% ethanol solution was used as a disinfectant to sterilize equipment after washing, and a standard laboratory-grade detergent was used to clean equipment and hands after waste analysis. Masking tape and markers were used for labeling

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samples. Protective clothing such as hand gloves, nose mask, overalls, wellington boots were worn to protect field staff. A shed was provided at the analysis site for the waste characterization study. Waste bins/sacks and polythene bags were used for collecting waste samples from households while plastic sheets were used to cover the worktable. Benches, recording booklets, brooms for cleaning the waste sorting and analysis site were all used in the study.

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3. 7 Data Collection Process

The study employed a mixed-methods approach, incorporating qualitative insights, laboratory analysis, and quantitative data derived from both primary and secondary sources. This approach was necessitated by the complexity of the research subject and the need for a comprehensive understanding of WtE potential in Tamale. A single method would have been insufficient to capture the multifaceted nature of waste management, which involves both technical and socio-environmental considerations.

3.7.1 Data Sources

The study covered the entire metropolis, utilizing the three sub-metros; Tamale South, Tamale North, and Tamale Central to ensure a comprehensive and unbiased sample representation. Various communities, reflecting diverse income classes, were strategically chosen across these sub-metros. Additionally, two of Tamale's most frequented markets and three highly sought-after hospitality establishments were purposefully included in the study. This decision stems from a lack of knowledge about the waste generation potential of the commercial space in Tamale, as previous attempts to characterize waste in the metropolis had overlooked these sectors.

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For source-based significance of waste, samples were retrieved from families, market skips and dumper bins, and hotels and restaurant bins. At the household source, waste samples were collected directly from households using the door-to-door method. At the market source, samples were gathered by intercepting waste designated for communal skips and dumpster bins. Finally, at selected hotels and restaurant sources, samples were obtained from identified main dumpster bins.

3.7.2 Analysis of The Types and Quantities of Waste Generated in Tamale and The Potential for WtE Conversion (Objective one).

3.7.2.1 Waste Characterization Study

To achieve an accurate representation and generalizable understanding of waste generation patterns in the Tamale metropolis, waste samples were collected from various sources over a three-month period from August to October 2023. The sampling process involved collecting waste data from two local markets, three hospitality establishments such as restaurants and hotels, and one hundred (100) households across the study area.

This sampling strategy was designed to capture waste amounts and types from different community generators across both commercial and residential sectors. The characterization method involved the daily distribution of polythene bags to participating households and commercial centers, subsequent collection by the research team, transportation to a sorting site, and a comprehensive compositional analysis to identify various waste components. Special attention was given to the organic fraction, requiring coning and quartering for representative sampling for chemical analysis, including proximate and elemental analyses.

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The sorters, supervisors and recorders were trained in theory and practice on all aspects of the sorting, measurement and recordings on paper and on excel sheet. The number of sorters per household per duration of the entire exercise was of ratio 1 sorter to 10 households, but for the sake of efficiency, the sorters worked in a group of 10. Thus the 10 sorters worked on 100 households per day. 10 sorters were used in all the three settlement zones in the metropolis; complimented with 2 spervisors who coordinated the collection and the transportation of the waste to the sorting venue and 1 recorder for data entry. Personal protective equipment was provided for each person involved in the study.

For hotels and markets, consent was first sought from managers of respective dumpster and skips in the study area. Manual sorting was performed under canopies and sheds in all sites by a research team of ten people. MSW was intercepted and unloaded at designated sites and divided into four waste heaps. The samples obtained from the quartered waste load were initially sorted and weighed. A large flat area lined with tarpaulin was used for the sorting exercise to prevent the risk of erroneous analysis resulting from rough surfaces and reduce the chance of contamination of samples by the ground. Waste samples were hand-sorted into nine major categories and put into labeled plastic bags. They included organics, paper, plastic, metal, glass, textiles, leather, and other components.

3.7.2.2 Weighting of sorted waste

Empty plastic containers were first weighed to obtain their "dry masses" before they were filled with sorted waste. The filled containers were weighed after all sorting

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activities. The percentage composition was calculated by the expression in Eq. (2), previously utilized by Lamb et al, (2014)

$$\% \text{ Composition } = \frac{Qi}{TQW} X 100\% \quad \textbf{(2)}$$

where Qi is the quantity of material under consideration, and TQW is the total quantity of waste, expressed as a percentage.

The per capita generation of each waste component was calculated using the formula for waste generation (Denteh et al.,2018)

$$\text{Pcwg}=\frac{wtofrecoveredquantity}{No.ofpeople} XNo.ofdays \quad \textbf{(3)}$$

Where wt of recovered quantity is weight of recovered quantity, No. of people is number of people and No. of days is duration of waste generation.

The formular for estimating waste generation rate per day is given by:

$$\text{WGR}= \left(\frac{Twg}{No.ofdays}\right) \frac{kg}{day} \quad \textbf{(4)}$$

Where Twg is the total waste generated of a given period and No. of days denote the duration of waste generation.

3.7.2.3 Chemical characterization of the Waste

3.7.2.3.1 Proximate analysis

Parameters including Moisture content, volatile solids, ash content, and fixed carbon were comprehensively assessed. Moisture content was determined following the guidelines outlined in ASTM E1756-08 (ASTM, 2020). To achieve this, zone-specific samples underwent oven drying at 103±2 °C for a duration spanning 24 to 48 hours. Post-drying, mechanical and manual methods were employed to reduce the sample size, ensuring the preparation of representative samples for each zone and waste source

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in readiness for subsequent tests. The percentage of volatile matter and ash content were meticulously analyzed in accordance with ASTM E872-82 (ASTM, 2019) and ASTM D1102-84 (ASTM, 2013), respectively. The determination of the fixed carbon content of the waste was executed using the difference method.

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3. 7.2.3.2 Elemental analysis

Waste samples underwent size reduction to attain the optimal size of 600 microns for elemental analysis. Prior to analysis, the samples were subjected to oven drying at 103±2 °C for a duration of 3 hours, followed by cooling in a desiccator for 30 minutes. The elemental composition, encompassing carbon, nitrogen, hydrogen, oxygen, and sulfur percentages in the dried samples, was meticulously determined using an elemental analyzer (Euro Vector 3000, EuroVector, Pavia, Italy). The analysis adhered to the standards outlined in ASTM E777-87 (ASTM, 2004), ensuring methodological consistency and precision in the assessment of elemental content.

3. 7.2.3.3 Energy content (calorific value) Analysis

Pellets, weighing between 0.5 and 1 g, were meticulously prepared using a manual press machine. Subsequently, the analysis of energy content was conducted using an adiabatic bomb calorimeter (6050 Compensated jacket Calorimeter, Parr Instrument Company, Moline, IL, USA). The procedures followed for this analysis strictly adhered to the guidelines outlined in ASTM E711-87 (ASTM, 1996), ensuring a standardized and rigorous approach to the determination of energy content.

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3.7.3 Analysis of the most suitable WTE technology for Tamale based on the available feedstock and MCDM

3. 7.3.1 Identification of Criteria and Alternatives

To tailor the WtE selection process to the unique context of Tamale-Metropolis, an extensive review of existing literature was conducted as specified by Afolabi et al., (2021). The goal was to discern the most relevant criteria and alternatives for the assessment of the most suitable waste-to-energy option in the region (refer to Table 3.1). Considering the specific characteristics of waste in Tamale, four distinct alternatives emerged: anaerobic digestion (AD), incineration, gasification, and landfill gas (LFG) (Darmey et al., 2023; Shao et al., 2020).

The chosen criteria and sub-criteria for evaluating and selecting the most suitable WtE technology encompass technical, economic, social, and environmental considerations (Shahnazari et al., 2020). These factors were identified through a comprehensive literature assessment, ensuring a holistic and contextually relevant approach (Rogers et al., 2020). Table 3.1 succinctly outlines and elaborates on these criteria, providing a clear framework for the subsequent evaluation and decision-making process (Johnson et al., 2020). The aim is to facilitate an in-depth understanding of the criteria guiding the selection of the optimal WtE technology for Tamale-Metropolis, Ghana (Volsuuri et al., 2023).

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Table 3. 1: Criteria selected for the evaluation of the Waste to Energy Technology.

Main criteria	Sub criteria	Description
Environment	*Pollution potential*	Minimal adverse environmental impacts on water, soil, and air
	Climate change impact	The WtE technology which has the least emissions of carbon dioxide and other greenhouse gasses is preferred
	Public and Occupational Safety	The public health and occupational safety issues associated with the selected technology
Technology	*Sophistication of technology*	Complexity and sensitivity of the specific technology to the consistency of supply as well as segregation. The lower the sensitivity the better the supply.
	Energy generating potential	WtE technology with the highest energy-generating potential from waste is preferred.
	Availability of know-how	Availability of experts and logistics for the running and maintenance of the selected waste-to-energy technology
Economic	*Capital cost*	This is the initial investment needed for the plant to start. The least initial cost is preferred.
	Operation and maintenance cost	Technology with the least operation and maintenance cost is preferred.
	Job creation	The potential of the selected technology to create employment opportunities
Social	*Impact on land & culture*	Technology with high land requirements can cause the displacement of dwellers, biodiversity loss, and devaluation of lands.
	Social acceptance	Technology with high social acceptance is recommended

To enhance the precision of the research outcomes and align them with the distinct dynamics of Tamale-Metropolis, Ghana, various input data on identified WtE options were meticulously gathered (Bohra et al., 2022). This encompassed critical

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information such as the process type, required reaction temperature, cost of operation and maintenance, environmental impact, applications and electricity generation potential (Bohra et al., 2022). A thorough review of pertinent research and journal papers served as the source for this data (see Appendix A) (Vindrola-Padros et al., 2020).

The details of these essential inputs, required for the evaluation of selected WtE technologies, have been organized systematically in Appendix A (Khan et al., 2022). This compilation not only ensures transparency in our research methodology but also lays the groundwork for a comprehensive and well-informed analysis (Jacobs et al., 2021). By drawing on reliable sources, we aim to provide decision-makers and stakeholders with robust data to facilitate a judicious and effective selection of the most fitting WtE technology for the Tamale metropolis

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3.7.3.2 Construction of Hierarchy Structure for the Selection of WtE Technology

Figure 3.4 illustrates a simplified hierarchy designed for Tamale-Metropolis waste-to-energy selection flow chart. At the top are fundamental criteria, followed by sub-criteria, and finally, the studied alternatives – anaerobic digestion (AD), incineration, gasification, and landfill gas recovery (LFG) (Sondh et al., 2022; Oteng-Ababio et al., 2020). This streamlined structure ensures a focused and organized assessment of waste-to-energy options in Tamale-Metropolis, Ghana.

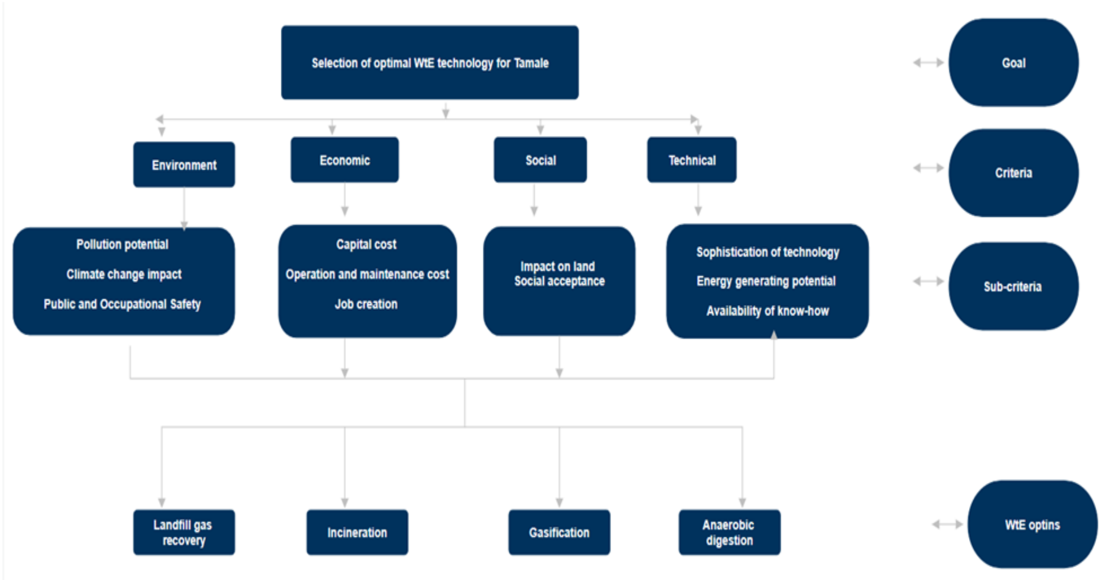

Figure 3. 4: Hierarchy structure of AHP analysis for waste-to-energy selection for the Tamale Metropolis

3.7.3.3 Stakeholder Identification and Selection for Analytic Hierarchy Process

Guided by literature, local authorities and researchers were first identified as key stakeholders, Subsequently, employing the snowball sampling technique, additional stakeholders were uncovered, as depicted in Figure 3.5. This technique is particularly useful in exploratory research where a well-defined stakeholder network may not be readily accessible at the outset. The identified stakeholders were thoughtfully categorized into four distinct groups: government officials, academic professionals, representatives from the private sector, and members of the local community and NGOs. Table 3 provides a clear breakdown of these stakeholder groups, facilitating a targeted and inclusive approach in our study.

Recognizing that Analytic Hierarchy Process (AHP) doesn't rely on statistical methods, no specific discussion on the optimal size of the stakeholder group has been

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undertaken (Munier et al., 2021; Afzal et al., 2021). Notably, stakeholders in influential positions, such as renewable energy and waste management experts or organizational directors, were deliberately chosen for this analysis (Dzhengiz et al., 2020). The engagement process involved circulating questionnaires to solicit their valuable insights (Vallance et al., 2022; Ansu-Mensah et al., 2021).

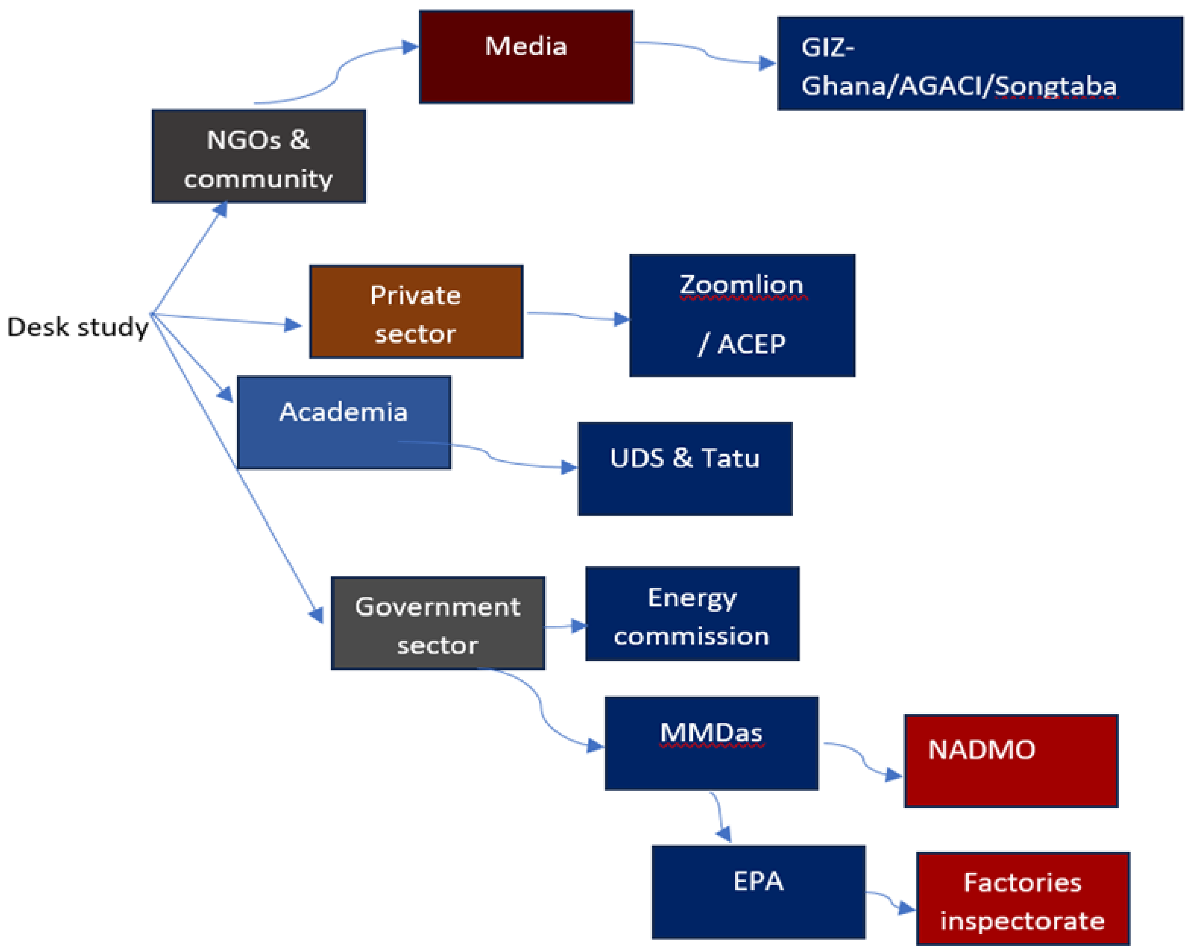

Figure 3. 5: Identification of potential stakeholders using a snowball sampling technique (Author's construct).

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Table 3. 2: Number of stakeholders who Participated in the Expert Survey

Stakeholder groups	Invitation	Response	Institutions
Academia	3	3	UDS/TATU
Governmental body	8	5	Energy commission/ NEDCo/NADMO/EPA/MMDAs -Sanitation dept/Factories inspectorate
NGOs/CSOs/INGOs/Media & local Communities	6	5	GIZ-Ghana, Songtaba, AGACI, Allied relief, Opinion leaders near Gbalahi landfill site
Private sector	4	4	Zoom lion ltd and ACEP
Total	21	17	80.9%

Before initiating direct contact and administering questionnaires, a comprehensive overview of the study was provided to the identified stakeholders in Tamale-Metropolis, Ghana (Zakaria et al., 2023). The purpose and the potential involvement in the study, particularly in responding to questionnaires, were clearly communicated (Nilsen et al., 2020).

Subsequently, questionnaires were disseminated among a diverse group of 21 stakeholders (Karlsson et al., 2021). This cohort included representatives from 8 government departments, 6 non-governmental organizations and community representatives, 3 educational institutions, 4 technical experts (Lazarus et al., 2022). Impressively, 17 stakeholders actively responded, signifying a commendable 80.9 percent response rate (Ndirangu et al., 2023). This level of participation underscores the keen interest and cooperation of the stakeholders in contributing to the insights crucial for our study on waste-to-energy technologies in Tamale-Metropolis (Kosoe et al., 2021).

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3.7.3.4 Questionnaire Development and AHP Analysis

The questionnaire's primary objective was to capture stakeholder perspectives on the importance of various Waste-to-Energy (WtE) technologies (Caferra et al., 2023). Each respondent was guided through a series of pair-wise comparisons, evaluating the relative significance of different criteria on a scale of 1 to 9 (refer to Table 3.3) (Terzioglu et al., 2021). Clear instructions on conducting these comparisons, aligned with the four-level hierarchical structure outlined in Figure 3.4 (Moe et al 2021). As an illustration, if stakeholders deemed "Economic" criteria as being "definitely important" than "Technology," the pair-wise comparison would reflect a scale of "5.". This systematic approach facilitated a nuanced understanding of the stakeholders' priorities within the context of the WtE evaluation (Jayasinghe et al., 2022; İlhan et al., 2020).

The subsequent Analytic Hierarchy Process (AHP) analysis was executed utilizing the Superdecision software (Nimawat et al., 2021). This software holds a distinct advantage in its capacity to amalgamate tangible factors, intangible considerations, and human judgments in decision-making processes (Bhaduri et al., 2023). The comprehensive steps undertaken for the AHP analysis are meticulously outlined in the next section (Zhang et al., 2020).

3.7.3 .5 Deriving Weighted Results from Pairwise Comparisons

To attain the overarching goal of our study, square matrices were constructed for the pairwise comparison of different criteria and sub criteria, as illustrated in Figure 3.4 (Khashei-Siuki et al., 2020). Expert opinions were captured through these matrices, expressing score values for each pairwise comparison (Lyu et al., 2020). Utilizing the additive Analytic Hierarchy Process (AHP) procedure, the score values from the expert-developed matrices were amalgamated. This involved calculating the arithmetic mean, ensuring a comprehensive and collaborative approach to synthesizing expert insights (El Akrami et al., 2023). The aggregated scores then underwent normalization, a crucial step in standardizing the values (Van Gassen et al., 2020). Subsequently, Eigenvectors were computed and employed to assign weights to the results corresponding to the four waste-to-energy alternatives (Adenuga et al., 2020). This methodological process ensures a robust and systematic assessment, aligning with the unique dynamics of the study area, and contributing to a well-informed decision-making framework for waste-to-energy technologies (Adenuga et al., 2020).

To ensure the consistency of the stakeholders and experts' judgments, a consistency check was performed for each matrix by calculating the consistency ratio (CR) (Hamadneh et al., 2022). First the eigenvalue (ƛ max) was calculated according to Equation (1).

$$A \cdot w = \lambda_{Max-w} \qquad (1)$$

where A is the comparison matrix, W is the normalized eigenvector (priority vector), and ƛ max is the eigenvalue. After that, the consistency index has been calculated using Equation (2).

$$CI = \frac{Imax - n}{n - 1} \qquad (2)$$

Considering the randomness in judgment, the consistency ratio by Equation (3):

$$CR = \frac{CI}{RI} \qquad (3)$$

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where RI is the random index which expresses expected value of the CI corresponding to the order of matrices.

Table 3. 3: Shows the values of the random index.

N	1	2	3	4	5	6	7	8	9
RC	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

In the case where the CR value is within acceptable range (usually less than 10%), the judgments are considered consistent (Aguarón et al., 2021).

3.7.3.6 Priorities Assessment of the WtE options

Once the consistency of the judgments was verified, the synthesis process involved aggregating the weights through the established hierarchy (Liu et al., 2020). This crucial step aimed at determining the comprehensive priorities for each waste-to-energy alternative tailored to the unique context of Tamale-Metropolis, Ghana (Afrane et al., 2022).

3.7.4 Analysis of Public Perceptions towards WtE as a Waste Management Strategy in Tamale (objective 3).

To explore the public perceptions towards WtE, a survey questionnaire was conducted. The initial section of the questionnaire aimed to gather demographic details from participants, including gender, age, education level, annual income, and distance from their residency to the WtE project site in the Tamale metropolis (refer to Table 1). The subsequent section focused on assessing various dimensions of social acceptance. It comprised 36 questions grouped into five categories: (1) Recognition, Awareness, and

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Understanding (RAU) of environmental concerns (Q12–Q13), (2) RAU towards WtE (Q14–Q17), (3) Perceived Risks (PR) of WTE (Q18–Q26), (4) Perceived Benefits (PB) of WtE (Q27–Q37), and (5) Residents attitude (RAT) towards WtE (Q38–Q42). The survey covered households, workplaces, and main thoroughfares in both urban and rural areas of Tamale.

By engaging participants from both urban and rural settings, the survey sought to ensure a comprehensive representation across various demographic groups, thereby enhancing the robustness of cross-group comparisons in the study. A total of 460 questionnaires were distributed, with 395 completed ones returned. Sample size was determined using slovin's formula, 1960 (Anugraheni et al., 2023).

$$n = \frac{N}{1+N(e^2)}$$

n = estimated sample size, N= total population, e= margin of error and 1= constant. The data were collected based on a five-point Likert scale, where responses ranged from 1 (Strongly Agree) to 5 (Strongly Disagree). The questionnaire data's reliability, correlation, and handling of missing values were examined using Stata 15.0.

To assess the significance of responses from the groups and elucidate mean value discrepancies, analysis of variance (ANOVA) test was performed. This test also aided the evaluation of the differences in residents' perceptions of the risks, benefits, and attitudes towards waste-to-energy (WtE) across various factors. The mathematical expression for the ANOVA model is given as:

$$Y_{ij} = \mu + \tau_i + \varepsilon_{ij}$$

Where:

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- Y_{ij} is the response variable (residents' attitudes) for the *i*-th observation in the *i*-th group.
- μ is the overall mean of the response variable.
- τ_i is the effect of the *i*-th group (factor level).
- ϵ_{ij} is the random error term.

The F-statistic for ANOVA was calculated as:

$$F = \frac{MS_{between}}{MS_{within}}$$

Where:

- $MS_{between}$ is the mean square between the groups.
- MS_{within} is the mean square within the groups.

The **Kruskal-Wallis Test** was used to validate the ANOVA findings through a non-parametric approach. The mathematical expression for the Kruskal-Wallis test is given as follows:

$$H = \frac{12}{N(N+1)} \sum_{i=1}^{k} \frac{R_i^2}{n_i} - 3(N+1)$$

Where:

- H is the Kruskal-Wallis statistic.
- N is the total number of observations.
- k is the number of groups.
- R_i is the sum of ranks for the i-th group.
- n_i is the number of observations in the i-th group.

The chi-square statistic for the Kruskal-Wallis test is approximately:

$X^2 = H$

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The p-value is then calculated to determine the significance of the differences between the groups.

Multiple Linear Regression was used to analyze the impact of socio-demographic and economic factors on residents' attitudes towards WtE and the influence of respondent's awareness and understanding (RAU), perceived risks (PR) and perceived benefits (PB) on respondents' attitude (RAT) towards WtE, a multiple linear regression model was utilized. The mathematical representation of the model is:

$$Y=\beta_0+\beta_1X_1+\beta_2X_2+\cdots+\beta_nX_n+\epsilon$$

Where:

- Y is the dependent variable (RAT responses).
- X_1, X_2,…, X_n are the independent variables (socio-demographic, economic factors and RAU of environmental issues—RAU towards WtE, PR, and PB).
- β_0 is the intercept term.
- $\beta_1,\beta_2,\ldots,\beta_n$ are the coefficients for the independent variables.
- ϵ is the error term.

Last but not least, t-test employed the t-distribution theory to ascertain the probability of differences, comparing whether the disparity between two mean values was significant.

Pre-testing: Generally, it's perceived that no matter how much developmental and pre-pretesting work is done on a questionnaire, the instrument would still have some challenges (Nanayakkara, 2019). Field testing usually implies administering a questionnaire to respondents selected from the target population using the procedures

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that are planned for the main study (Nanayakkara, 2019). For this study, probability or convenience sampling are used to select respondents to complete the set of questionnaires (See appendix C) with respondents ranging between 20 and 70 (Nanayakkara, 2019). For the characterization of waste in Tamale and measurement of public perception towards WtE, 10 households and 31 respondents were randomly selected within Tamale metropolis to undergo pilot testing. The feedback received was largely positive, resulting in no modifications to the protocol and questionnaire respectively.

Reliability Test : To ensure the reliability of the survey instrument used to assess public perceptions towards WtE as a waste management strategy in Tamale, Ghana, internal consistency reliability testing was conducted using Cronbach's alpha coefficient for each section of the questionnaire deployed under objective 3. The survey comprised demographic details and questions related to social acceptance dimensions categorized into Recognition, Awareness, and Understanding (RAU) of environmental concerns and WtE, Perceived Risks (PR) of WtE, Perceived Benefits (PB) of WtE, and Residents Attitude (RAT) towards WtE. Cronbach's alpha coefficients were calculated for each section, indicating the consistency of responses within each dimension. The interpretation of Cronbach's alpha values followed standard guidelines: coefficients above 0.70 signified acceptable internal consistency reliability, those between 0.60 and 0.70 suggested marginal reliability, and coefficients below 0.60 indicated potential issues with reliability. These reliability analyses contribute to the robustness of the study's findings by ensuring the dependability and consistency of the survey instrument across various dimensions of social acceptance

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towards WtE in Tamale. It is worth noting that the study achieved a coefficient exceeding 0.70 across all five subsections of the questionnaire.

3.7.5 Analysis of the nexus between waste management systems and waste-to-energy adoption and implementation in the metropolis (Objective 4)

In order to analyze the nexus between waste management systems and WtE, the barriers and critical success factors related to the integration of WtE into municipal solid waste management (MSWM) in the Tamale metropolitan area, a diverse range of data sources were utilized. To mitigate bias, information was gathered from various stakeholders in the waste management sector through a combination of techniques, including focus group discussions, in-depth interviews, observation, and site visits.

Stakeholders were chosen in accordance with recommendations from Batista et a., 2021 and Rathnayake et al., 2022. All participants in the study were over 18 years old. They were selected from various entities, including the Tamale Metropolitan Assembly's Department of Waste and Sanitation, Zoomlion Ghana Ltd., the Environmental Protection Agency (EPA), researchers (Academic), and other private waste service providers. Participants comprised directors, office and operations staff. The University for Development Studies Research Ethics Committee approved this study on the 21st of November 2023.

Fieldwork took place from January 1st, 2024, to February 5th, 2024. Initially, the primary researcher held informal meetings with key stakeholders, including the Manager of Zoomlion Gh. Ltd., the Manager of waste and sanitation under the Ministry of Local Government, and the Director of the EPA in Tamale. Subsequently,

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formal letters, along with questionnaires, were sent to these stakeholders. Between January and February 2024, the primary researcher received acceptance letters from the aforementioned stakeholders, including Zoomlion Ghana Ltd. and the Tamale Metropolitan Assembly, indicating their willingness to participate in the study. The methodology involved conducting focus group discussions and in-depth interviews.

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Figure 3. 6: Field visit (Source: Field work 2024)

3.7.5.1 In-depth interviews and focus group discussion

From January to February 2024, the principal researcher conducted 10 face-to-face, semi-structured interviews with managers, researchers, administrators, and other staff members from environmental and municipal solid waste management (MSWM) institutions in Tamale. Additionally, three focus group discussions (FGDs) were held with community members, waste aggregators, transporters, and recyclers, providing diverse perspectives on waste management practices and challenges (refer to Table 3.4). The selection of these ten interviewees was based on the notion of thematic

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saturation, as articulated by Guest et al (2006), who suggested that saturation in qualitative research is typically achieved with six to twelve respondents. This sample size was deemed appropriate to capture a wide range of perspectives and aid in an in-depth data analytic presentation.

Interview durations varied from 20 to 40 minutes per person, with scheduling tailored to accommodate the technical and cultural backgrounds of the interviewees. Upon agreeing to participate, potential interviewees were contacted by the principal investigator to schedule an appointment. Nonprobability sampling was employed for participant selection, utilizing a technique where the primary researcher extended an invitation, which included the research instruments, to two initial potential participants from different sectors (academia, industry, community and NGO sector). This was followed by employing a Snowball sampling technique (Khosravani et al., 2023; Soltanian et al., 2022), where each participant was encouraged to recommend others from related fields who might be interested in participating. Each of the three focus groups consisted of no more than fifteen participants, with sessions lasting between 60 and 90 minutes. The research team for each session included the researcher, a moderator, a note-taker, an audio recorder, and an organizer. Audio recordings of the focus group discussions were made for subsequent review. During these sessions, the moderator played a crucial role in maintaining the focus of the discussion, ensuring active participation from all attendees, and prompting participants to elaborate on their responses.

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Table 3. 4: Stakeholders for Interviews and Focus Groups on Tamale Waste Management

Group	Number	Gender
Key informat interviews		
Zoomlion Ghana limited	3	3M
Tamale Metropolitan Assembly	3	1M/2F
Community leaders	2	2M
The Environmental Protection Agency	1	1M
Institute of Local Governance	1	1M
Total	10	8M/2F
Focus group discussions		
Informal waste service providers - Aggregators	10	8F/2M
Informal waste service providers - Transporters	9	9M
Informal waste service providers - Recyclers	10	4F/6M
Total	29	12F/17M

Nb:Where F denote female and M denote male participants.

The researcher transcribed the audio recordings from ten face-to-face semi-structured interviews and two focus group talks onto a word processor, thereafter, uploading and analysing them for thematic content using NVivo software (Allsop et al., 2022). Analyses were conducted promptly to avert bias or loss of nuance that could result

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from translated terminology or idioms. Notable quotations were recorded for inclusion in the study.

The analytical framework for this research was constructed by incorporating factors or aspects that were identified in the literature on solid waste management. These sources included the US EPA (2002), Parikh et al. (1995), and a cross-national study conducted by Wang et al. (2021) that specifically examined developing countries. Technical, institutional, socio-political, and financial aspects comprise the framework's thematic components.

3.8 Limitations of the study

The study encountered several limitations that required attention. Firstly, financial constraints restricted waste characterization to a limited number of households. Additionally, during waste sorting, certain fractions were contaminated with fecal matter, oil, and other liquids, posing challenges for precise classification. Despite these hurdles, proactive measures were taken to mitigate their impact. While these limitations exist, the researcher remains confident that the findings offer a valuable and informative assessment of the potential for WtE technology in Tamale within the chosen framework.

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CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Introduction

The chapter gives a detailed discussion on findings and results from the study of the most suitable WtE technology for Tamale, Ghana. It is structured into four (4) sections. The first part gives findings and discussions on the types and quantities of waste generated in Tamale and the possibility for waste to energy conversion. Section two (2) dealt with findings on the selection of the most suitable WtE technology for Tamale based on the available feedstock using MCDM. Section (3) dealt with findings on Public Perceptions towards WtE as a Waste Management Strategy in Tamale. Section four (4) presents the nexus between waste management systems and WtE adoption and implementation in the metropolis.

4.2 Types and quantities of waste generated in Tamale and the potential for waste to energy conversion

4.2.1 Waste Generation and Types in Tamale Metropolis

The study reveals that the quantity of MSW generated in the Tamale metropolis amounts to 176.1 tonnes, accompanied by a per capita Waste Generation Rate (pcwg) of 0.47 kg/capita/day, as presented in Table 3. The three residential income classes collectively contribute nearly 70% of the waste in the metropolis, whereas markets and hotels contribute the remaining 30%. The average waste generation rates (WGR) for households, markets, and hotels are 73.3 kg/day, 87.1 kg/day, and 99.5 kg/day, respectively. In Ghana, Miezah et al. (2015) reported a comparable figure of 0.47 kg/p/day for all regional capitals in the country. In a similar vein, a recent study by

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Volsuuri et al. (2023) identified a waste generation rate of 176 tonnes in the Tamale metropolis, corroborating the findings of this study.

The recorded per capita waste generation rate in this study falls within the spectrum typical of waste generation in developing countries, which generally ranges from 0.4 to 0.6 kg/person/day (Ahmadi et al., 2020). It also, corresponds with per capita waste generation figures from relevant studies include Uyo, Nigeria, at 0.49 kg/capita/day (Nnaji, et al., 2021); Allahabad, India, at 0.40 kg/capita/day Vanlalliantluanga, (2021); Laga Tafo Laga Dadi town, Ethiopia, at 0.43 kg/capita/day (Fereja & Chemeda, 2022);Onitsha, Lagos, at 0.43 kg/p/day (Uttayarnmanee et al 2019); Gujranwala city, Pakistan, at 0.46 kg/p/day Attia-Ismail (2008) ; and Dhanbad-Jharkhand, India, at 0.41 (Singh et al., 2023).

However, it contrasts with the per capita waste generation rate which was recorded in Vittin in the Tamale Metropolitan area (0.34 kg/person/day) by Denteh et al. (2018), the per capita waste generation rates in the Kumasi Metropolitan area (0.75 kg/person/day), and that of the greater Accra region (0.74 kg/person/day) (Miezah et al. (2015). Moreover, the per capita generation recorded in this study falls below the 0.75 kg/person/day forecasted by the Ministry of Local Government and Rural Development (MLGRD) in the National Environmental Sanitation Strategy and Action Plan (NESSAP) 2010–2015. The per capita waste generation disparities observed in this study compared to previous research in the area may be attributed to the current surge in economic activities, accompanied by an escalation in production and consumption patterns in the Tamale metropolis. The waste generation variations between the current study and earlier research could also be influenced by temporal

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and seasonal factors (Asare et al., 2020). In a similar vein, a recent study by Volsuuri et al. (2023) identified a waste generation rate of 176 tonnes in the Tamale metropolis, corroborating the findings of this study. Cheela et al. (2021) contribute evidence suggesting that waste policies, taxable income per capita, and geographic location are pivotal factors influencing waste production.

The Further, an analysis of the waste types/composition in Tamale (see Table 4.1) revealed a consistent trend of high organic content across all income groups and sectors (43.7% to 62.3%) except at markets where it a recorded a value of 13.1%. Plastic waste is notably higher in markets (28.2%) compared to households, where it ranges from 18.3% to 21.5%. Hotels and markets exhibit somewhat appreciable levels of paper and textile waste percentages (11.4 and 14.7, 6.0 and 2.5 respectively). Glass and leather are generally low across all sectors and household income. Finally, “others” which constitute the miscellaneous group of materials was mostly high except for the markets where it recorded a value of 0.14%. The significant organic content across various income groups and sectors particularly low-income residential class and hotels, ranging from 43.7% to 62.3%, underscores the potential for WtE applications that capitalize on biodegradable fraction of MSW.

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Table 4. 1: Waste Composition in the Tamale-Metropolis

Percentage fraction of waste	Low-income Households	Middle-income Households	High-income Households	Average Households	Markets	Hotel and restaurant
Organic (%)	46.2	44.8	43.7	44.9	13.1	62.3
Plastic (%)	18.3	20.4	21.5	20.1	28.2	18.6
Metal (%)	1.9	1.8	1.6	1.8	0.3	1.0
Paper (%)	5.2	8.3	11.2	8.2	11.4	14.7
Textile (%)	1.7	1.5	1.7	1.6	6.0	2.5
Leather (%)	0.2	0.25	0	0.2	0.06	0.06
Glass (%)	1.3	2.5	3.6	2.5	1.8	0.7
Others (%)	24.7	19.9	16.7	20.4	39.0	0.14

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4.2.2 Waste generation in the different residential income Zones in Tamale metropolis

The per capita waste generation data reveals distinctive patterns across different income classes within the Tamale metropolis (Table 4.2). In high-income households, such as Vittin Estate, the per capita waste generation is found to be 0.47 kg/day, representing the lowest pcwg in the high-income communities in the metropolis with Kalpohin estate and Naaluro estate recording 0.52kg/p/day and 0.59kg/p/day respectively. On average, the high-income households within the metropolis exhibited a per capita waste generation rate of 0.52 kg/person/day, a finding consistent with the reported figure of 0.52 kg/person/day for the high-income class in the Sunyani regional

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capital by Miezah et al., 2015. Middle-class income areas exhibit a slightly lower per capita waste generation rate (0.48 kg/p/day), while low-class income areas exhibit a much lower rate (0.42 kg/p/day). The observed disparities align with studies that argue higher income levels often correlate with increased per capita waste generation due to elevated consumption (Arif et al., 2023; De koker, 2019; Romano et al. 2019 and Sinha et al., 2022). The findings also align with previous research indicating that waste generation is a complex interplay of socio-economic and demographic factors such as population density, household size, lifestyle, or cultural practices within specific neighborhoods (Saidu, 2023; Celestino et al., 2022; Goggins et al. 2019). While income levels contribute to waste patterns, the specific characteristics of localities within income classes underscore the need for nuanced waste management strategies tailored to the unique dynamics of each area.

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Table 4. 2: Sample size, localities and generation of solid waste

Tamale metropolis	Total waste generated	Total No. of people generating the waste	No. of household surveyed	Waste generation rate kg/day	Average per capita waste generation kg/p/day
High-income household	194.9	178	30	70.6	0.52
Middle-income household	179.9	191	30	69.4	0.48
Low-income household	157.4	256	40	79.9	0.42
Average household	176.1	N/A	100	73.3	0.47
Markets	4082.4	N.D	2	90.1	N.D
Hotels and restaurants	3788.0	N.D	3	84.2	N.D

Where N.D = not determined

4.2.2.1 Differences in Waste generation across income classes

The mean per capita waste for low income, middle income, and high-income groups are 0.42, 0.48 and 0.52 kg/p/day, respectively. Bartlett's test for equal variances supports the assumption of homogeneity of variances across the groups, with a chi-squared value of 0.0888 and a p-value of 0.957. This high p-value suggests that the variances are not significantly different, justifying the use of ANOVA. The ANOVA test confirms a statistically significant difference in waste generation among the different income levels ($F = 5.90$, $p = 0.0038$). This indicates that at least one of the income groups differs significantly in terms of waste generation. Post-hoc comparisons using the Bonferroni correction show significant differences in waste generation between low and high-income groups ($p = 0.013$), as well as between middle and high-income groups ($p = 0.010$). The results further reveal no statistically significant difference between low and middle-income groups ($p = 1.000$), likely due to the lack of a clear demarcation between these categories. Individuals from middle-income groups often reside close to those from low-income groups, leading to overlapping characteristics. Conversely, the high-income group demonstrates significant differences, which can be attributed to higher per capita waste generation. This finding is consistent with the higher levels of consumption and a greater propensity for purchasing observed among individuals in higher-income brackets.

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4.2.2.2 Multiple Linear Regression Analysis of Factors Influencing Waste Generation.

The multiple linear regression analysis was conducted to determine the factors influencing waste generation. The independent variables included in the model were gender, age, education, residence, family employment in the environmental sector, and income level.

The results showed (see Table 4.3) that, age (coff =1.840), was statistically significant at $P<0.015$. This suggests that as age increases, waste generation also increases thus, being equal. As individuals age, their consumption patterns often change. Older adults might have larger families or more stable financial situations, leading to increased consumption and consequently an increase in waste.

Also, the coefficient for education was 14.533, which was statistically significant at $p< 0.071$ indicating that higher levels of education are associated with increased waste

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generation (Eberle et al., 2022). Higher education levels are often associated with higher socioeconomic status and greater consumption of goods and services (Eberle et al., 2022). Educated individuals might have more disposable income and access to a wider variety of products, leading to increased waste.

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Furthermore, Income level is statistically significant at $p < 0.042$ with a coefficient of 20.818, which suggests that higher income levels are associated with higher waste generation. Higher income levels enable individuals to purchase more goods and services, leading to increased waste generation (Thyberg and Tonjes, 2016). Wealthier individuals are likely to have higher standards of living and greater consumption patterns.

These findings highlight the importance of demographic and socioeconomic factors in influencing waste production. Specifically, older individuals, those with higher levels of education, and those with higher income levels tend to generate more waste. The positive association between income and waste generation implies that wealthier individuals may consume more resources, leading to increased waste. Similarly, the positive impact of education on waste generation could be due to higher consumption patterns among more educated individuals.

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Table 4. 3: Multiple linear regression of variables predicting waste generation

Variables	*Coefficients*	*Std. Err*	*p-values*
Gender	-5.179	26.63	0.846
Age	1.840	0.740	0.015**
Educational level	14.533	7.968	0.071*
Residence type	-35.852	51.860	0.491
Family Employed in environmental sector	-11.776	24.478	0.632
Income	20.818	10.117	0.042**
Household size	-4.496	3.181	0.161
Constant	166.8	73.59	0.026

****, **, and * at 1%, 5% and 10% significance level respectively.*

Source: Field work, 2024

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4.2.3 Physical Waste Composition

4.2.3.1 Organic waste

Figure 4.1 unveils intriguing patterns in organic waste generation across diverse zones, markets, and the hospitality sector in the metropolis Notably, low-income households emerge as significant contributors, constituting 46.2% organic waste in the overall waste composition. This inclination implies a potential correlation between economic constraints and heightened reliance on perishable food items, leading to increased organic waste generation. Low-income households are often associated with the prevalence of inappropriate food preservation methods often leading to waste generation (Fereja et al. 2022; Mansor, 2023). Furthermore, the data in Table 4.1

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underscores that the low-income households exhibit the highest overall household size (256) among the different income groups in the metropolis, corroborating the observed link between income levels, household dynamics, and waste generation as significant factors influencing food waste generation (Espuny *et al.*, 2021). Additional support for the observation in this study can be found in studies conducted globally, including those by Iqbal et al. (2023) in Pakistan, Yakubu (2023) in Nigeria, Elliott & Fox, (2022) in Washington, District of Columbia, USA and Muñoz-Cadena (2009) in Mexico City, all of which report that low-income households tend to generate a substantial amount of organic waste.

In contrast, middle-income and high-income households contribute slightly lower percentages of organic waste at 44.8% and 43.7%, respectively, suggesting less frequent utilization of perishable foods, lower household sizes and more effective food management practices among higher-income households. In the context of commercial sectors in the Tamale metropolis, although markets in the metropolis play a crucial role in generating organic waste, the proportion of organic waste in relation to the total waste mix is the smallest among the three waste sources examined in this study (constituting 13.1% of the overall waste mix). The intricate dynamics within markets, involving the sale of both perishable and non-perishable goods, as well as the competitive trade of organic waste—particularly sought after by animal farmers, especially during the dry season when there is limited grazeland available for livestock in the predominantly agrarian metropolis—emerges as the primary contributing factor to the observed percentage. However, the hotel and restaurant sector in the Tamale metropolis stands out with a remarkably high organic waste percentage of 62.3%,

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attributed to food preparation, plate waste, and significant utility of perishable items, this observation is mirrored in analogous studies by Nilsen et al. (2020), Iakovou (2021), and Azarmi (2018). Furthermore, the geographical location and cultural diversity exert additional influence on waste generation, as elucidated in the study by Bowan and Teirobaar (2014). This study recorded a municipal solid waste organic fraction of 47% in Wa. Although to a slight degree, the observation in the average household category from Table 4.2 deviates by only 3% from the findings of Bowan and Teirobaar (2014), affirming a notable similarity in percentage compositions between the study area and Wa. Both locations are in the same geographic zone, specifically the northern region. It is worth noting that the vegetation in the northern region, particularly during the wet season, supports animal breeding. However, due to prolonged dry seasonal patterns, livestock breeders' resort to utilizing organic residue from markets, households, and fields. This practice effectively diverts organic waste from open dumps and landfills.

Overall, the results indicate a predominance of organic waste in the metropolis, highlighting significant potential for resource recovery and energy generation. This is particularly evident in low-income residential areas and the hospitality sector, which should be prioritized as primary sources for Waste-to-Energy (WtE) technologies. Given the high organic content, technologies such as anaerobic digestion and landfill gas capture are especially suitable for these sectors.

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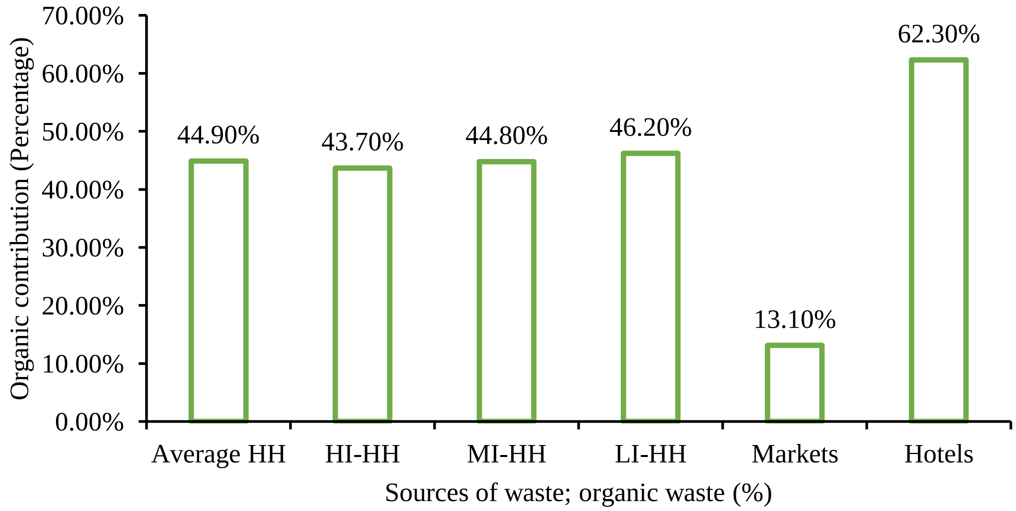

Figure 4. 1: Organic waste percentage

4.2.3.2 Plastic waste

It was observed that plastic waste in the Tamale metropolis tends to increase along increasing income zones (Table 4.4). High-income households recorded the highest percentage of plastic waste fraction at 21.5%, indicating a potential link between affluence and heightened consumption of plastic-packaged products (Jiang et al., 2022). Conversely, low-class income areas contribute 18.3% of plastic waste, suggesting a comparatively lower reliance on plastics. The observation could be attributable to the comparatively higher patronage and consumption of plastics-packaged food and refreshment products in the high-income households within the metropolis. Research conducted by both Puopiel et al. (2010), and Bowan and Tierobaar (2014) documented a plastic content of 20% in the northern regions of Ghana, specifically in Tamale and Wa, respectively. This aligns with the recorded 20.1% of plastic waste for average household category in the present study (see Figure 4.2). It's worth noting, however, that this percentage was higher than the 10.9% plastic

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waste fraction reported in a household survey conducted in Tamale by Miezah et al. (2015). The noted disparity could be ascribed to the surge in economic activities over the period, accounting for the higher prevalence of plastic waste in the present study compared to before. Markets play a pivotal role in plastic waste generation, contributing a substantial 28.2% of plastic waste fraction to the overall waste stream. The bustling nature of markets, characterized by the prevalence of individually wrapped items and disposable packaging, significantly influences plastic waste levels (Le, 2022). This is exemplified at the Tamale-Aboabo market, which serves as an all-year-round hub for a diverse array of secondhand (used) clothing, consistently packaged in plastic materials referred to as "bales". Consequently, plastic constitutes a significant portion of the overall composition of market wastes in the metropolis, as illustrated in Figure 4.2. It is equally crucial to emphasize that markets occupy a prominent position with a notably high percentage of plastic waste among the waste sources examined in this study (See Figure 4.2). Within the hotel and restaurant sector, the plastic waste fraction was recorded at 18.6%, highlighting the significant impact of single-use containers and packaging practices within the metropolis's hospitality industry. This aligns with the findings of Lindegren et al. (2021), who reported that the hospitality sector contributes substantially to plastic waste generation due to high reliance on disposable packaging, takeaway containers, and bottled beverages.

In the metropolis, the predominant types of waste within the plastic waste fraction encompass polyethylene bags for drinking-water sachets, PET bottles containing soft drinks and vegetable cooking oil, low-density polyethylene, and polystyrene, which is utilized for food wrapping and as carrier/garbage bags. This observation aligns with

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the outcomes of earlier investigations by Addae et al. (2021), Amos & Cardé, (2022), and Lindegren et al. (2021). In general, a substantial percentage of plastic is observed across all waste sources in the study. This trend may be attributed to the widespread use of packaging materials for staple foods (such as adua, sagam, waakye, etc.) in the northern regions (Qian et al., 2021). Additionally, the consumption of "sachet water" and other cold products packaged in plastics is prevalent among consumers as a means to alleviate discomfort caused by the hot conditions, especially since the study was conducted during the time of the year when rainfall had subsided significantly, making way for the dry season. Comparable findings by Grini (2022) also note an increase in packaging waste during the summer period on the beaches of northern Crete.

The findings imply that within the metropolis, the dominant types of waste in the plastic waste fraction include polyethylene bags from drinking-water sachets, PET bottles from soft drinks and vegetable cooking oil, low-density polyethylene, and polystyrene. These materials are primarily sourced from markets and high-income areas, where the results indicate a high volume of plastic waste. This makes these areas particularly suitable for plastic recycling initiatives.

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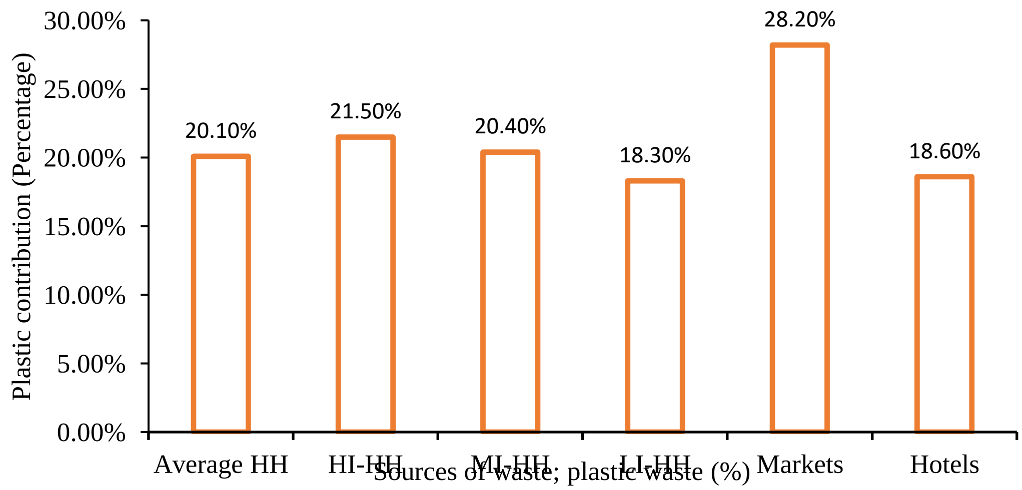

Figure 4. 2 Plastic waste percentage

4.2.2.3 Metal Waste

The analysis of the distribution of metal waste reveals intriguing patterns across various sectors, including households, markets, and the hotel/restaurant sector. Noteworthy is the consistent and relatively low presence of metal waste across all sectors and socioeconomic strata, demonstrating minimal fluctuations. Contributions from low-income households stand at 1.9%, middle-income households at 1.8%, and high-income households at 1.6%, suggesting a persistent trend irrespective of economic status (See Figure 4.3). This uniformity may suggest effective metal recycling practices, or the inherent value associated with metal, prompting individuals to actively segregate and recycle such materials, as proposed by Yu et al. (2023). This finding aligns with the conclusions drawn by Addae et al., (2021) and Amos & Cardé, (2022), who similarly reported a comparatively low contribution of metal waste fraction in comparison to organics, plastics, and paper and cardboard. In the context of commercial sectors, both markets and the hotel/restaurant industry exhibit relatively

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lower percentages of metal waste at 0.3% and 1.0%, respectively. The average recorded metal waste fraction for households in this study is 1.8%, presenting a lower figure when compared to the findings of Miezah et al. (2015), who focused on households in Tamale, reporting 2.8%, Puopiel (2010) whose work centered on Tamale and recorded 10%, and Addae et al. (2021), who reported an average of 2.4% in their study on Kumasi markets. However, the observation in this study aligns favorably with the work of Asase (2011), who recorded a metal waste fraction of 1.8% in Asokwa-Kumasi.

Although parts of this study were conducted in two of Tamale's busiest markets, where a diverse range of metal waste was expected, the influence of buyer and seller activities was anticipated to significantly increase the generation of canned drink waste. This expectation was further reinforced by the timing of the study, which coincided with the dry season in Ghana, a period when beverage consumption typically rises due to reduced rainfall and increased temperature. However, contrary to expectations, market areas contributed the lowest metal waste fraction among the three waste streams analyzed in this study. A possible explanation could be the high prices of canned drinks and foods in comparison with plastic packaged ones and also the vibrant nature of the scrap metal enterprise in the metropolis. Scrap metal dealers were observed to be more widespread in market areas where they find their enterprise more accessible as compared to the households, a possible explanation to the low percentage of metal waste fraction in the market compared to households. The metal waste items observed in the study area comprised of ferrous and non-ferrous metals, however, the greater portion consisted of empty tins/cans from used canned foods and drinks. The scrap

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metal sector holds significant economic value both within Ghana and internationally, making it appealing to itinerant buyers and consequently decreasing its representation in the municipal waste stream. These metals find applications in local steel industries and are even subject to exportation (Miezah et al., 2015). Consequently, further inquiry is imperative to discern the preferred metal types and collect data regarding the activities of metal waste pickers. Additionally, efforts to educate the public on the environmental and economic benefits of metal recycling may contribute to sustained low levels of metal waste across diverse socioeconomic and commercial contexts.

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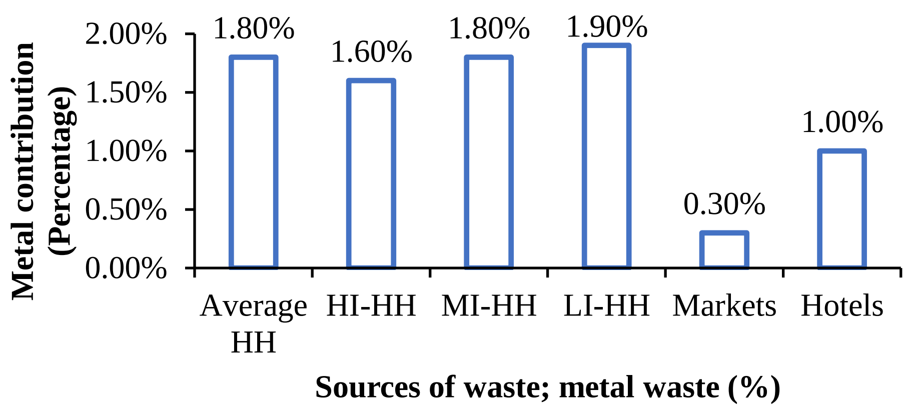

Figure 4. 3: Metal waste percentage

4.2.2.4 Paper waste

The analysis of paper waste distribution unveils discernible patterns across various socio-economic strata, markets, and the hotel/restaurant sector in the Tamale metropolis (see Figure 4.4). Among the socio-economic income strata, high-income households demonstrate the most substantial proportion of the paper waste fraction, recording paper waste at 11.2%. This observation implies a plausible correlation between affluence and an increased consumption of paper-based products, as noted in

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the study by Hermannsson et al. (2023). Following closely are middle-income and low-income households, presenting percentages of 8.3% and 5.2%, respectively (refer to Figure 4.4). This progression signifies a diminishing gradient in paper waste as one descends the income spectrum. On the commercial aspect, Markets emerge as substantial contributors to the paper waste fraction, constituting 11.4% of the total. The vibrant commercial activity within markets, where items are frequently wrapped or packaged using paper materials, markedly influences this percentage (Cenci-Goga et al., 2020). The hotel/restaurant sector assumes a noteworthy role, contributing a significant 14.7% of the paper waste, arguably the most substantial paper waste fraction among the three waste sources considered in this study. This elevated percentage can be ascribed to the widespread use of disposable paper products within the hospitality industry. The paper waste fraction identified in the study primarily comprises exercise book chapters, magazines, tissue papers, newspapers, corrugated cardboard, cartons, and folding boxes.

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Analogous research conducted by Miezah et al. (2015), Poupiel et al. (2010), and Monney (2013) in the northern regions of Ghana, specifically in Tamale and Wa, documented paper waste contents of 3.2%, 5%, and 3%, respectively. These figures are notably lower than the recorded 8.2% paper waste fraction for the average household category in the current study (refer to Figure 4.4). However, it is noteworthy that this percentage aligns with the observed range of 6.2% to 10.5% for the paper waste fraction reported in a market characterization study conducted in Kumasi by Addae et al. (2021). The observed disparity with earlier research in the study area could be attributed to heightened socioeconomic activities, urbanization, and changing

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lifestyle patterns in today's Tamale metropolis compared to approximately eight years ago when the earlier studies were conducted. Collectively, paper waste fraction ranks as the fourth largest in the waste mix considered in this study. This observation is unsurprising, considering that plastics have supplanted certain paper packages due to their flexibility and price competitiveness. Moreover, despite being prohibited, it is a prevalent practice among janitors assigned to collection bins to burn papers, aiming to create space in skips, accommodate other waste forms, and generate extra income.

Overall, the results indicate that high-income areas, markets, and the hotel sector record the highest percentages of paper waste in the metropolis. Consequently, targeted paper recycling initiatives should focus on these sectors. Additionally, given that paper constitutes a biodegradable and combustible fraction of waste, it is well-suited for various Waste-to-Energy (WtE) technologies, including incineration, gasification, and anaerobic digestion. However, it is important to note that the overall percentage of paper waste in the city's total waste mix is relatively low. Therefore, paper should best be considered as a complementary feedstock alongside other waste forms when evaluating WtE technology options for the metropolis.

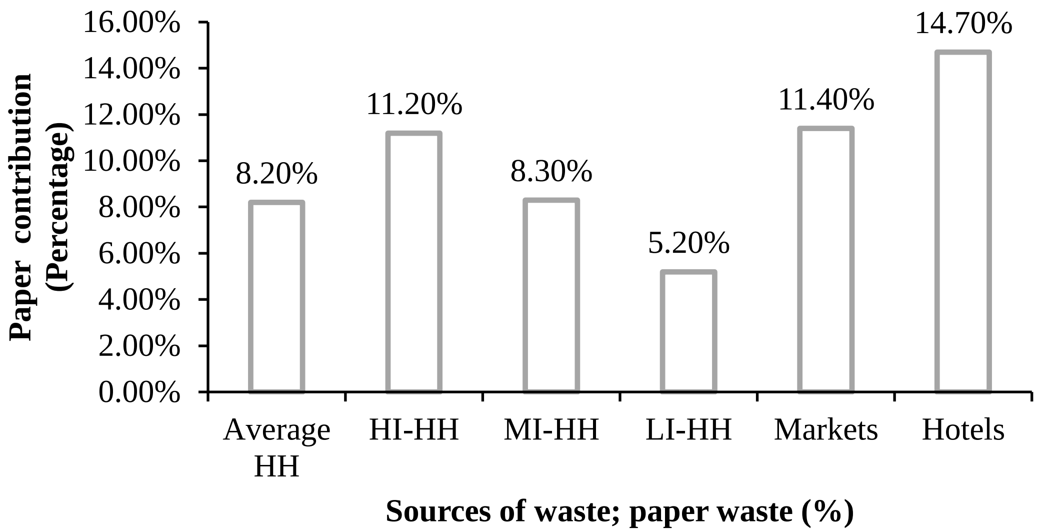

Figure 4. 4: Paper waste percentage

4.2.2.5 Textile waste

The analysis of textile waste distribution unveils discernible patterns among income classes, markets, and the hotel/restaurant sector. Within low-income households, there is a modest contribution of 1.7% to textile waste, indicative of potential economic constraints that restrict textile disposal. Similarly, middle-income and high-income areas demonstrate comparable percentages of 1.5% and 1.7%, respectively, suggesting a relatively consistent generation of textile waste across these economic strata (see Figure 4.5). This uniformity may imply similar consumption patterns or disposal behaviors associated with textile products within the metropolis. In the commercial sector, specifically within markets, there is a noteworthy surge in textile waste, constituting 6.0% of the overall waste stream. The hotel/restaurant sector contributes 2.5% to textile waste, derived from linens, uniforms, and other disposable textile items utilized within the industry. The observed heightened percentage of textile waste fraction in markets and hotels aligns with the transient and disposable nature of fast

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fashion, especially prevalent in market settings where low-cost textiles are frequently used (Fisher et al., 2020). Also, the observed phenomenon can be attributed to factors, including the significant number of tailoring shops located within the two market centers under consideration in this study. These markets are bordered on all fronts by densely populated Muslim communities within the metropolis. The populace in these areas has a penchant for the consumption of fast fashion in the form of tailor-made or hand-made clothing. This inclination is ostensibly driven by the desire to make appearances at cultural and social gatherings, especially weddings, which are a frequent occurrence in the study area thus generating textile waste. Additionally, the sale of second-hand clothing in the markets, which often requires apparel alteration before they are fit for purpose, also generates substantial textile waste (Addae et al.,2021). Furthermore, the reopening of schools in Ghana at the beginning of the academic year in September coincided with the period when the present study was conducted. This alignment possibly led to an increased demand for textiles, as students in this period typically purchase locally-tailored fabrics, including dresses, curtains, bedsheets, napkins, etc. The production and use of these items contribute to waste generation, both at the point of sewing and eventually after usage. Parallel investigations carried out by Miezah et al. (2015) and Monney (2013) in the northern regions of Ghana, particularly in Tamale and Wa, reported textile waste contents of 0.9% and 4%, respectively. These figures diverge from the recorded 1.6% textile waste fraction for the average household category in the present study (refer to Figure 6). It is worth noting that this observation aligns with the findings (2%) of Miezah et al. (2015) covering all ten regions in Ghana. This consistency is also reflected in the

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observation of Addae et al. (2021), who reported a 1.8% textile waste fraction in Kumasi. Textile waste origins within the metropolis include worn-out carpets, curtains, remnants of clothing remaining from the sale of imported "used" clothing, and discarded fabric remnants obtained from dressmaking and apparel alteration processes. Furthermore, sanitary textile waste, encompassing items like baby nappies and sanitary napkins, adds to the comprehensive textile waste stream. The notable volumes of textiles documented in the commercial sector of the Tamale metropolis constitute a persuasive business opportunity for textile recycling within the markets—an opportunity that merits proactive exploration and exploitation in the Tamale metropolis.

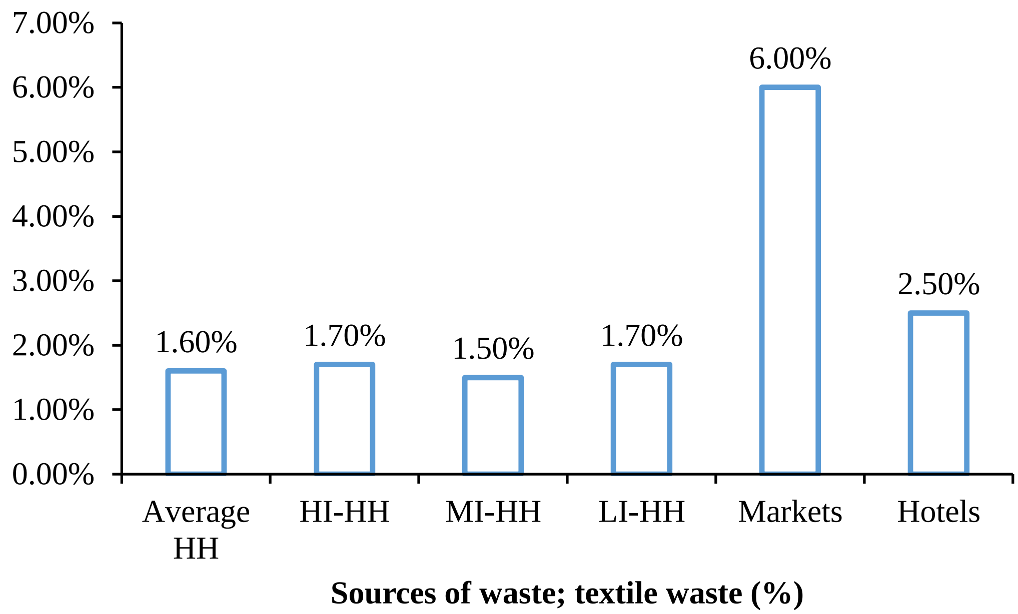

Figure 4. 5: Textile waste percentage

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4.2.2.6 Leather waste

The analysis of leather waste yields insights into disposal trends across residential classes, markets, and the hotel/restaurant sector (see Figure 4.6). Notably, the contribution of leather waste remains minimal across all strata, with low- and middle-income households reporting minimally high percentages at 0.2% and 0.25%, respectively. Intriguingly, high-income households register zero leather waste, suggesting a potential aversion to leather goods in wealthier communities or efficient recycling practices. In the commercial sector, specifically in markets, leather waste accounts for only 0.06%, suggesting a minimal contribution from this sector. This low percentage may reflect the limited use of disposable leather products in commercial settings or a preference for alternative materials, such as synthetic substitutes, which dominate market transactions. Similarly, the hotel/restaurant sector reports a modest 0.06% leather waste, reinforcing the limited impact of leather disposal within the hospitality industry in the metropolis. The relatively low percentages recorded in all three waste sources in the study could stem from various factors, including a comparatively low number of cobbler shops and stores with leather products in the metropolis, as well as the presence of itinerant bargain hunters collecting unwanted leather items, diverting them from the waste stream. Another contributing factor could be the incineration of this waste at dumping sites.

Investigations carried out by Miezah et al. (2015) reported a leather waste fraction content of 1.0% in the northern region of Ghana, specifically in Tamale, and across all ten regions of Ghana. Despite being higher than the recorded 0.2% of leather waste fraction for the average household category in the current study (refer to Figure 4.6),

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it is important to acknowledge that both percentages, including the earlier research value, are relatively low if not the least in the waste stream. In the context of this research, the items in the leather waste basket encompassed deteriorated "previously used" leather items, including shoes, bags, belts, garments, wallets, remnants from unsold or substandard leather products, and leftovers from cobblers, furniture, and upholstery establishments.

The findings of the present study underscore an encouraging pattern of limited leather waste production across the three residential income classes and commercial settings. Approaches aimed at preserving and enhancing this favorable trend might entail advocating for sustainable leather manufacturing practices, increasing awareness regarding the durability and recyclability of leather goods, and fostering responsible consumer conduct in the disposal of leather items.

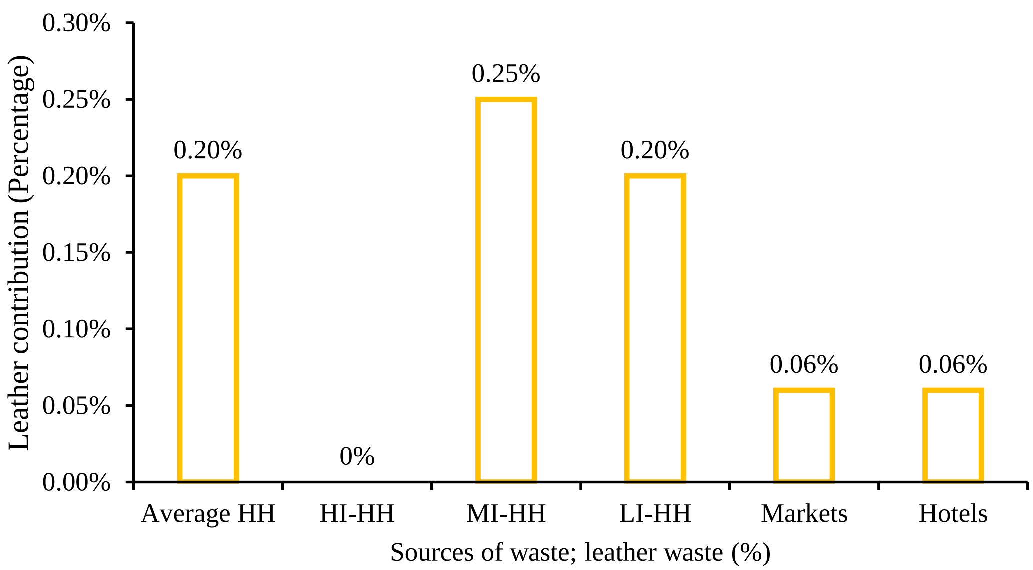

Figure 4. 6: Percentage of Leather waste measured waste in the Tamale Metropolis

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4.2.2.7 Glass waste

Examining the disposal of glass waste unveils clear trends across different income brackets of residents, markets, and the hotel/restaurant sector. In well-off neighborhoods, the highest proportion of glass waste stands at 3.6%, hinting at a possible connection between wealth and a preference for glass-packaged items (Kim, 2020). The middle-income and low-income households echo this pattern with percentages of 2.5% and 1.3%, respectively, indicating a gradual decline in glass waste as one descends the income ladder (refer to Figure 4.7). Shifting our focus to the business side, particularly in markets, there's a distinct decrease in glass waste, contributing 1.8% to the overall waste stream. This lower figure can be ascribed to active material recovery initiatives within markets, where residual glass bottles and other glass-packaged goods are frequently recycled using circular economy models like reuse and refill. These methods play a significant role in diminishing glass waste fraction across various waste streams (Medina-Mijangos et al., 2021). Relatedly, the hotel/restaurant sector reports an even lower proportion of 0.7% in glass waste, potentially signaling a limited use of glass. Also, this might be attributed to the substitution with plastic, given its relatively lower cost and greater convenience in handling. Supporting this observation, Table 4.1 underscores the point, detailing a breakdown of 18.6% plastic compared to a mere 0.7% of glass in Tamale hotels.

Investigations carried out by Puopiel et al. (2010) and Miezah et al. (2015) uncovered that the northern region of Ghana, specifically Tamale, exhibited a 5.0% glass waste fraction content, a figure that surpassed the recorded 2.5% glass waste fraction in the average household category of the current study (see Figure 4.7). Notably, Miezah et

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al. (2015), in their comprehensive research spanning all ten regions of Ghana, reported a glass waste percentage of 3%, aligning with the findings in this study. Additionally, (Addae et al., 2021), in their study characterizing Kumasi markets, noted a glass fraction ranging from 3.3% to 3.6%. While their results only slightly deviate from the current study, this difference could be attributed to the higher population, economic activities, and the prevalence of pubs, restaurants, and drinking spots in Kumasi compared to the Tamale metropolis where this research took place.

In general, glass waste remained minimal across all waste streams considered in this study, possibly due to its limited utility driven by factors like affordability and ease of handling. Furthermore, concerns related to health and safety, particularly with chipped edges and cracks in broken bottles, contribute to the reduced use of glass, especially in residential areas. Additionally, the predominantly Muslim community in Tamale exhibits relatively lower consumption of alcoholic beverages, which are commonly packaged and served in glass containers. Despite these factors, an active material recovery center was observed at the Aboabo market, intercepting unbroken glass bottles before they are discarded into the main market skip. In a related vein, bottles rejected by collectors from beverage companies such as Coca Cola, Guinness, etc., find new life as measuring vessels for traders dealing in kerosene, cooking oil, honey, and other goods. In households, these bottles serve as both decorative pieces and containers for drinking water. Overall, the quantity of glass waste generated in Tamale doesn't pose a significant environmental threat, and the volumes across the different residential income classes and sectors are not substantial enough to justify recycling

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into glass powder, a practice often employed as a substitute for fine powder in high-performance concrete (HPC) (Esmaeili, & AL-Mwanes, 2021).

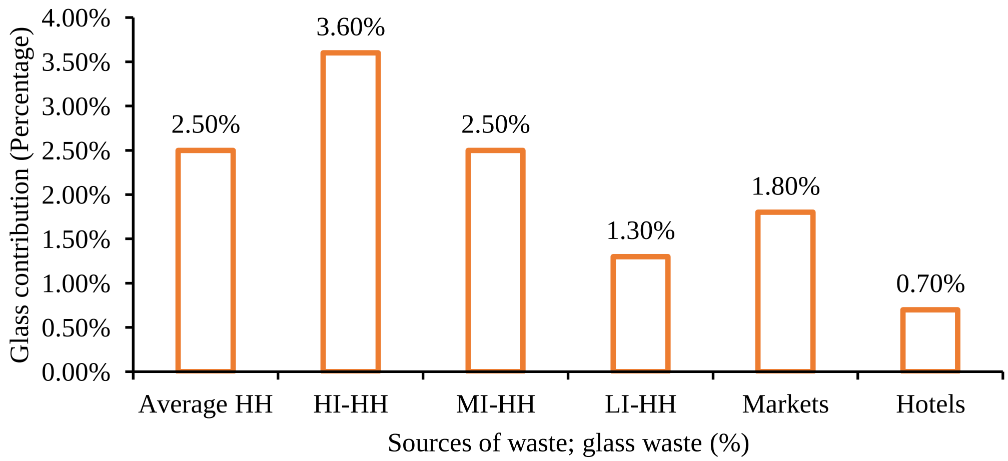

Figure 4. 7: Glass waste percentage

4.2.2.8 Other Waste

The "Other" waste category encompasses a diverse array of inert and miscellaneous materials, ranging from wood trimmings and fine soils to charcoal ash, small stones from unpaved compounds, and toddler diapers. Upon delving into this waste category, intriguing disparities emerge across different income classes, markets, and the hotel/restaurant sector. Notably, in low-income households, "Other" waste makes up a substantial 24.7%, highlighting the prevalence of various non-standardized materials in the waste stream. This can be linked to the diverse and often informal nature of activities in these areas, resulting in the generation of a heterogeneous mix of waste materials. In contrast, middle- and high- income areas show decreasing percentages at 19.9% and 16.7%, respectively, suggesting a potential correlation between affluence and a more streamlined waste composition (refer to Figure 4.8).

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Markets play a significant role in contributing to this miscellaneous waste category, accounting for a noteworthy 39.0% of the total waste. The dynamic and multifaceted nature of market activities likely contributes to the diverse array of materials found in this waste stream. Additionally, the blending of street sweeping and drain cleaning waste has elevated the percentage of other waste in the market. In contrast, the hotel/restaurant sector reports a minimal 0.14% of other waste, indicating a more controlled and potentially regulated waste generation process within the hospitality industry.

The observed components of other waste in the Tamale metropolis include, but are not limited to, sand, silt, grit, ash, inseparable sand and food residues, street sweepings and drain cleaning waste, unpaved road particles, and some amount of construction debris and diapers.

The present research uncovered a notable prevalence of "other" waste materials, with average residential income households registering 20.4%, and markets documenting 39.0%. This aligns favorably when compared to earlier studies by Essumang (2000) in Cape Coast at 26%, Asase (2011) in the Ashanti region at 31.4%, and Monney et al., (2013) in Wa at 33%, all of which conducted Municipal Solid Waste (MSW) composition analyses among households in Ghana. However, in a waste characterization study in Tamale, Miezah et al. (2015) reported a waste fraction for both inert and miscellaneous materials at 7.9%, a notably lower figure than the ones recorded in the current study. The observed difference might be ascribed to the advancements in socioeconomic activities in the Tamale metropolis and increased population coupled with cultural and lifestyle shifts over the years.

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To tackle "Other" waste in the Tamale metropolis, interventions should be customized to suit the specific characteristics of each sector. In low-income areas, implementing community engagement and waste segregation initiatives could effectively manage the diversity of materials. For markets, strategies might involve conducting waste stream analyses and implementing targeted recycling programs. The minimal contribution from hotels and restaurants implies that existing waste management practices are effective; however, continuous improvement and the adoption of sustainable material choices could further reduce environmental impact.

The preceding analysis suggests that the waste stream in the metropolis is characterized by a prevalence of miscellaneous or other waste forms, including wood trimmings, fine soils, charcoal ash, small stones from unpaved compounds, and toddler diapers. These types of waste are particularly significant in low-income residential areas and market centers. Given their mixed and nearly inseparable nature, incineration emerges as a potentially suitable WtE option for their management.

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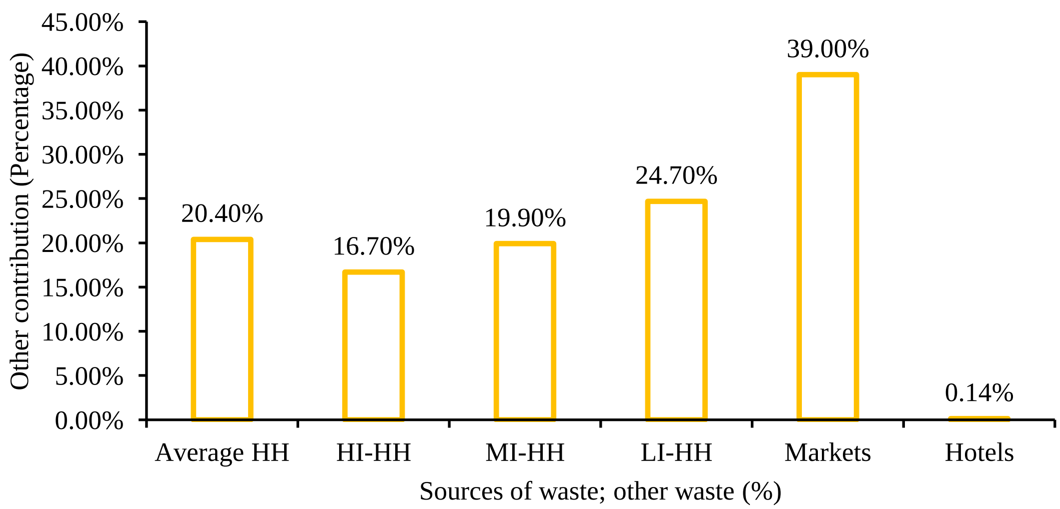

Figure 4. 8: Other waste percentage

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4.2.4 Chemical Waste Composition

4.2.4.1 Proximate Analysis and Potential WtE Conversion Options

The study started on the onset of the dry season, coinciding with reduced humidity levels in northern region of Ghana. This may have impeded the decomposition of organic matter, contributing to the low moisture content values across waste streams (refer to Table 4.4).

According to the Central Pollution Control Board's (CPCB) criteria, the Tamale metropolis falls within the population bracket of 1 lakh to 10 lakhs as the Metropolis generates 176.1 tons/day of waste, with an average organic matter percentage of 44.9%.

Again, going by CPCB criteria, recommended waste processing technologies for this category include (a) an Integrated Waste Plant with bio-methanation, composting, and Refuse Derived Fuel (RDF); (b) a WtE plant for power, employing gasification, pyrolysis, incineration, and mass burning; and (c) RDF for the cement industry and plastic to fuel oil (CPCB, 2016).

The subsequent proximate analysis results and the potential WtE options are presented and discussed under category (b):

Anaerobic Digestion (AD): The recorded moisture range (5.4% - 12.6) falls within the acceptable range for AD (<20%) (Aromolaran, 2021). However, high ash content (up to 65.4%) could significantly reduce digester efficiency and methane yield by diluting organic matter content (Villamil et al., 2020). Pre-treatment to remove ash or blend with readily biodegradable wastes might be necessary. Volatile matter content

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(21.81% - 77.20%) shows promising potential for methane production, as higher levels indicate greater availability of readily degradable organics (Li et al., 2020). Conversely, low fixed carbon (5.00% - 12.5%) suggests limited long-term methane generation potential due to the slow decomposition of this fraction.

Incineration: The relatively low moisture content of the waste presents an advantage for efficient combustion as high moisture reduces energy recovery (Logeswaran et al., 2020). However, the wide range of ash content poses both challenges and opportunities. While high ash content (up to 65.4%) reduces the waste's calorific value and increases handling costs, it can also act as a bed material in fluidized bed incinerators, potentially improving combustion efficiency (Huang et al., 2021). Volatile matter content suggests good combustion potential due to its rapid burning (Logeswaran et al., 2020). The low fixed carbon content might contribute to faster incineration but could also reduce overall energy output.

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Landfill Gas (LFG): The low moisture content is beneficial for landfill aeration and efficient methanogenesis, as excess moisture can impede decomposition (Ermolaev et al., 2019). While the ash content range is significant, its non-biodegradable nature limits its contribution to LFG generation and necessitates proper landfill management. The observed volatile matter content exhibits promising potential for high-quality LFG production due to its readily decomposing nature, leading to higher methane concentration (Mukherjee et al., 2020). The low fixed carbon content suggests a potentially faster initial LFG generation but might limit long-term production due to slower decomposition.

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Gasification: The low moisture content facilitates efficient gasification as high moisture increases energy input for evaporation (Speight, 2020). The ash content range presents both challenges and opportunities. While high ash content can lead to slagging and fouling issues, it can also benefit slagging gasifiers by providing bed material and enhancing heat transfer (Abelha et al., 2019). The volatile matter content of the waste samples suggests good syngas generation potential due to its readily gasifying nature (Weiland et al., 2021). The low fixed carbon content could lead to faster gasification but might result in syngas with lower heating value.

Comparing the study's findings with similar works reported in literature further refines our understanding. Singh et al. (2023) reported municipal solid waste in India with a comparable ash content range (25-45%) but lower volatile matter (15-30%). This implies potentially lower methane production in AD and LFG compared to our study's waste. Li et al. (2020). studied food waste with lower ash content (5-10%) and higher fixed carbon (20-25%) than the present study. Suggesting a potentially higher AD efficiency for the food waste but slower LFG generation compared to the waste in the present study. While the present study's waste exhibits promising characteristics for various WtE options, careful consideration of technology-specific optimization strategies is crucial. Further detailed analysis of the elemental components of the waste in the Tamale metropolis, as well as an assessment of the institutional capacity, socioeconomic and environmental impact of waste-to-energy technologies, is required to provide a more comprehensive understanding of the suitability of the aforementioned WtE options for the study area. This information is essential for informed decision-making regarding their sound implementation in the metropolis.

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4.2.4.2 Elemental Analysis and Potential for WtE Conversion

The elemental composition of solid waste in the metropolis reveals carbon ranging between 17.96% and 40.70%, oxygen between 20.02% and 43.43%, hydrogen between 2.67% and 5.01%, nitrogen between 1.05% and 2.21%, and sulfur between 0.18% and 0.34%.

For anaerobic digestion (AD), the carbon (C) range in this study falls within the optimal 20:1 to 30:1 C:N ratio for stable AD, suggesting efficient methane production potential (Villamil et al., 2020). However, high oxygen (O) levels (up to 43.43%) pose a challenge, potentially inhibiting methanogenesis due to dissolved O_2 presence (Wang et al., 2020). As such, pretreatment or blending with readily biodegradable wastes may be necessary to reduce oxygen content and maximize AD efficiency. In the case of incineration, the high carbon content implies a strong calorific value, potentially leading to high energy recovery (Saqib et al., 2019). However, CO_2 emissions might elevate due to the observed correlation between oxygen and carbon content (IPCC, 2017). Flue gas treatment using technologies like wet scrubbers or dry sorbents might be necessary to comply with emission regulations (Wang et al., 2020). Regarding landfill gas (LFG), the wide range of carbon content (14.36% - 40.7%) suggests varying methane concentrations in the waste sample (Meneses-Quelal et al., 2021). Optimization strategies like controlled landfill aeration or waste layering could be employed to achieve a more consistent and potent LFG composition. The minimal nitrogen (N = 1.05% - 2.21%) and low sulfur (S = 0.18% - 0.34%) levels are beneficial for LFG quality, minimizing ammonia and SO_2 emissions, respectively. For gasification, the recorded carbon content aligns with desirable levels (Revocatus et al.,

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2023). The low nitrogen (N) and sulfur (S) content further contribute to a cleaner syngas with reduced NOx and SOx emissions (Man et al., 2020). However, the oxygen (O) content requires careful control to optimize gasifier operation and syngas quality (Soria-Verdugo et al., 2019).

It is important to note that the observed C:N range (8.1 to 31.5) is in the optimum range for various waste-to-energy technologies. However, segregating the waste feedstock can further enhance the quality of the final product. Comparing the study's findings with literature, Singh et al. (2023) reported a carbon range of 35-45%, similar to this study, aligning with expectations for efficient AD and incineration. Conversely, Mukherjee et al. (2020) on food waste reported lower carbon content (15-25%) and slightly higher nitrogen levels (3-5%), emphasizing the need to tailor WtE strategies to specific waste profiles for optimal results.

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Table 4. 4: Chemical composition of waste in the Tamale metropolis

SAMPLE	M.C (%)	Ash(%)	V.M(%)	F.C (%)	C(%)	H(%)	O(%)	N(%)	S(%)	C/N	NCV MJ/Kg	GCV (MJ/kg)
Hotels	5.4	56.8	30.30	12.90	17.96	2.67	20.02	2.21	0.34	8.13	3.65	8.4
Market	9.6	65.4	21.81	12.79	14.36	3.01	15.39	1.61	0.23	8.92	3.28	7.9
Residential												
LI-HH	7.4	21.17	42.36	8.6	32.55	3.15	41.83	1.12	0.18	20.13	6.11	23.4
MI-HH	12.6	19.31	54.83	7.46	33.08	2.89	43.43	1.05	0.24	31.50	5.91	26.2
HI-HH	11.4	17.8	77.2	5.0	35.91	5.01	39.93	1.12	0.23	32.06	8.33	27.4
Composite	10.2	29.4	57.11	13.49	40.70	4.68	23.58	1.37	0.27	29.71	9.68	28.9

VM: Volatile Matter, M.C: Moisture content, FC: Fixed Carbon, C: Carbon, H: Hydrogen, O: Oxygen, N: Nitrogen, S: Sulfur, GCV: Gross Calorific Value, NCV: Net Calorific Value, HI-HH: High-income Household, LI-HH: Low-income Household, MI-HH: Middle-income Household.

The analysis of moisture content reveals significant variations that correlate with specific sectors and income classes. Within the composite waste sample category, we observe a p-value of 0.04, suggesting statistical significance in moisture content. This significance might be influenced by the prevalence of organic waste (44.90%), which is known to retain more moisture. Another factor that could account for this observation is the dietary habits of the residents of Tamale, which are predominantly high in moisture-rich foods.

Similarly, in the markets sector, where the p-value is 0.03, the significant variance in moisture content can be attributed to the types of goods sold and waste handling

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practices. Markets in Tamale primarily sell fresh produce, which generates waste with higher moisture content.

Conversely, the hotel sector demonstrates a p-value of 0.18, indicating a lack of statistical significance in moisture content variation. This non-significance could be due to uniformity in waste management practices across various hotels, which often adhere to standardized procedures for waste disposal and treatment, thus minimizing variation in moisture content regardless of the hotel's size or client demographic.

The analysis of fixed carbon, oxygen, and nitrogen content across different income classes revealed distinct patterns, particularly in fixed carbon levels. To determine whether these differences were statistically significant, a one-way ANOVA test was performed, yielding a p-value of 0.02. This result indicates that the variation in fixed carbon content among the three income groups is unlikely to be due to chance. The differences are likely influenced by variations in waste composition, particularly the proportion of biodegradable materials and plastics, which are known to differ based on socioeconomic factors and consumption patterns across income levels. Similarly, in the market and hotel sectors, the recorded p-values for fixed carbon content were 0.04 and 0.016, respectively, as determined through a one-way ANOVA test. These values confirm the statistical significance of the observed variability, reinforcing the influence of specific waste stream components on the values reported in Table 4.4. Notably, the high presence of organic materials and paper products in hotel waste bins and biodegradable food waste in market refuse likely contribute to these variations.

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Additionally, a one-way ANOVA was also conducted for oxygen and nitrogen content within the composite income classes, yielding p-values of less than 0.05 and 0.003, respectively. This indicates that similar waste components, such as food scraps, packaging materials, and organic matter, are significantly influencing these parameters as well.

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4.2.4.3 Gross calorific value (GCV)

Limited literature exists on universally prescribed criterion for categorizing gross calorific value (GCV) as either standard or substandard. Nevertheless, in a broad sense, a high GCV is coveted, denoting superior energy density and enhanced heat production per unit of fuel. Illustratively, natural gas boasts a GCV of approximately 55 MJ/kg, whereas coal registers a GCV of roughly 24 MJ/kg (Zhang et al., 2024). The current investigation reports a GCV value of 28.9MJ/Kg for average households in the Tamale metropolis, rendering it a viable candidate for energy generation through the utilization of waste-to-energy technologies (see Table 4.7). Similar findings are reported in literature (Groß et al., 2016; ibikunle et al., 2021).

The calculated mean energy content in the Tamale metropolis, amounting to 6693.8 kcal/kg, constitutes a noteworthy observation. In accordance with the findings of Shahri (2020) the requisite minimal waste calorific value for employing thermal disposal methods is suggested to be within the range of 2000–2500 kcal/kg. This criterion adjusts to a lower threshold of 1500–1600 kcal/kg when contemplating self-burning in the absence of supplementary fuels. The outcomes derived from this study affirm that the mean waste calorific value inherent in the analyzed waste samples supports its suitability for application in both thermal conversion technology and

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biochemical conversion technology. Examination of Table 4.4 underscores that the identified attributes of low moisture content, elevated carbon content, and substantial organic composition within the waste of the metropolis contribute significantly to the observed calorific values especially for the household waste. This aligns coherently with previous studies by Amen et al. (2021); Kuleape et al. (2014); and Shekhar et al. (2023).

Furthermore, the gross calorific values exhibited a range of 7.9 MJ/kg to 28.9 MJ/kg, as indicated in Table 4.7. Notably, market and hotel waste demonstrated the lowest calorific values, registering at 7.9 MJ/kg and 8.4 MJ/kg, respectively. Conversely, household waste displayed the highest calorific value of 28.9 MJ/kg in the metropolis. This discrepancy can be ascribed to the significantly elevated organic composition of household waste in comparison to that of markets and hotels in the Tamale metropolis. Comparable findings were presented by Kuleape et al. (2014) in their exploration of energy recovery from solid waste in Akosombo, reporting a calorific range of 13.9 MJ/kg to 29.9 MJ/kg. Similarly, research conducted by Kazimbaya-Senkwe and Mwale (2001) in Kitwe, Zambia, recorded values ranging from 15.02 MJ/kg to 25.96 MJ/kg on a dry basis. Also, Fobil et al. (2005) reported an analogous calorific value of 14 MJ/kg - 20 MJ/kg for municipal solid waste in Accra, Ghana. In light of these outcomes, the solid waste from the study area emerges as a promising resource for fuel in both thermal and biochemical waste-to-energy conversion plants.

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4.3 Most suitable WTE technology for Tamale based on the available feedstock and MCDM

4. 3. 1 Prioritization of sustainability factors by stakeholder groups

A multi-part pairwise comparison of the analytical hierarchy process preceded the physical composition and the energy content anis. This focused on the main criteria relevant to the research goal: environmental, technical, social, and economic factors. This process aimed to determine the relative importance of the different stakeholder groups attached to the factors that contribute to waste-to-energy technology selection. The result of this pairwise comparison is presented in Table 4.5. The result shows priority weights allocated to each criterion by academia, government, NGOs, and the private sector. The consistency ratio (CR) for the pairwise comparisons was 0.063, well below the acceptable threshold of 0.1. This indicates a high degree of consistency in the judgements made by the stakeholders. Notably, with a weight of 40%+ across stakeholder groups, except private institutions, the environmental criterion merged as the most critical factor in waste-to-energy selection across all stakeholder groups. This aligns with previous research by Qazi et al. (2018), Alao et al. (2020), and Agbejule et al. (2021), who also found environmental concerns to be paramount in WtE technology selection.

Following the environmental criterion, is the social criterion, with weights ranging from 0.236 to 0.357 across different stakeholder groups. This highlights the significance of social acceptance and community impact in the decision-making process of waste-to-Energy Selection. Economic and technical criteria followed, with weights ranging from 0.087 to 0.270 for economic considerations and 0.085 to 0.152

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for technical aspects respectively. Interestingly, the private sector deviated from the other groups by prioritizing the economic criterion (ascribing a weight of 27% to it) over the environmental factor. This suggests that private entities may place a greater emphasis on financial viability and returns on investment when considering WtE technologies. In contrast, NGOs and community groups consistently prioritized social and environmental criteria over economic concerns, reflecting their focus on the broader societal and ecological impacts of WtE projects (refer to Table 4.5). Generally, the environment criterion received the most priority, followed by social, economic and technical criteria.

These findings underscore the diverse perspectives and priorities of different stakeholder groups in the context of WtE technology selection. While all groups recognized the importance of environmental considerations, their relative emphasis on social, economic, and technical factors varied based on their specific interests and concerns. This highlights the need for a comprehensive and inclusive decision-making process that takes into account the diverse viewpoints of all stakeholders to ensure the successful and sustainable implementation of WtE technologies in Tamale.

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Table 4. 5: Pairwise comparison of Main criteria by stakeholder groups

Criteria	Stakeholder groups (Priority vector)				Consistency ratio
	Academia	Gov't	NGOs	Private sector	
Environment	0.423	0.414	0.468	0.406	0.063
Economic	0.124	0.198	0.087	0.270	
Social	0.301	0.303	0.357	0.224	
Technical	0.152	0.085	0.088	0.146	

Influences of sub-criteria on WtE selection by stakeholder

To prioritize the twelve sub-criteria for selecting the most suitable waste-to-energy alternative for Tamale, four pairwise comparison matrices were created for each main criterion based on expert opinions. Table 4.6 presents a summary of these pairwise comparisons of the subcriteria in relation to the main criteria. Regarding environmental sub-criteria, with the exception of NGO's all other stakeholders (academia, government, and private sector) prioritized "pollution potential" over "public and occupational safety" and "climate change impact." This suggests a primary concern with minimizing immediate, localized environmental harm. However, the NGOs and community group placed the highest weight (0.613) on "public and occupational safety" indicating a heightened awareness of the potential health risks associated with WtE technologies, particularly for those directly involved in plant operations and residing near facilities. This divergence in priorities underscores the importance of considering both short-term and long-term environmental impacts, as well as the differential vulnerabilities of various stakeholder groups.

Technical Sub-Criteria; Across all stakeholder groups, "energy-generating potential" emerged as the most significant technical sub-criterion with weighted scores of (0.779, 0.724, 0.677 and 0.808), followed by "availability of know-how" at (0.079, 0.193, 0.192 and 0.074 weighted scores) and "sophistication of technology" at (0.143, 0.083, 0.310 and 0.118 weighted scores). This prioritization reflects a pragmatic focus on maximizing energy output and ensuring the availability of local expertise for the operation and maintenance of WtE plants. However, the relatively lower emphasis on technological sophistication may indicate a preference for simpler, more proven technologies that are easier to adapt and maintain in the local context.

Table 4. 6: Pairwise comparison of sub criteria with respect to main criteria across various stakeholder groups

Criteria	Sub criteria	Groups (Weighted scores)			
		Academia	Government	NGO's	Private sector
Environment	*Pollution potential*	*0.443*	*0.411*	*0.269*	*0.556*
	Climate change impact	*0.169*	*0.328*	*0.118*	*0.09*
	Public and Occupational Safety	*0.387*	*0.261*	*0.613*	*0.354*
Technology	*Sophistication of technology*	0.143	0.083	0.31	0.118
	Energy generating potential	0.779	0.724	0.677	0.808
	Availability of know-how	0.079	0.193	0.192	0.074
Economic	*Capital cost*	0.484	0.619	0.444	0.579
	Operation and maintenance cost	0.423	0.187	0.096	0.472
	Job creation	0.092	0.234	0.284	0.084
Social	*Impact on land and culture*	0.100	0.333	0.333	0.25
	Social acceptance	0.900	0.667	0.667	0.75

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Economic Sub-Criteria; In the economic dimension, all stakeholders agreed that "capital cost" is the most crucial factor, followed by "operation and maintenance cost" and "job creation." This prioritization suggests a strong emphasis on financial viability and cost-effectiveness in WtE technology selection. However, the NGOs and community groups assigned the least weight to "operation and maintenance cost," potentially reflecting a greater concern with the initial investment required for project implementation. Conversely, the private sector placed the highest emphasis on this sub-criterion, likely due to their interest in long-term profitability and operational efficiency.

Social Sub-Criteria; interestingly, there was a clear consensus among all stakeholder groups regarding the social dimension, with "social acceptance" overwhelmingly prioritized over "impact on land and culture." This finding underscores the critical importance of public perception and community support for the successful implementation of WtE projects. The strong emphasis on social acceptance may be attributed to the well-publicized concerns and protests by communities near existing WtE facilities in Tamale (Kan-uge et al., 2023), highlighting the need for proactive engagement and communication strategies to address potential social and cultural impacts. Overall, the observed variations in stakeholder opinions can be attributed to their diverse backgrounds, interests, and lived experiences (Mjahed & Abdulrahman, 2021; Johnson et al., 2022; Bowness et al., 2024).

4.3.2 Ranking of Waste-to-Energy alternatives

By bringing together the perspectives of the four stakeholder groups on the sub-criteria in this study, the researcher was able to establish the preferences of each group regarding the WtE options under consideration. Figure 4.7 highlights the pairwise comparisons of the sub-criteria in relation to the WtE alternatives.

As depicted in Figure 4.11a, 4.11b, 4.11c and 4.11d, anaerobic digestion emerged unanimously as the preferred alternative across all groups for sub-criteria such as "pollution potential," "operation and maintenance costs," "climate change impact," "availability of know-how," and "capital cost". Unanimously, stakeholders favor anaerobic digestion as the optimal choice for waste treatment in the Tamale metropolis. This decision is grounded in its advantages, including lower greenhouse gas emissions, decreased hazardous waste output, relatively reduced capital and operating costs, and heightened social acceptability (Liew et al., 2021; Dutta & Bose, 2022). From an environmental standpoint, anaerobic digestion not only facilitates MSW recycling and the generation of renewable energy but also has the potential to aid in climate change mitigation by capturing methane that would otherwise be released into the atmosphere (Sagar et al., 2022) as such, the observed widespread endorsement of anaerobic digestion among various stakeholder groups for climate change and pollution potential sub-criteria is unsurprising.

Although there are many operational small-scale anaerobic digesters in the Tamale Metropolis, primarily used for lighting and cooking (Opoku et al., 2022; Abdul-Wahab et al., 2023), which should have contributed to the technology's high social acceptance among stakeholder groups in the metropolis (Awafo et al., 2020), anaerobic digestion still received the least preference from nearly all stakeholders in terms of 'energy-generating potential' and 'job creation. This may be due to the belief that alternative WtE technologies, with larger plant sizes, have greater job creation potential than the

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predominantly small-scale anaerobic digestion facilities scattered across the study area. Additionally, its sensitivity to mixed waste, which is prevalent in the study area due to a relatively inadequate waste segregation practice among residents of Tamale metropolis, accounts for the energy potential limitation, resulting in lower energy generation potential compared to other WtE technologies. Consequently, initiatives supporting anaerobic digestion development in Tamale must include policies enforcing waste separation to realize the maximum benefits of this WtE technology.

Landfill gas (LFG) recovery stands out as the second most favored option among stakeholder groups (refer to figure 4.9). The appeal may stem from potential cost-effectiveness and availability of the Gbalahi landfill site in the Metropolis. This proximity may eliminate the need for intensive infrastructure, making LFG a potentially cheaper option to implement in the Tamale metropolis. However, LFG's popularity isn't uniform. Notably, the NGOs and community group ranked it considerably low, particularly on the social acceptance sub-criteria (0.15) (See figure 4.9). The observed disparity reflects the lived experiences of the various stakeholder groups especially in respect of the negative impacts of the Gbalahi landfill plant on surrounding communities in the Sagnarigu district. Specifically, there have been concerns on the health and environmental issues arising from improper management of the landfill, making stakeholders understandably cautious about further relying on the landfill site in the Tamale metropolis for gas generation. This contrasting perspective highlights the importance of considering diverse viewpoints of stakeholders in waste management decisions. The input from NGOs and community groups is crucial for informing policy changes, environmental regulations, and

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enforcement measures. Bodies like the Ghana Factories Inspectorate and Environmental Protection Agency can utilize this information to improve landfill management practices and mitigate negative impacts on surrounding communities.

Meanwhile, while private and government sectors prioritize economic considerations such as "job creation" and "Capital cost" sub criteria at a weight of 0.472 and 0.619 respectively (See figure 4.9b and 4.9c), the academic group (Figure 4.9d) placed emphasis on the pollution potential sub-criteria (weight = 0.423), leading all of them to view LFG more favorably. It can be inferred that they see its potential for generating revenue since it comes at a relatively low capital and operational cost, relatively environmentally friendly and contributing to energy security, outweighing the social concerns raised by NGOs and community groups. Navigating these diverse perspectives and finding a sustainable solution for waste management requires careful consideration of environmental, technical, social and economic factors. While LFG recovery presents a seemingly cost-effective option, addressing the concerns of affected communities and implementing robust environmental regulations are crucial for its responsible implementation. Only by prioritizing both ecological and societal well-being, and addressing fluctuating volumes of gas produced, can we ensure sustainable adoption of LFG as a waste management strategy that benefits everyone in the metropolis (Alam et al., 2022).

Gasification emerged as the third-preferred waste-to-energy (WtE) technology (see Figure 4.9). The technical sub-criteria (weight range between 0.677 to 0.808) shows that this preference is likely due to its strong ability to generate energy and its advanced plant features that allow for the treatment of mixed waste. However, the limited

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awareness and lack of existing gasification facilities in the study region raised concerns about its practical adoption, as stakeholders expressed skepticism regarding the technical expertise, infrastructure requirements needed for its successful implementation. This, together with its subpar economic and environmental performance as indicated by the scores of the sub criteria (weights ranging as low as 0.07 to 0.22), may have caused the stakeholder groups to place this WtE technology lower on the preference scale. From a technical standpoint, the absence of gasification infrastructure in Tamale may be as a result of lack of expertise in the field, as evidenced by the low weight assigned to "available technical know-how" (weight= 0.12) (see figure 4.9). Nevertheless, the social appeal of gasification (weight = 0.248) lies in its ability to reduce waste volume by 50–90%, offering a significant reduction in the land required for MSW disposal in Tamale. Additionally, the high temperatures and abundant sunshine in Tamale create an optimal environment for thermal treatment of MSW with reduced moisture content. Gasification can present a promising solution for MSW management in Ghana, particularly due to its waste-agnostic nature and substantial volume reduction potential. However, economic and environmental limitations in the context of Tamale, underscore the need for further research to determine its feasibility for managing waste in the city.

Incineration faced considerable reservations under various criteria and sub-criteria among stakeholder groups as has been observed by Wang et al., (2023) in their study on evaluating barriers and strategies to green energy innovations for sustainable development in China. Notably, all groups ranked it the least favorable option in terms of pollution potential, operation and maintenance costs, and climate change impact

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(refer to figure 4.9a, 4.9b, 4.9c, 4.9d). Concerns regarding its low social acceptability, potential impact on land, and high capital costs may have further contributed to this negative perception. However, incineration did find some Favour when it came to energy generation potential (Mostakim et al., 2021; Adeleke et al., 2021). A significant portion of stakeholders, particularly within the private sector, viewed incineration (weight = 0.231) and gasification as the most promising options for energy generation. This aligns with Liew et al. (2021), who found that gasification of refuse-derived fuel (RDF) from municipal solid waste is a highly efficient and cleaner alternative to conventional waste disposal methods. Their study highlighted gasification's lower emissions, higher energy recovery potential, and ability to integrate with existing waste management systems, reinforcing its viability as a sustainable waste-to-energy solution. Stakeholder support likely stemmed from incineration's well-established technology and its capability to generate substantial energy from mixed waste (weight = 0.40) (see Figure 4.9).

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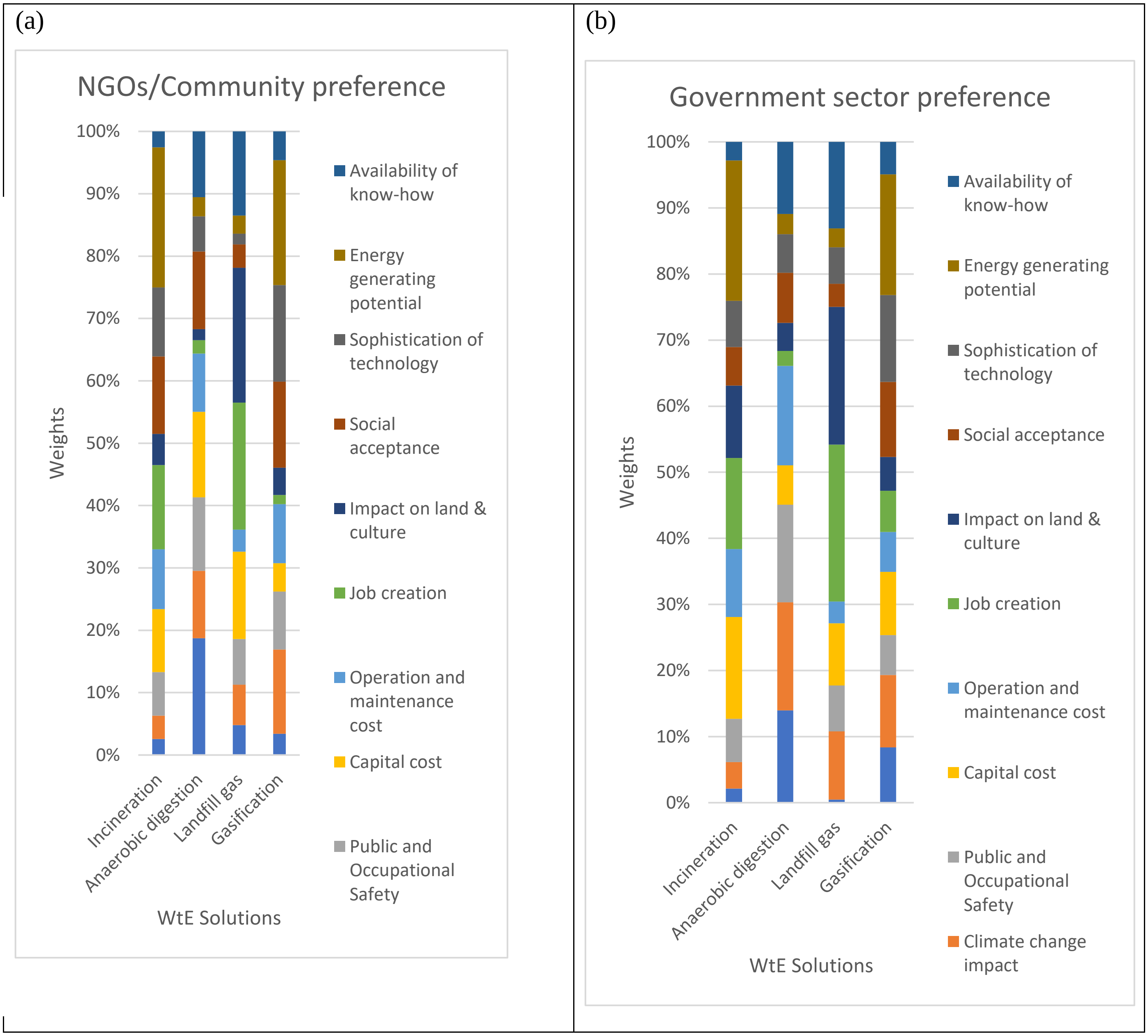

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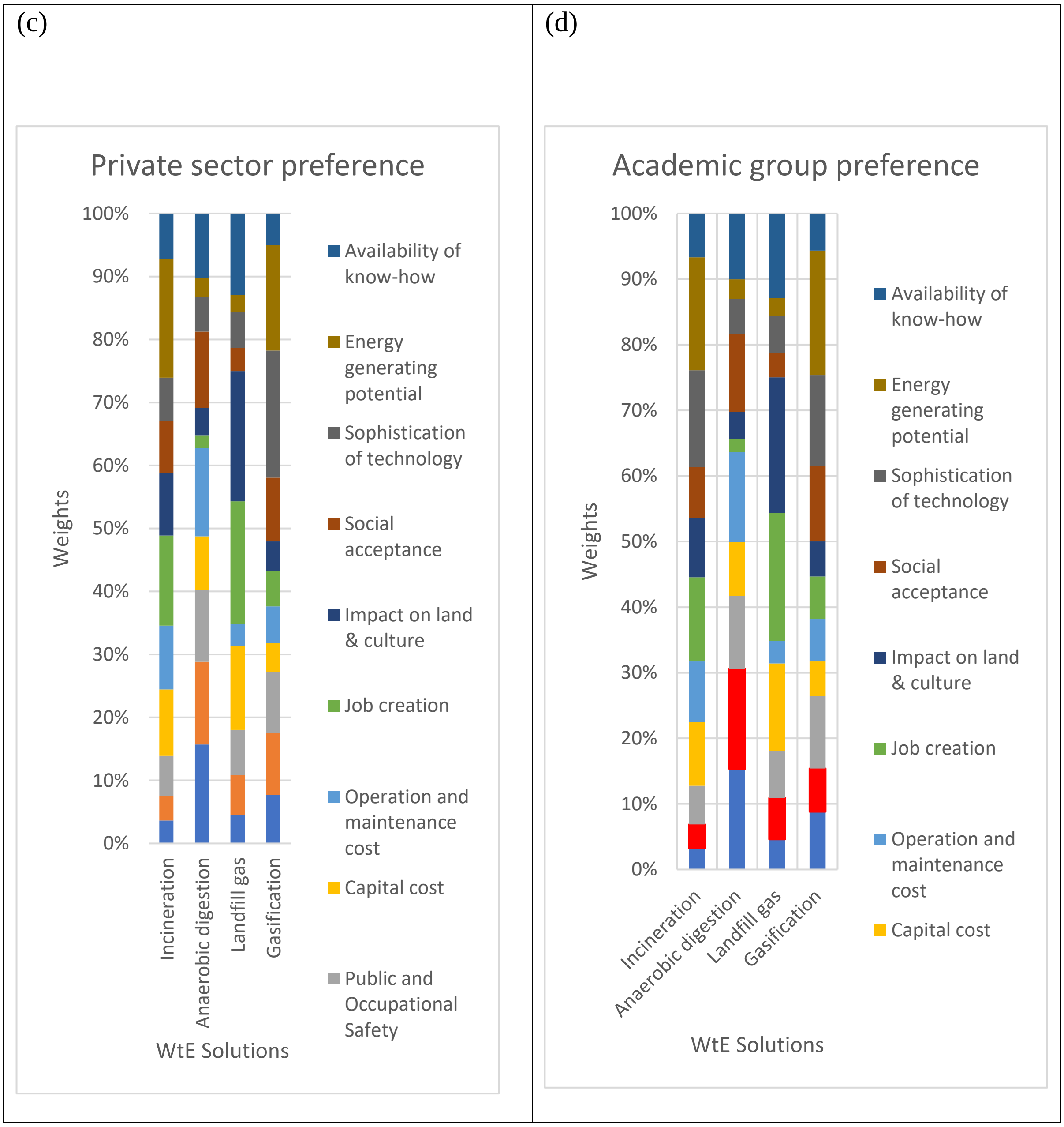

Figure 4. 9. Preference of stakeholders on waste to energy technologies (Author's construct, 2024).

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4.3.3 Trade-offs in Stakeholder Preferences for Waste-to-Energy (WtE) Technologies

Table 4.7 and Figure 4.9 illustrate the weighted scores, global priorities, and the varying trade-offs in stakeholder preferences for WtE technologies within the Tamale metropolis. These findings highlight the diverse priorities and perspectives shaping WtE decision-making in the region. To further evaluate the significance of these preferences, a statistical analysis of the weighted scores for each WtE technology was conducted, with the detailed results provided in Tables 4.8 and 4.9.

In comparing the options among stakeholders, the government group's higher preference for incineration (0.16) compared to NGOs (0.08) reflects a potential trade-off between energy recovery and environmental concerns. While incineration offers immediate energy benefits, NGOs prioritize minimizing emissions and long-term sustainability, favoring anaerobic digestion (0.48) and landfill gas (0.35). Even though gasification received generally low weighted priority, government's higher weighting for gasification (0.25) over the private sector (0.07) might indicate a trade-off between public interest and economic considerations. Also, the government group may view gasification as a solution for the future aligning with sustainability goals, whereas the private sector might prioritize proven and matured technologies with lower upfront costs, like anaerobic digestion (0.42). The stark contrast between academic preference for anaerobic digestion (0.53) and the private sector's low prioritization (0.42) highlights a trade-off between innovation and risk aversion. Academic's value resource recovery and environmental benefits, while the private sector leans towards established technologies with lower risk profile. In respect of incineration**,** the

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consistent preference for anaerobic digestion across all groups, particularly academics (0.53), contrasts sharply with the low prioritization of incineration, especially by NGOs (0.08). This underscores a widespread trade-off between sustainable resource recovery and immediate energy generation. While anaerobic digestion might have longer implementation timelines, its environmental benefits and potential for biogas production are valued over the immediate energy output and potential environmental concerns of incineration.

Overall, these trade-offs highlight the complexity of WtE decision-making. Governmental stakeholders need to balance energy needs with environmental concerns, while the private sector seeks economic viability alongside sustainability. Academics advocate for innovative solutions, whereas NGOs prioritize long-term environmental impact reduction. Understanding these trade-offs is crucial for the development of WtE implementation strategies as it considers diverse stakeholder priorities and promotes sustainable waste management.

Table 4. 7: Aggregation of prioritization of the waste to energy alternatives by stakeholders in Tamale

Institutions	Incineration	Anaerobic digestion	Landfill gas	Gasification
Government	0.16	0.3	0.25	0.25
Academia	0.05	0.53	0.15	0.2
NGO's	0.08	0.4	0.35	0.1
Private	0.25	0.42	0.3	0.07
Overall	0.15	0.41	0.26	0.15

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To assess whether stakeholder perspectives on waste-to-energy (WtE) technologies varied significantly across different groups and WtE options, a one-way ANOVA test was conducted. The dependent variable in the analysis was the stakeholder preference score for WtE technologies, while the independent variables included the type of stakeholder group (Government, Academia, NGO, Private) and the WtE technology option (Incineration, Anaerobic Digestion, Landfill Gas, Gasification). The ANOVA results (see Table 4.8) indicate that the overall model is statistically significant, with a p-value of 0.0325. This suggests that there is a significant difference in mean responses across stakeholder groups and WtE options. Specifically, the factor representing stakeholder group type yielded a p-value of 0.0498, indicating that perspectives on WtE technologies vary significantly between government, academic, NGO, and private sector respondents. Additionally, the WtE option factor produced a p-value of 0.0247, suggesting that stakeholder preferences are significantly influenced by the type of WtE technology under consideration. These results highlight that both stakeholder affiliation and technology type play a crucial role in shaping perceptions of WtE adoption.

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Table 4. 8: ANOVA for evaluating the significance of stakeholder groups and waste-to-energy options

Source	**Partial SS**	**Df**	**MS**	**F**	**Prob > F**
Model	0.1658	3	0.0553	3.89	0.0325
Group	0.0732	3	0.0244	2.75	0.0498
WtE Option	0.0926	3	0.0309	3.36	0.0247
Residual	0.1104	12	0.0092		
Total	0.2762	15	0.0184		

The post hoc analysis using Tukey's HSD test (see Table 9) reveals differences between the groups. The comparison between Academia and Government groups shows a mean difference of 0.200 with an adjusted p-value of 0.010, indicating a significant difference. Academia has a higher mean response than Government. Similarly, the comparison between Academia and NGO groups shows a mean difference of 0.100 with an adjusted p-value of 0.045, also indicating a significant difference, with Academia having a higher mean response than NGO. However, the comparison between Academic and Private groups shows no significant difference, with an adjusted p-value of 0.500.

Comparisons involving the Government group reveal significant differences as well. The mean response for Government is 0.100 lower than for NGO, with an adjusted p-value of 0.045, indicating a significant difference. Additionally, the mean response for Government is 0.250 lower than for Private, with a highly significant adjusted p-value

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of 0.002. This suggests that the Private group has a significantly higher mean response compared to the Government group.

Lastly, the comparison between NGO and Private groups shows a significant mean difference of 0.150, with an adjusted p-value of 0.018, indicating that the Private group has a higher mean response than the NGO group. These results highlight specific pairwise differences in mean responses among the different groups, with several significant differences indicating varying perceptions or evaluations among the groups concerning waste-to-energy options.

Table 4. 9 :Post hoc analysis of mean differences between responses of stakeholders

Stakeholder groups	Mean Difference	Std. Err.	T	Adjusted P-value
Academia vs Government	0.2	0.05	4	0.01
Academia vs NGO’s	0.1	0.045	2.22	0.045
Academia vs Private	-0.05	0.05	-1	0.5
Government vs NGO`s	-0.1	0.045	-2.22	0.045
Government vs Private	-0.25	0.05	-5	0.002
NGO’s vs Private	-0.15	0.045	-3.33	0.018

Lastly, the global priorities of the WtE alternatives were estimated by aggregating the local weights of all criteria, sub-criteria, and alternatives. As depicted in Figure 4.10, anaerobic digestion emerged as the top choice with a global weight of 0.45 an equivalence of 40% of the total weight in all stakeholder categories (Figure 11a, 11b,

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11c, and 11d). Trailing behind anaerobic digestion, landfill gas recovery (0.26) was second option in the metropolis's WtE preference hierarchy. Gasification and incineration, on the other hand, received minimal support, third (0.15) and fourth (13) options, respectively, owing to their adverse environmental impact and low social acceptance. The ranking of WtE alternatives in this study aligns with findings from other developing countries and similar research contexts. For instance, in a study by Qazi et al. (2018) evaluating eight WtE technologies for treating MSW in Oman, the AHP model led them to conclude that anaerobic digestion was the optimal choice due to its environmental benefits. Similar results were reported by Agbejule et al., 2021 in Accra, Khoshand et al., 2018-tehran, Rahman et al., 2022-dhaka, Kurbatova & Abu-Qdais, (2020) in Moscow, Thengane, 2019-japan, Sadhya et al., 2021 and Torres-Lozada et al., 2023. These consistent findings underscore the global consensus regarding the environmental advantages of anaerobic digestion (AD) as a preferred waste-to-energy technology.

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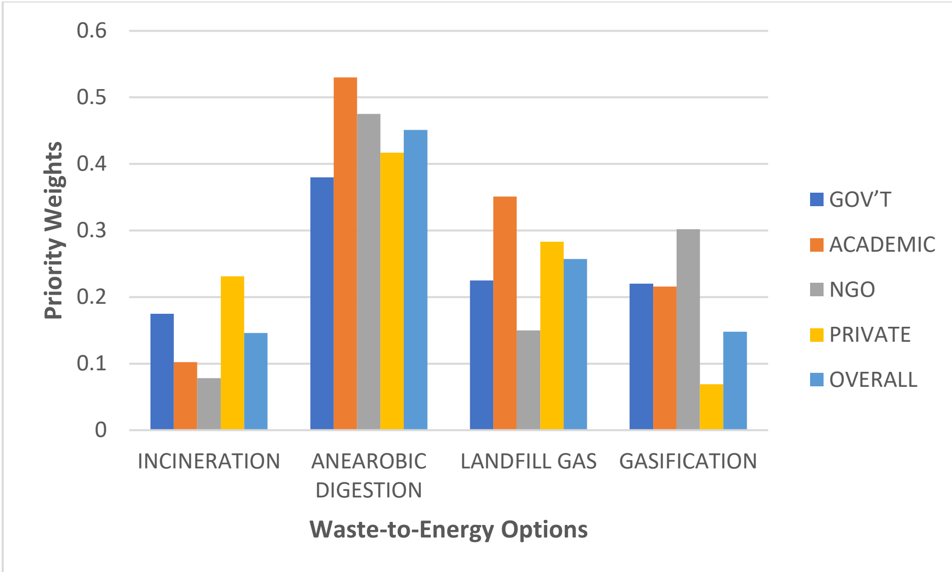

Figure 4. 10: Global priorities of the waste to energy alternatives for Tamale Metropolis (Author's construct; 2024)

4.3.4 Sensitivity analysis of the waste-to-energy technology selection by stakeholders

A sensitivity analysis is conducted to assess and identify which sustainability factors have the greatest impact on the selection of WtE technologies, enabling more informed and resilient decision-making. This analysis evaluated the stability of the priorities by changing one of four main criteria while keeping the others in the same percentage. Figure 4.11 represents the results of the sensitivity analysis. According to the analysis, the only criterion influencing anaerobic digestion is the "economy". LFG would become the first choice for waste-to-energy production if the economy's weight increased by more than 85%, as shown in Figure 4.11a. According to Figure 4.11b, when the weight of environmental criteria increases, the preference of gasification and anaerobic digestion rises, while the priority of LFG recovery and incineration

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decreases. If the importance of the environment increases over 0.3, gasification replaces incineration as the third most important option, no further change is observed in this category.

While the priority of AD and incineration increases as the social criterion's weight increases, the opposite is observed in LFG and gasification. According to the sensitivity analysis of the social criterion (Figure 4.11c). If the importance of the social criterion increases over 0.4, incineration replaces gasification as the third most preferred option.

Noteworthy, Anaerobic digestion and LFG maintain their positions in this criterion as first and second options respectively. Sensitivity analysis on technology, represented in Figure 4.11d, shows that the first position of AD as preference is insensitive to this criterion. However, incineration would become the third preferred option if the priority on this criterion rises over 0.2 and the second most preferred choice over LFG if the priority on this criterion increases over 0.79.

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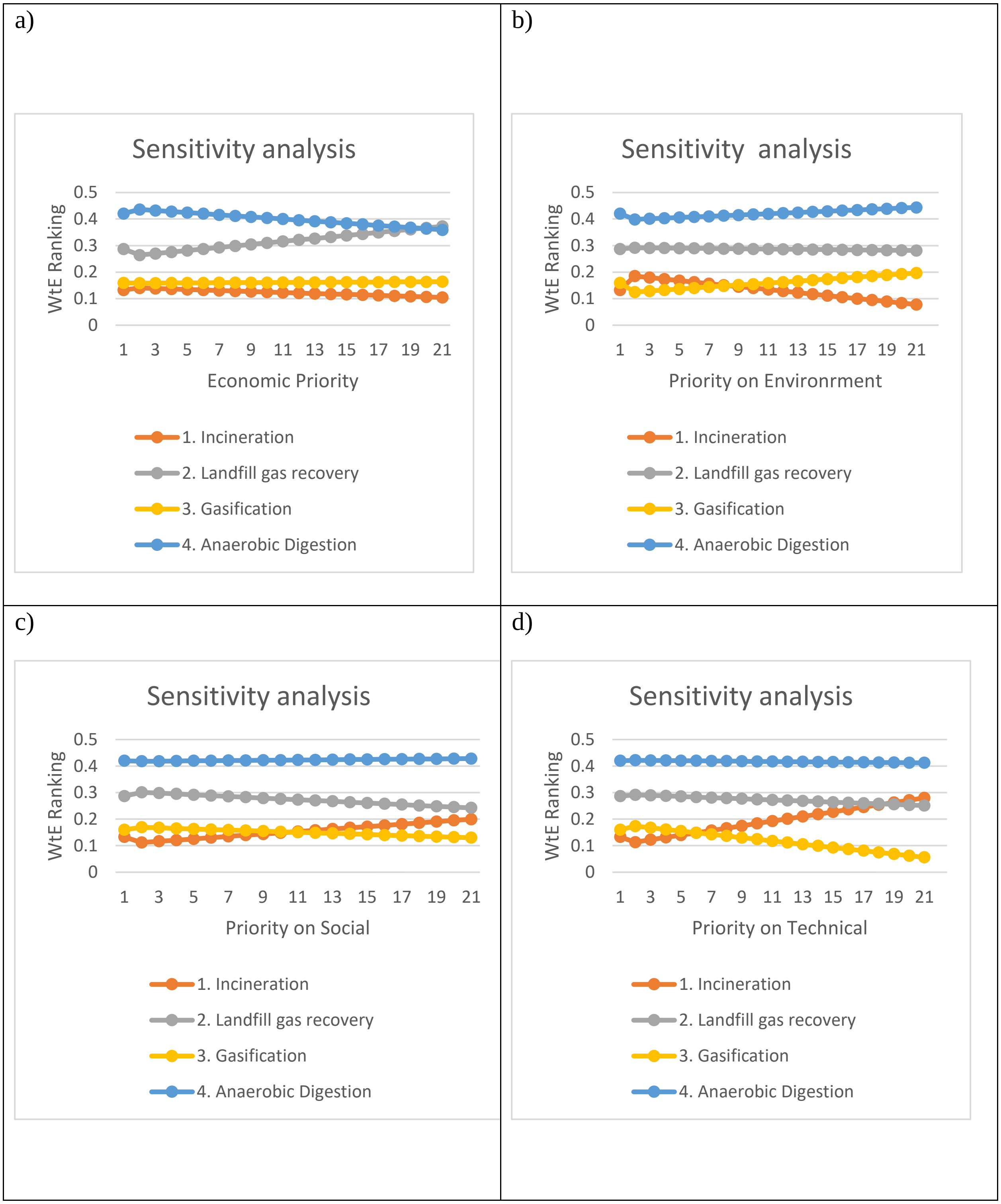

Figure 4. 11:Sensitivity analysis selection criteria in various perspectives; (a) Economy, (b) Environment, (c) Social aspect (d) Technical (Author's construct).

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4.4 Public Perceptions towards Waste-to-Energy as a Waste Management Strategy in Tamale.

Table 4.10 outlines the demographic data of Tamale residents surveyed on their perceptions of WtE technologies. Most of the participants were urban residents, primarily aged between 26 and 35, and male. Educational backgrounds varied, with a notable portion having no formal education. Most lived more than 5km from the city center, and the majority were married. Key insights and a deeper understanding of their perceptions of WtE technologies are discussed in the following sections.

Table 4. 10: Demographic information of respondents in the metropolis.

Respondent source	Age	Gender	Education	Distance	Marital status
Urban = 283	<25 = 39	Male = 312	No formal education = 117	Near (≤ 5km) = 116	Married= 271
Rural = 112	26 – 35 = 196	Female = 83	Basic education = 70	Far (> 5km) = 279	Single = 106
	36 – 45 = 84		Secondary education = 88		Divorced = 14
	46 – 70 = 76		Tertiary = 120		Widowed = 4

4.4.1 Respondents awareness and understanding (RAU) of Environment Issues and WtE Technologies

The study aimed to measure the level of awareness and understanding that residents (RAU) in the metropolis have regarding Waste-to-Energy (WtE) and the environment as a whole. As shown in Table 4.11, respondents were widely concerned about environmental issues. The mean score of "environmental pollution issues" is slightly lower than "concern about the shortage of resources and energy". This indicates that the RAU level of environmental pollution issues is higher than that of the shortage of

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resources and energy, but the difference is not significant. The percentage of respondents who disagree or strongly disagree with the statement about caring for the shortage of resources and energy, and about environmental pollution issues are approximately 7.34% and 6.23% respectively. This indicates that a small proportion of the respondents are not in agreement with the concern over resource and energy shortages, and environmental pollution in Tamale. These finding parallels those of Ingaldi et al. (2020, which measured public awareness in three countries: Poland, the Czech Republic, and Slovakia.

Relatedly, the mean scores shown in Table 4.11 indicates that the awareness level of respondents regarding “familiarity with the concept of WTE technology” and “the national policies about WTE” is quite low, an outcome that is similar to findings by Suryawan, et al., (2023) in their study on residents in Jakarta city - Indonesia. The questions in table 4.14 were further employed as dependent variables to perform further statistical analysis using ANOVA and t-test. The significance level was set as 0.05. The results are presented in Table 4.16.

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Table 4. 11: Mean scores of RAU Towards WtE and the Environment in the Tamale Metropolis.

Question	Mean value
You care about environmental pollution issues	1.08
You care about the shortage of resources and energy	1.27
MSW is adequately disposed of in Tamale?	2.55
You are familiar with the concept of waste-to-energy technology	3.16
You know WtE may cause environmental pollution	2.06
You know the national policies about WtE	3.96

* Mean value = (1* the number of respondents who strongly agree + 2 * the number of respondents who agree + 3* the number of respondents who choose neutral + 4 * the number of respondents who disagree + 5 * the number of respondents who strongly disagree)/395.

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Table 4. 12: Differences of Demographic and Socioeconomic Variations in Residents' Views on Waste to Energy

Question	Residence	Gender	Age	Education	Distance	Income	Family Employed in Env. -related career	Knowledge of waste to energy plants
Adequate disposal of MSW	0.0219**	0.8701	0.4213	0.3952	0.2058	0.7758	0.0855*	0.0196**
Familiar with WtE	0.6811	0.8242	0.6923	0.2476	0.5781	0.6452	0.0210**	0.0000***
Envt'l pollution from WtE	0.6500	0.0311**	0.5871	0.0313**	0.0075***	0.2350	0.3189	0.1915
WtE Policies	0.1125	0.2264	0.3798	0.9171	0.2032	0.5394	0.0943	0.0943*

Note: *Stands for the significant *p*-value where, ****p*<0.01, ***p*<0.05, **p*<0.1

Table 4.12 shows that significant differences exist within all groups. For the question "pollution from waste", significance at 0.05 is observed under the Education, Gender and Distance variables. Multiple comparisons and independent samples t-tests were performed. The mean scores are shown in Figures 4.12 – 4.16.

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Figure 4.12 illustrates notable disparities across all groups. Significant disparities exist between urban and rural residents (See appendix C), with urban residents exhibiting a lower mean score than their rural counterparts. This suggests that urban residents possess a greater awareness of WtE technology, its potential risks, and associated policies compared to rural residents. This conclusion aligns with the research conducted by Huo et al. (2019), who investigated the societal acceptance of waste-to-energy incinerators in China. Additionally, the t-test results were more positive in favor of urban residents (3.8, 3.7, 3.4, 3.6 for questions in Table 4.12) than those of rural residents (2.0, 2.2, 2.0 and 2.3). Therefore, efforts are required to educate rural residents and improve their knowledge of WtE.

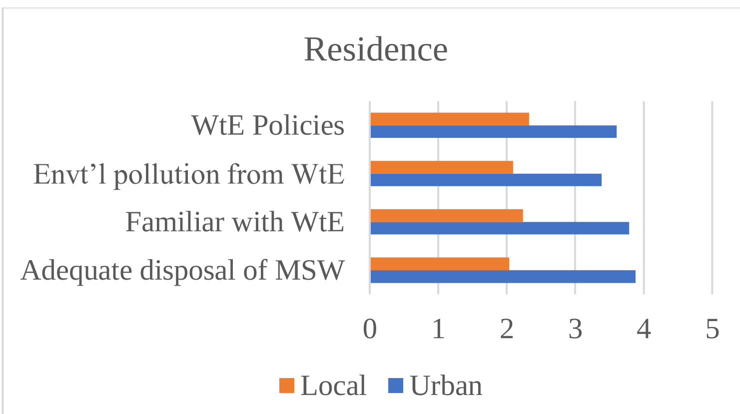

Figure 4. 12: Mean score of Residence group

Statistically significant differences were observed in Table 4.14 concerning awareness and attitude towards WtE between male and female residents. The findings indicate that male residents of Tamale tend to demonstrate a more favorable awareness and disposition towards WtE technology in contrast to their female counterparts (see Figure 4.15). Ren et al. (2016) supported these results in their study titled "Risk Perception and Public Acceptance Toward a Highly Protested Waste-to-Energy

Facility" in China. This difference may stem from the persistence of harmful gender norms, which afford male residents' greater access to information, education, and participation in decision-making processes, including those related to WtE technology, compared to their female counterparts in the metropolis. It is crucial to acknowledge that the sample size for this study predominantly consists of males (78%).

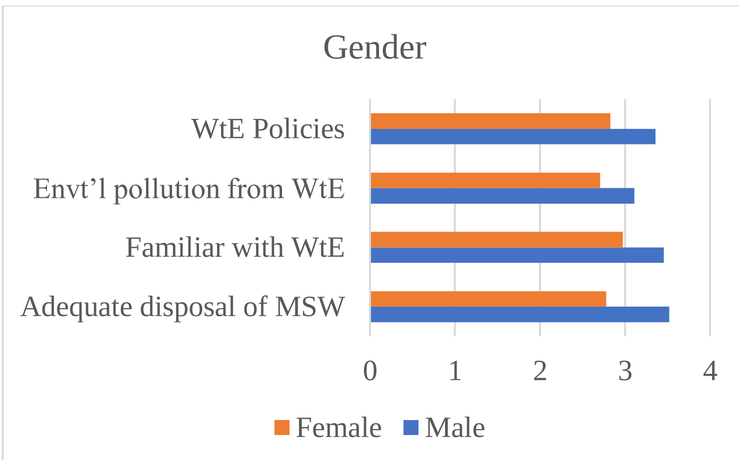

Figure 4. 13:Mean score of Gender group

In the "age" group (refer to Figure 4.16), significant differences are observed across all questions by one-way ANOVA. The findings indicate that individuals below the age of 36 reported the highest mean scores in the questions: "Familiar with WtE", "Environmental pollution from WtE", and "waste to energy policies" (See appendix C). Additionally, respondents aged between 46 and 70 years reported low mean scores compared to other age groups. This suggests that older individuals have greater knowledge of national Waste-to-Energy (WtE) policies and higher awareness of WtE. This finding aligns with Liu et al. (2018), who studied the impact of community engagement on public acceptance of waste-to-energy incineration projects in China. Notably, the low mean scores across all age groups for the question "Adequate

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disposal of MSW" suggests a general agreement on the inadequacy of waste disposal in the Tamale metropolis.

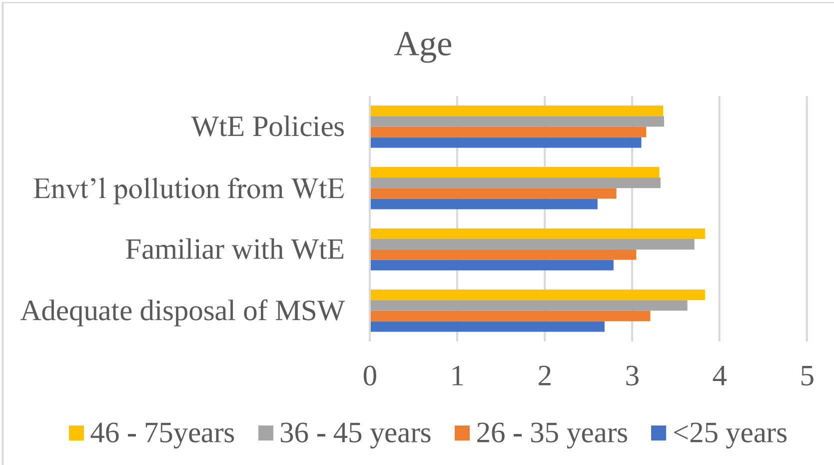

Figure 4. 14: Mean score of Age group

Within the 'education' category (as depicted in Figure 4.17), significant variations were observed across all questions in Table 4.15, as indicated by the one-way ANOVA analysis. The study finds that individuals with higher levels of education tend to have greater awareness and understanding of waste-to-energy (WtE) technologies compared to those with lower education levels. This finding aligns with Debrah et al. (2021), who highlighted the role of formal education in raising awareness about solid waste management in developing countries. Their study demonstrated that individuals with higher education are more likely to adopt and support sustainable waste management practices, reinforcing the positive correlation between education and societal acceptance of WtE initiatives. Therefore, it is imperative for the government and relevant stakeholders to prioritize educational outreach and awareness campaigns

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targeting individuals with lower education levels to enhance public acceptance and successful implementation of WtE projects in the metropolis.

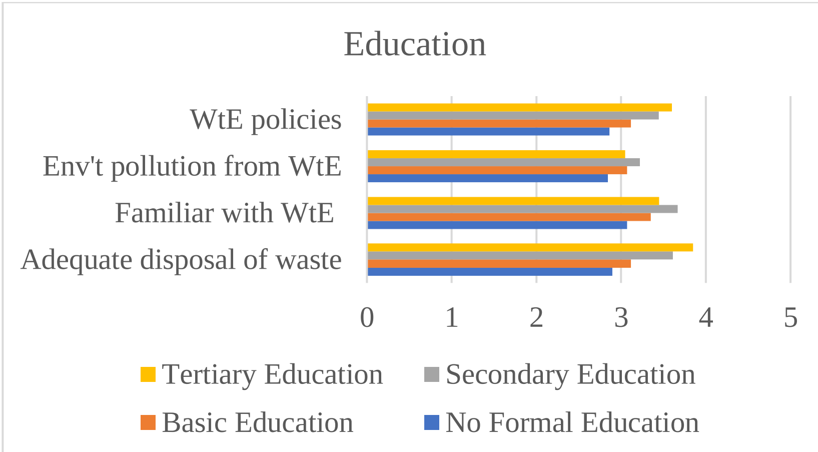

Figure 4. 15: Mean score of Education group

In the “distance” group (see Figure 4.18), significant differences exist within all questions in table 4.16. The t-test indicates a link between proximity to WtE plants and awareness: residents living farther away (>5 km) demonstrate lower knowledge and awareness compared to those closer (≤ 5km). This finding, suggesting greater positivity toward WtE among nearby communities, is consistent with Wan et al. (2023), who studied public participation in waste incineration power projects in China.

The observed trend might be attributed to the fact that individuals within the ≤5km radius have increased access to information about WtE or employment opportunities within WtE facilities in their localities. Additionally, the infrastructure supporting WtE plants offers added convenience to this particular demographic.

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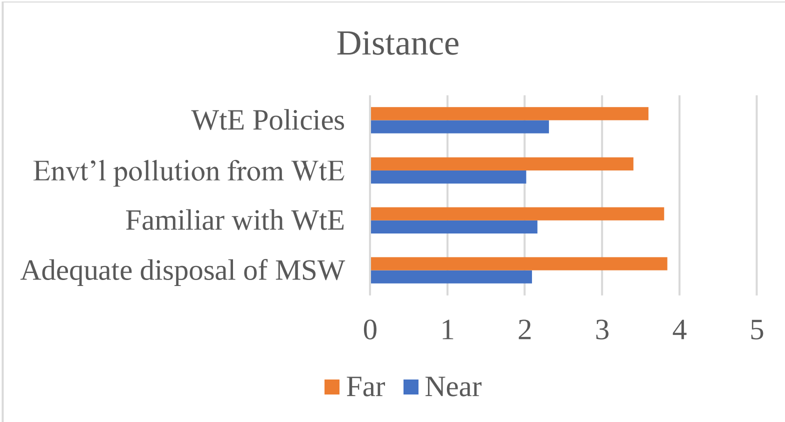

Figure 4. 16: Mean score of Distance group

4.4.3 Perceived Risks Associated with Waste-to-Energy

While WtE offers potential benefits, residents in the Metropolis expressed concerns about various environmental and health risks associated with WtE implementation (Table 4.13). For instance, the most significant worry, with a mean score of 1.76, is "WtE may produce odor" (Q22), followed by other air and water pollution risks, which are ranked in 2nd and 3rd place. "WtE may emit air pollutants" (Q18) ranked 3rd with a mean score of 2.87, while "WtE may discharge leachate" (Q19) ranked 2nd with a mean score of 2.26. This suggests that residents are more concerned about broader air and water quality impacts in the Tamale metropolis. Residents also ranked concerns about health impacts highly. "The impact on resident health" (Q23) scored 2.91 and ranked 4th, indicating a significant worry. "The transport process of MSW has environmental impacts" (Q24) and "MSW disposal process has environmental impacts" (Q26) followed in 6th and 7th place, respectively, revealing concerns about potential harm throughout the waste management cycle. These findings align with existing research (Tanveer et al., 2021; Khan, & Kabir, 2020; Mukherjee et al., 2020).

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Interestingly, noise was the least concerning issue. "WtE may cause noise pollution" (Q21) ranked 9th with a mean value of 4.05. This might suggest that noise control measures are perceived as effective or that aforementioned concerns outweigh noise concerns in the metropolis. The ranking of perceived risks reveals that residents prioritize potential health impacts, and broader environmental pollution over specific issues like noise. Addressing these top concerns and ensuring proper communication and community engagement are essential for building trust and acceptance of future WtE implementation.

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To test for the statistical significance of the results on the perceived risk associated with WtE, ANOVA and Kruskal-Wallis Tests were conducted. The results of the test conducted had the following indications. The ANOVA test was conducted to evaluate the differences in perceived risks associated with WtE among various risk factors. The analysis yielded an F-statistic of 41.05 with a p-value of 0.000. These results indicate statistically significant differences in the mean perceived risk levels among the different risk factors. In other words, at least one of the risk factors is perceived significantly differently from the others. To further validate the findings, a Kruskal-Wallis test was performed, which is a non-parametric method suitable for comparing medians across groups. The test produced a chi-square statistic of 249.278 with a p-value of 0.0001. These results corroborate the ANOVA findings, confirming that there are statistically significant differences in the perceived risk levels among the various risk factors.

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Table 4. 13: Mean value of the Perceived risk associated with Waste-to-energy.

Risk	Mean	Std. Error	Rank
WtE may emit air pollutants	2.89	0.076	5
WTE may discharge liquid waste	2.25	0.078	1
WTE may produce solid waste	2.32	0.081	2
WTE may cause noise pollution	2.55	0.082	3
WTE may produce odor	3.79	0.054	4
WTE will impact the health of residents	3.01	0.078	8
The transport process of MSW has environmental impacts	2.99	0.078	7
The storage process of MSW has environmental impacts	2.94	0.076	6
The MSW disposal process has environmental impacts	3.63	0.055	9
ANOVA Test F-Statistic = 41.05 P-value = 0.000		Kruskal-Wallis Test Chi-square statistic = 249.278 P-value = 0.0001	

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4.4.4 Perceived benefits associated with WtE

While residents have voiced apprehensions regarding WtE, they also acknowledge its potential advantages, as highlighted in Table 4.14. It is essential to understand these perceived benefits to advocate for WtE in a manner that resonates with community needs. The benefits of WtE are evident in terms of ecological preservation and energy generation (Nathaniel et al., 2021). Moreover, the establishment of WTE plants offers opportunities for employment (Ram et al., 2021).

By comparing the data in Tables 4.13 and 4.14, it is evident that the mean values of perceived benefits surpass perceived benefits. This suggests that respondents generally prioritize concerns regarding the benefits associated with WTE, despite recognizing its risks, similar findings are documented in the literature (Steger et al., 2021; Hedlund et al., 2023; Keady et al., 2021). The question regarding the possibility that "WtE can address Tamale's waste issues" ranked highest among the benefits of WTE, followed by "WtE can create job opportunities" and "WtE can enhance public health". Overall, respondents perceive WTE as an efficient approach to managing solid waste and safeguarding the environment.

To test for the statistical significance of the results on the perceived benefits associated with WtE, ANOVA and Kruskal-Wallis Tests were conducted. The results of the test conducted had the following indications. The ANOVA test was conducted to evaluate the differences in perceived benefits associated with waste-to-energy (WtE) among various benefit factors. The analysis yielded an F-statistic of 6.45 with a p-value of 0.000. These results indicate that there are statistically significant differences in the mean perceived benefit levels among the different benefit factors. In other words, at

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least one of the benefit factors is perceived significantly differently from the others. To further validate the findings, a Kruskal-Wallis test was performed, which is a non-parametric method suitable for comparing medians across groups. The test produced a chi-square statistic of 80.389 with a p-value of 0.0001. These results corroborate the ANOVA findings, confirming that there are statistically significant differences in the perceived benefit levels among the various benefit factors. Both the ANOVA and Kruskal-Wallis test results strongly suggest that the perceived benefits associated with WtE vary significantly among the different benefit factors.

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Table 4. 14: Mean value of the perceived benefits of WtE.

Benefits	**Mean value**	**Standard Error**	**Rank**
WtE can solve the waste siege in Tamale	1.77	0.055	1
WtE can provide jobs	1.98	0.056	2
WtE can enhance public health	2.52	0.057	3
WtE have significant social benefit	2.78	0.054	5
WtE have significant environmental benefit	2.61	0.057	4
WtE have significant economic benefits	2.79	0.056	9
WtE can increase the income of local residents	2.73	0.055	6
WtE can improve local environmental quality	2.75	0.55	7
WtE can reduce the consumption of fossil fuel	2.67	0.058	5
WtE can promote general economic development	2.76	0.055	8
ANOVA Test F-Statistic = 6.45 P-value = 0.000		Kruskal-Wallis Test Chi-square statistic = 80.389 P-value = 0.0001	

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4.4.5 Respondents attitude (RAT) Towards WtE

Table 4.15 highlights the nuanced attitudes of Tamale residents towards WtE technology. While they strongly oppose (ranked 1st) having a WtE plant in their immediate vicinity ("Not In My Backyard" syndrome), they strongly support (ranked 2nd) its establishment within the Tamale metropolis, this finding aligns with similar observations reported in the literature (Kassah, 2020; Adeniyi, 2023; Ogutu, et al., 2019). Interestingly, the least preferred option (ranked 5th) is "relying on electricity generated from fossil fuels rather than WtE". This seemingly contradictory preference for WtE within the metropolis can be attributed to several factors. The most prominent are the well-documented problems surrounding the only WtE plant (Gbalahi landfill), including forced relocations, water contamination, noise and odor pollution, and increased disease risk in nearby communities (Iddrisu & Debrah, 2021). This negative experience naturally fuels strong opposition to having another such facility in their immediate vicinity.

Additionally, residents' skepticism towards "WtE-generated electricity" likely stems from broken promises surrounding the existing plant. As noted by Nuripuoh et al. (2022), those living near the Gbalahi landfill expressed disappointment over unfulfilled promises made before the plant's construction. Residents had been told to expect benefits like electricity and fertilizer production, none of which materialized. This study suggests that such unkept promises might explain the low ranking given to WtE electricity, indicating a lack of trust in its potential.

To test the statistical significance of residents' attitudes towards WtE, both ANOVA and Kruskal-Wallis tests were conducted. The ANOVA test yielded an F-statistic of

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6.26 with a p-value of 0.0001, indicating significant differences in the mean attitudes among various factors. Similarly, the Kruskal-Wallis test produced a chi-square statistic of 24.085 with a p-value of 0.0001, corroborating the significant differences found by ANOVA. These results strongly suggest that residents' attitudes towards WtE vary significantly across different factors, highlighting diverse perceptions and attitudes based on the specific factors considered.

The findings suggest that the populace is generally apprehensive about the establishment of WtE facilities in their immediate vicinity. Therefore, it is crucial to conduct stakeholder consultations and engage in social and behavioral change advocacy to alleviate concerns and increase acceptance for future WtE plant developments.

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Table 4. 15: The mean value of Residents Attitude (RAT) towards WtE.

Questions	**Mean value**	**Standard Error**	**Rank**
You prefer electricity from WtE rather than fossil fuel	3.52	0.058	5
You support the establishment of WtE in Tamale metropolis	2.31	0.054	2
You think WtE has a bright prospect	2.71	0.053	3
You think WtE is the best way to dispose of waste	3.44	0.054	4
Do you oppose the construction of a WtE plant in your backyard (NIMBY)	1.85	0.055	1
ANOVA Test F-Statistic = 6.26 P-value = 0.0001		Kruskal-Wallis Test Chi-square statistic = 24.085 P-value = 0.0001	

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Multiple linear regression was used to predict the value of the dependent variable, respondents' attitude (RAT), based on the values of the independent variables (socio-demographic factors), while also assessing the strength and significance of their relationships. Using equation (1) and setting the significance level at 0.05, the results are detailed in Table 4.15

RAT = F1 (residence, gender, age, education, distance, Family Employed in an Env.t -related career, Household Size, Income, knowledge of waste to energy plants) (1)

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Table 4. 16: Analysis of socio-demographic and economic factors on Residents attitude (RAT) responses.

Residence	Gender	Age	Education	Distance	Family Employed in Env. - related career	Household Size	Knowledge of waste to energy plants	Income
/	/	/	/	/	/	-0.044	/	-5.92
/	-0.37	/	/	/	/	/	/	-4.80
/	/	/	/	/	/	/	-0.41	/
/	/	/	/	0.893	-0.443	/	/	/
/	/	/	/	/	/	/	/	-5.00

Note: "/" stands for non-significant linear regression.

As indicated in Table 4.16, the variable "distance" demonstrates a positive influence on RAT. This suggests that as distance increases by one unit, the response to RAT also increases by 0.893 units, all things being equal. Conversely, the variables "gender", "family employed in an environment-related career", "knowledge of waste to energy plants", "household size", and "income" exhibit negative influence on RAT. This indicates that as these variables increase, RAT decreases.

4.4.6 Influence of Independent Factors on Respondents' Attitude (RAT) Towards WtE.

To evaluate the strength and significance of the prediction of respondents' attitudes (the dependent variable) against the four independent variables in the study, including respondents' awareness and understanding (RAU) of WtE and environmental issues, perceived risk (PR), and perceived benefits (PB), multiple linear regression was

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employed. Using equation (2) and setting the significance level at 0.05, the results are presented in Table 4.17.

RAT = F2 (RAU of environmental issues, RAU towards WtE, PR, PB) (2)

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Table 4. 17: B-values of independent variables of multiple regression analysis.

Independent variables	**RAT**
RAU of environmental issues and WtE	-
Perceived risk	0.371
Perceived benefit	0.195
Adjusted R-Square	0.5001

Note: "-" stands for non-significant linear regression.

The results in Table 4.17, reveal that while resident's awareness of environmental issues and towards WtE (RAU) does not significantly impact resident's attitude (RAT), both perceived risk (PR) and perceived benefits (PB) demonstrate a positive association. This suggests that individuals with higher levels of PR and PB are more likely to exhibit high WtE technology acceptance, this aligns with findings reported in the literature **(**Todaro et al., 2023; Wang et al., 2021).

The positive correlation between PB and RAT is less positive compared to PR. Furthermore, the adjusted R-squared value of 0.5001 indicates that roughly half (50.01%) of the variation in RAT can be attributed to the combined influence of the two independent variables (PR and PB) included in the model. This signifies a relatively good fit of the model to the observed data, suggesting that PR and PB are

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effective predictors of RAT in this context. Consequently, efforts to enhance WtE adoption should focus on addressing residents' perceptions of risks and benefits rather than solely increasing awareness.

4.5 Assess the Nexus Between the Existing Waste Management System and WtE Adoption and Implementation in Tamale-metropolis.

This section concludes the four-part structure of this thesis, where insights are derived through content analysis of in-depth interviews and focus group discussions. It presents a framework for integrating waste-to-energy technologies into the existing waste management system in Tamale. Outlined below are the results and discussions from the content analysis of data gathered, highlighting the issues most frequently cited during the study:

4.5.1 Structure of Waste Management in Tamale-metropolis.

In Tamale, the waste management system consists of several components seeking to tackle the waste disposal demands. This structure is made up of governmental agencies, private sector partnerships, and community interest. To understand the effectiveness and challenges of this system, focus group discussions and in-depth interviews were conducted with various stakeholders, including government officials, private sector partners, and community members.

"The Metropolitan Waste Management Department (MWMD) in Tamale is legally tasked with managing the cleanliness of public spaces, including drains, streets, and markets, and maintaining sanitary facilities. Our operations involve treating and disposing of all waste forms, largely facilitated through partnerships with private

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entities like Zoomlion GH Ltd, savannah waste management service, sewage system ltd and other private waste service providers who are mostly unregistered. Challenges persist in the system, characterized by a lack of waste bins, inconsistent waste collection schedules, inadequate segregation practices, and logistical constraints." - Local Government Officer, MWMD 2 (In-depth Interview).

"Zoomlion Ghana Limited's involvement has bolstered the waste management capacity within Tamale, providing additional equipment, vehicles, and labor. This enhancement has increased service coverage to approximately 70% of the Metropolis, improving the cleanliness of main streets, lorry parks, and enabling gutter dredging alongside selective door-to-door services." – Zoomlion Gh ltd Staff, Z1 (in-depth interview)

" "In Tamale, the waste management structure and waste collection vary significantly across different residential classes. To illustrate, Savannah Waste Management Service, a subsidiary of the Jospong Group, provides solid waste sanitation services on behalf of Zoomlion Gh Ltd in the metropolis. High-class areas benefit from regular door-to-door service, contributing to their cleanliness through this service provider. Middle-class areas also have access to these services upon request, but most residents prefer communal containers, which can become overcrowded. In low-class neighborhoods, which are fraught with irregular layouts and crowded public places such as markets, communal containers are mostly utilized. However, they are often insufficient as they frequently overflow. It is critical to mention that the irregular layout of these areas complicates regular waste collection. Additionally, through the partnership with the Jospong Group's subsidiary, all sludge and wastewater are

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collected and treated by Sewage System Ltd. The form of treatment entails converting fecal sludge into compost." – Local government staff, MWMD 1 (In-depth Interview) (In-Depth Interview)

The waste management framework in Tamale, as elucidated in the interviews, employs a multi-stakeholder strategy. This system comprises governmental entities, business sector collaborations, and community participation, each fulfilling a specific function in waste management and disposal. The Metropolitan Waste Management Department (MWMD) oversees the city's waste management initiatives, while commercial entities such as Zoomlion GH Ltd, Savannah Waste Management Service, Sewage System Ltd, and other private trash service providers conduct routine operational activities. This collaborative structure aims to address the city's increasing waste management requirements. In this study, interviewees reported irregular rubbish collection services in Tamale. According to them, the municipal garbage management trucks are dispatched sporadically, lacking a consistent schedule, hence exacerbating waste accumulation. The inconsistency in service provision, along with inadequate urban planning particularly in low-income areas impedes the effectiveness of waste management in the Tamale metropolis.

4.5.2 Waste management system and waste-to-energy in Tamale

Stakeholders collectively recognize the potential benefits of Tamale's emerging waste-to-energy facility, though they also identify key areas needing enhancement to maximize its impact.

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A local government staff member discussed the limitations of the new 1,000 metric ton Wastewater Treatment Plant at Gbalahi, stating, *"While the plant marks a significant step forward in our sanitation efforts, it currently only converts fecal waste into compost and does not address solid waste treatment. Moreover, it cannot yet convert waste into energy, which is a critical function for advancing our waste management goals (Local Government Staff, ID LGS1, focus group discussion).*

An environmental protection officer emphasized the importance of expanding the scope of the plant: *"The waste-to-energy operations by Zoomlion Ghana Limited effectively manage sludge water disposal and provide an energy solution. However, to fully harness the benefits and minimize environmental impacts, it's crucial to broaden these solutions to also tackle the growing solid waste issues in our municipality, ensuring compliance with environmental standards throughout" (Environmental Protection Officer, ID EPO2, in-depth interview).*

A Zoomlion employee shared their firsthand experience with the plant's operations: *"Working at Zoomlion, I see the effectiveness of our waste management practices daily. It's rewarding to contribute to a project that not only mitigates waste in Tamale but also has the potential to generate energy" (Zoomlion Gh Ltd staff, ID Z3, in-depth interview).*

An academic perspective highlighted the broader implications of integrating this technology with existing systems*: "The new plant represents a crucial development. Integrating it with our current waste management system could significantly reduce health issues stemming from improper waste disposal. It's essential to expand this*

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initiative to encompass municipal solid waste too" (Academia, ID A3, in-depth interview).

Overall, there is a consensus among stakeholders about the positive contributions of the waste treatment plant towards improving waste management and energy production in Tamale. However, a critical limitation is its current inability to treat solid waste or fully convert waste to energy, underscoring an urgent need for system enhancements to address these challenges effectively.

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4.5.3 Challenges of the waste management system in Tamale

4.5.3.1 Policy Perspectives

One of the key challenges to implementing Waste-to-Energy (WtE) technology in Tamale, Ghana, is the absence of clear and consistent government policy (Tahiru et al., 2024). Both Zoomlion Gh. Ltd. staff and representatives from the Tamale Metropolitan Assembly's (TMA) Waste Department highlight the need for cohesive national and local policies, along with supportive regulations, to facilitate the mainstreaming of WtE technology. The current fragmented policy framework hampers the sustainable integration of WtE into Tamale's waste management system, obstructing progress toward the city's energy security and environmental sustainability goals.

"There is a need for clear government policies supporting the adoption of WtE technologies. Without supportive regulations, it's challenging to incentivize investment in these initiatives." Zoomlion staff – ID Z4 (focus group)

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"Policy coherence between national and local levels is crucial. Local authorities need guidance and support from the central government to effectively implement WtE projects." Local government staff – ID LG2 (in-depth interview)

While the dominant narrative suggests a lack of effective policy, a minority of interviewees presented a different viewpoint. Three local government representatives (15%) in a focus group expressed the belief that existing policies are sufficient. For example,

"Policy is not the problem." Local government staff – ID LG5 (focus group).

"We at Zoomlion Gh. Ltd have recently commissioned a €20-million wastewater treatment plant at Gbalahi, a suburb of Tamale. This feat was achieved with funding from the Hungarian Government. Therefore, with the right funding and willpower from the Ghanaian government, we should be able to smoothly integrate WtE into the existing solid waste management system to address issues of solid waste " Zoomlion Gh ltd staff - ID Z3 (in-depth interview)

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4.5.3.2 Financial Implications

Amidst considerable financial hurdles linked to municipal solid waste management in the Tamale Metropolis, Ghana, both Zoomlion Staff and TaMA Waste Department Officials emphasize the urgent need for sufficient financing and thorough cost-effectiveness assessments to support the implementation and long-term viability of WtE initiatives. The paucity of accessible financial incentives and investment mechanisms hampers private sector engagement in the sector, while the absence of

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comprehensive economic feasibility studies poses risks to the financial sustainability of WtE projects.

"Securing adequate financing for WtE projects is a major challenge. Financial incentives and investment mechanisms are needed to attract private capital into the sector." Zoomlion Gh ltd Staff -ID Z1 (in-depth interview)

"Waste-to-Energy (WtE) plants require a high initial investment, coupled with ongoing maintenance and operation costs. Economic viability studies are therefore crucial to assess their long-term financial sustainability and ensure value for money. Unlike the Gbalahi landfill site in Tamale, which fell short of expectations, WtE plants, when properly assessed and managed, can deliver a more sustainable waste management solution." Local Government Staff- ID LG3 (Focus group)

However, it's important to acknowledge a minority (10%) viewpoint within the focus group discussions. Some participants expressed concerns that the social burden of WtE projects might outweigh the potential financial benefits.

"While WtE offers potential benefits, we shouldn't rush into significant debt for these projects. A thorough cost analysis is crucial, but the long-term social implications on the community need careful consideration." - Community Representative - ID CR8 (Focus group discussion)

4.5.3.3 Socio-political Dynamics

Participants, including private waste service providers, waste experts, local assembly staff, and Zoomlion Ghana Ltd representatives, emphasized that social acceptance,

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public awareness, community involvement, political commitment, and stakeholder engagement are crucial for the success of Waste-to-Energy (WtE) projects. They noted that failure to address misconceptions and community concerns, and to build public support through effective communication, could lead to resistance and complicated project implementation. Moreover, the absence of political will and inclusive decision-making could slow the prioritization and development of sustainable waste management strategies, hampering progress toward environmental sustainability and energy generation goals in Tamale.

"Political will and stakeholder engagement are key determinants of WtE success. Decision-makers must prioritize sustainable waste management solutions and involve relevant stakeholders in the decision-making process." Waste Researcher -ID WR 1 (in-depth interview)

Although most participants (80%) agree with the need for stakeholder engagement and political will, not everyone (20%) agrees that the level of public engagement is necessary. Some participants expressed concerns that extensive public discussions could delay project implementation and potentially lead to misinformation campaigns.

"While public awareness is important, shouldn't the focus be on technical expertise and ensuring the proper functioning of the plant? Extensive community engagement can be time-consuming and potentially delay progress." – Community representative - ID CR10 (in-depth interview)

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"There's a fear that community concerns might be used to stall the project altogether. While some engagement is necessary, the final decisions should be left to the experts." – Local Government Staff - ID LG4 (in-depth interview)

"We support sustainable waste management, but WtE shouldn't come at the expense of our livelihoods. We need assurances that WtE won't significantly reduce the number of recyclable materials available for collection." - Private Waste Service Provider – ID PWS 1 (Focus group discussion)

These quotes from minority viewpoints (15%) in the focus group discussion highlight contrasting perspectives on the importance of social engagement. They raise concerns about potential delays and the impact on waste pickers' livelihoods, suggesting a need to balance public participation with project efficiency and social responsibility.

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4.5.3.4 Institutional Framework

Majority of participants (70%) stress the importance of efficient collaboration between public and private entities and highlight the need to enhance institutional capacity for successful implementation of Waste-to-Energy (WtE) initiatives. Without strong partnerships between the public and private sectors, the effective operation and maintenance of WtE facilities may be compromised. Similarly, the absence of institutional capacity and trained personnel could hinder the planning, execution, and management of WtE projects.

"Building institutional capacity is crucial for successful WtE implementation. Training and skill development programs are necessary for waste management personnel." Local Government Staff – ID LG 1 (focus group discussion)

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"Public-private partnerships (PPPs) are not just essential, they offer the most promising path forward for WtE in Tamale. By leveraging the expertise of the private sector alongside public resources, we can ensure efficient operation and maintenance of WtE facilities, while mitigating financial risks for the government. PPPs can also foster innovation and technology transfer, leading to a more sustainable WtE solution for the city" Zoomlion Gh. Staff – ID Z2 (in-depth interview)

"I understand the potential benefits of PPPs, but concerns exist about potential profit motives overriding environmental considerations. Local businesses should be given a fair chance to participate in WtE initiatives, ensuring transparency and community benefit." – Waste researcher - ID WR1 (In-depth interview)

Additionally, the minority group (30%) voiced concerns about potential knowledge gaps within the local government when entering PPPs with private waste management companies.

"Collaboration is crucial, but capacity building within the government sector is essential. We need to ensure local authorities have the necessary expertise to effectively negotiate and manage PPP agreements related to WtE projects." – Environmental protection agency - ID EPA 2 (In-depth interview)

4.5.3.5 Technical Considerations

The technical implementation of waste-to-energy (WtE) initiatives in the Tamale Metropolis, Ghana, highlights the imperative of performing feasibility evaluations,

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embracing technological innovations, and promoting ongoing research and development to improve WtE methodologies. Resolving these technical issues is crucial for the effective integration of WtE technologies into the waste management system in Tamale, hence fostering sustainable development and resource optimisation in the region.

"Thorough feasibility studies are crucial, but we should also consider adaptable technologies that can accommodate the evolving nature of our waste stream. Tamale's waste composition may change over time, and we need WtE solutions that can adapt to maintain efficiency and environmental benefits." - Environmental Protection Agency - ID EPA3 (in-depth interview)

"Technological advancements play a vital role in optimizing WtE processes. Continuous research and innovation are necessary to improve efficiency and environmental sustainability." Waste researcher – ID WR 3 (in-depth interviews)

While the focus on technical considerations was widely shared, some dissenting voices emerged within the focus groups.

Additionally, an environmental expert (10%) expressed concerns about potential limitations of current WtE technologies.

"While advancements are promising, WtE still carries inherent environmental risks. We need to prioritize stricter emissions regulations and ongoing monitoring to ensure WtE projects in Tamale are truly sustainable and don't create new

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environmental burdens." - Environmental Protection Agency Representative - ID EPA 2 (In-depth interview)

These quotes from participants in the study highlight contrasting perspectives on the technical aspects of WtE implementation. They raise concerns about the suitability of complex technologies and the potential environmental impact, suggesting a need to consider simpler solutions and prioritize robust environmental safeguards.

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4.5.4 Prospects for Enhancing Tamale's Current Waste System with WtE.

The incorporation of Waste-to-Energy (WtE) technologies into Tamale's waste management system presents several challenges, as highlighted by the qualitative survey results. The study reveals diverse perspectives alongside a shared understanding of key issues and opportunities for improvement.

4.5.4.1 Policy and Financial Hurdles:

A consensus among stakeholders emphasizes the critical necessity for supportive government policies and clear regulations to incentivize investment in Waste-to-Energy (WtE) projects, a finding reflected in the literature (Lazaro et al., 2023; Lewis et al., 2021). Participants underscored the importance of conducting financial feasibility studies to ensure long-term economic viability, a sentiment echoed in the literature (Debnath et al., 2023; Dokter et al., 2021; Nyimakan, 2022). Similarly, Ali et al. (2021) reported similar findings, highlighting that like many cities in developing countries, the majority of Municipal Solid Waste Management (MSWM) budgets are allocated to collection and disposal rather than supporting innovative waste minimization efforts. Moreover, a significant majority of stakeholders identify

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financial hurdles as a major barrier to implementing Waste-to-Energy (WtE) initiatives. Concerns primarily revolve around the substantial upfront costs, operational and maintenance expenses, and the lack of readily available financing mechanisms to support these projects. Moving forward, it is imperative to explore WtE alternatives that are potentially less expensive for waste management, alongside conducting thorough examinations of WtE's financial feasibility and social impact. This aligns with findings from the literature (Schroeder et al., 2019; Govindan & Hasanagic, 2018; Manamela, 2022), where finance emerges as one of the primary barriers to developing a Waste-to-Energy (WtE) system in developing nations.

On the contrary, a minority viewpoint (23%) in this study suggests that existing policies might be sufficient. This underscores a potential gap in understanding and/or the need for more targeted policy interventions (Williams et al., 2023; Giest and Samuels, 2020; Pillai et al., 2023; Lafont, 2020; Norris, 2023).

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4.5.4.2 Social and Political Considerations:

The research highlights the importance of public awareness campaigns, community town hall meetings, and stakeholder involvement for successful Waste-to-Energy (WtE) implementation. Similar findings were reported by Ogutu et al. (2021) and Han et al. (2021) in their studies on sustainable cities as alternatives for improving solid waste management in Nairobi. However, concerns were raised about potential delays in WtE projects due to extensive public engagement, aligning with the observations of McLaren et al. (2023), Karmacharya (2022), and Volsuuri et al. (2023). Furthermore, waste pickers articulated concerns regarding the effects of Waste-to-Energy (WtE) on their livelihoods, a sentiment that aligns with prior research conducted by Hayoun

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(2021), which examined the relationship between waste governance frameworks and livelihood opportunities for urban garbage pickers. The divergent perspectives indicate the necessity for a balanced strategy that emphasizes transparency, community education, and social effect evaluations in conjunction with project efficiency (Bahadorestani et al., 2020).

4.5.4.3 Institutional Collaboration and Capacity Building:

Stakeholders in the study widely recognize the value of public-private partnerships (PPPs) for tapping into expertise and reducing financial risks, a sentiment supported by existing literature (Knickmeyer, 2020; Debela, 2021; Akomea-Frimpong, et al., 2022). However, concerns have arisen regarding the possibility of profit motives overshadowing environmental concerns, echoing findings in the literature (Williams et al., 2023; El Meouchy, 2020). Also, a critical challenge lies in the observed knowledge gaps and know-how within the local government and waste industry in Tamale. This is highlighted in the limited experience in both entering Public-Private Partnership (PPP) agreements and managing waste-to-energy plants. This situation underscores the need for robust PPP frameworks that prioritize transparency, local participation, and capacity building initiatives.

4.5.4.4 Technical Considerations and Innovation:

The significance of performing feasibility studies, adopting technological innovations, and fostering continuous research for effective and environmentally sustainable waste-to-energy processes was prominent within the technical and innovation theme, corroborating literature findings (Burke et al., 2023; Adapa, 2018; Velasco-Herrejón et al., 2022). Dissenting views, however, championed simpler, low-maintenance

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solutions appropriate for Tamale's surroundings and underscored the necessity for more stringent environmental restrictions to alleviate potential hazards. Although the opinions are not highly divergent, the findings underscore the necessity of evaluating both technical efficiency and environmental protections when choosing and executing WtE technologies, as reflected in the literature (Moss et al., 2021; Koene et al., 2019).

Leveraging insights from the focus group discussions, in-depth interviews, and literature, Figure 4.17 provides a schematic summary outlining the barriers and prospects for the transition of the current waste management system to one that incorporates WtE.

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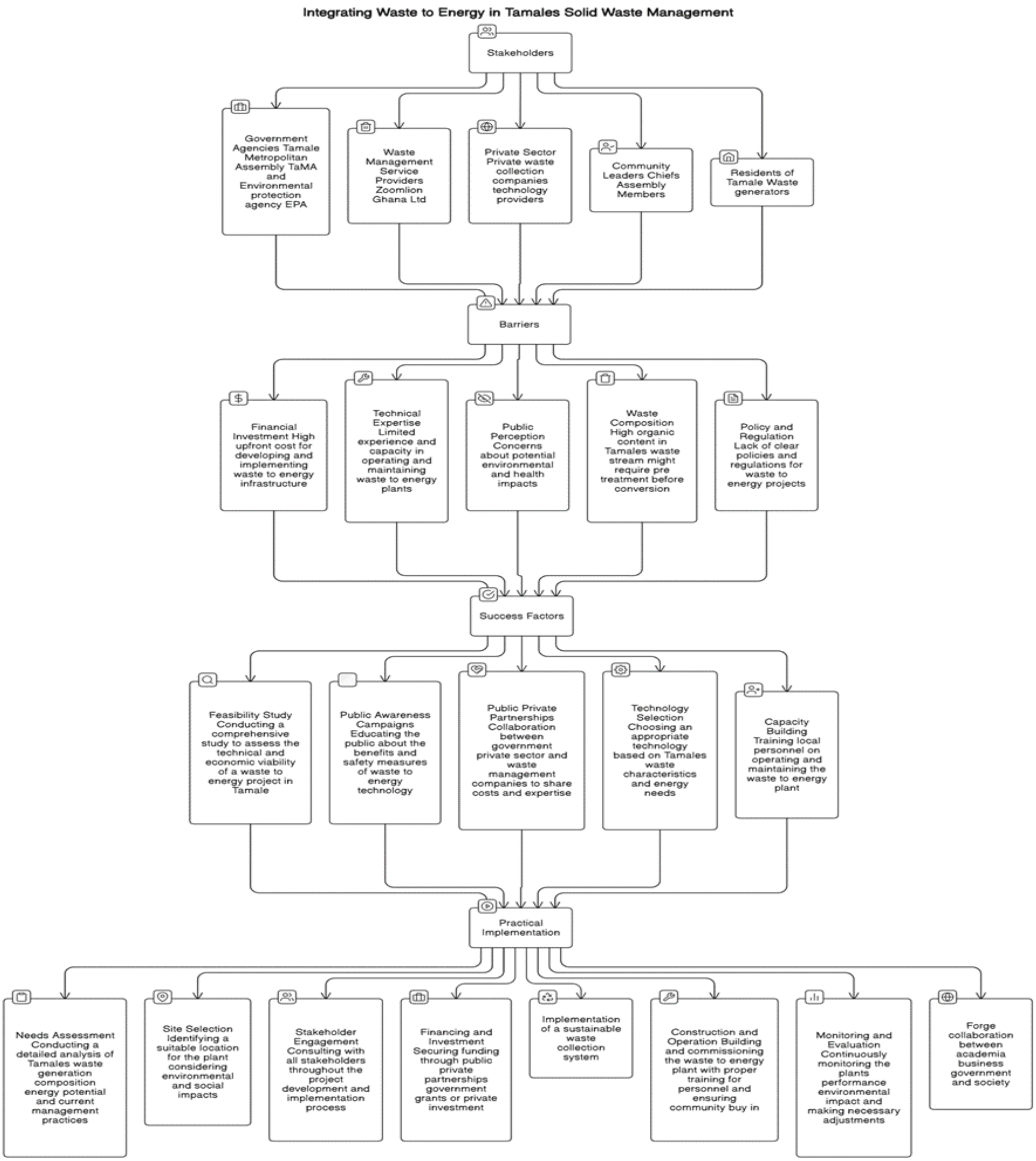

Figure 4. 17: Barriers, success factors and practical transition plan of WtE into the existing system of solid waste management in Tamale.

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4.5.5 Transition to an integrated sustainable waste management framework that integrates WtE in Tamale

A block diagram of an integrated waste management system featuring WtE facilities is presented below. This framework was designed exclusively for Tamale. This innovative design will set a new standard for circularity and sustainability in waste management in the metropolis as it efficiently tackles the various challenges associated with MSW from both business and residential sources. The initial phase of the process entails the careful gathering and conveyance of municipal solid garbage to a central sorting facility. These facilities employ a blend of manual and automated technology to segregate recyclable materials from non-recyclable ones. Employing this strategy significantly minimises waste and enhances resource recovery. Non-recyclable materials, along with waste that cannot be recycled or composted by standard methods, are directed to a landfill facility equipped with gas capture and scrubbing technology. This facility converts methane from trash into heat and energy while concurrently mitigating its environmental impact through stringent emission controls. These measures encompass the regulation of smells, nitrogen oxides (NOx), and additional pollutants. The city and the waste-to-energy facilities may fulfil their energy needs through the clean energy produced by biogas and landfill waste-to-energy processes. This fosters sustainability and energy autonomy.

This waste management paradigm signifies a significant shift towards comprehensive and sustainable practices. It encompasses circularity, resource efficiency, and environmental care. By employing waste-to-energy technologies and innovative solutions, Tamale is strategically positioned to advance towards a more sustainable,

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greener, and prosperous future.

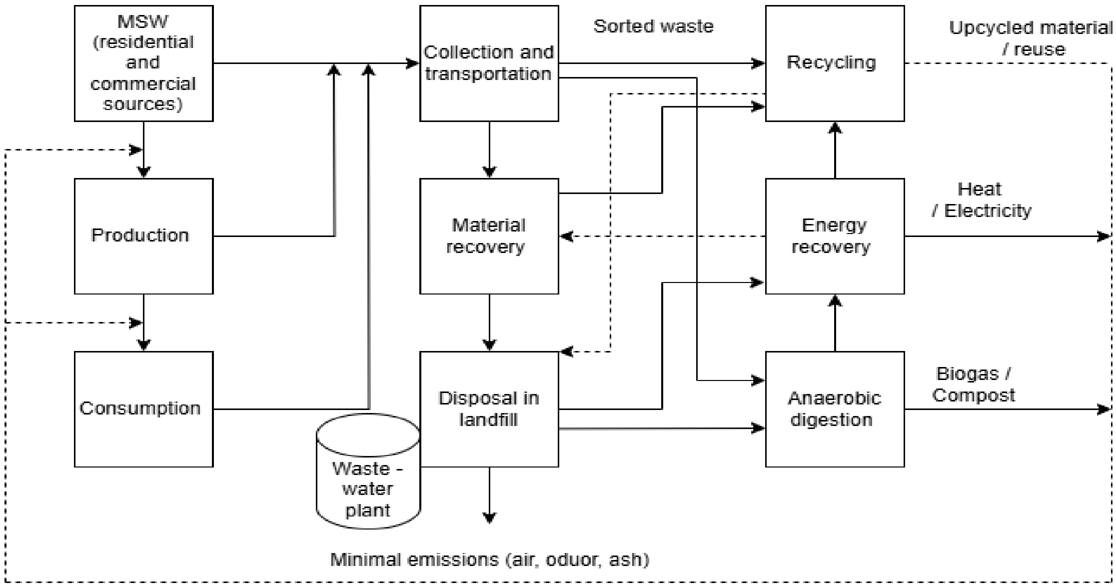

Figure 4. 18: Roadmap for WtE focused IWMS for Tamale

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4.5.7 Validation of proposed framework

Effective solid waste management requires an Integrated Solid Waste Management (ISWM) system (Cole et al., 2019). Given that the Tamale Metropolitan Assembly (TaMA) is responsible for MSW management in the northern region, it was vital to include its personnel in the validation process of the proposed framework under section 4.5.5. Representatives from the Environmental Protection Agency (EPA), which oversees environmental regulations, and Zoomlion Ghana Limited, a prominent private waste management company, also participated. Their involvement was crucial in validating the proposed framework and either confirming or challenging its conclusions. The answers to the framework validation questions are presented in Table 4.18. A consensus was reached among participants about the framework's logical structure, its effectiveness in addressing WtE and MSW management issues, its adequacy, and its feasibility.

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Table 4. 18: Stakeholder feedback on framework validation

	Responses		
Question	**EPA**	**Zoomlion Gh. Ltd**	**TaMA**
How important are all the elements of waste-to-energy in the framework to effective MSW management?	Crucial. All elements in the framework are essential for a comprehensive MSW management	Highly important. The framework provides a roadmap for integrating WtE seamlessly into existing system	Essential. WtE can address waste challenges, but a holistic approach like this is needed for long-term success.
How easy is it to understand the framework?	The framework is well structured and easy to follow.	Easy to understand and focus on key action points.	The framework is straightforward.
To what extent will you say this framework is adequate for effective MSW management decision-making?	A well-developed framework. It provides a strong starting point for informed decision-making.	Valuable tool. The framework helps assess the feasibility and optimize WtE integration for Tamale's specific needs.	The framework offers an innovative approach to effective MSW management.
To what extent is this framework logical?	Logical and well organized. The framework builds on a sequential process, ensuring a comprehensive approach	Logical	Makes good sense. Framework aligns with best practices for sustainable waste management.
Do the elements suggested in the framework address MSW siege in the metropolis?	The framework, if implemented effectively, can significantly reduce reliance on landfills and promote waste diversion through WtE.	By addressing waste composition and optimizing WtE technology, the framework tackles MSW challenges.	The framework offers a strategic approach to tackling the waste crisis in Tamale.

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Question	Responses		
	EPA	**Zoomlion Gh. Ltd**	**TaMA**
How transferable is this framework to other jurisdictions with similar challenges as Tamale?	The framework can be adapted to other cities with similar waste composition and development level. However, local context needs to be considered.	We see potential for adaptation of this framework in other cities with similar waste management needs.	The framework can be a valuable blueprint for other cities facing similar waste issues, with necessary adjustments for local specifics.
What do you consider the strengths and weaknesses of the framework?	Strengths: Holistic approach, focus on public engagement, and emphasis on financial sustainability. Weaknesses: None	Strengths: Clear focus on WtE integration. Weakness: Financial projections might need collaboration with relevant stakeholders.	Strengths: Addresses long-term waste management needs. Weakness: None
What can be added to and/or removed from the framework?	- Add or remove nothing	- Nothing	- Remove nothing

All three organizations, EPA, Zoomlion Gh. Ltd., and TaMA agreed that efficient management of municipal solid waste (MSW) depends critically on the waste-to-energy (WtE) system. They report that the framework had an easy-to-understand structure that concentrated on feasible solutions. The framework, which offered a rational and thorough approach, was also well-received as sufficient assistance for MSW management decision-making. They highlighted how the efficient application of WtE technology might lessen dependency on landfills and encourage waste diversion.

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The respondents also agreed that the paradigm could be used in other cities with comparable waste management issues, provided local contexts were considered. They emphasized the framework's advantages, including its all-encompassing strategy, emphasis on public participation, and consideration of financial sustainability. Though some indicated that additional cooperation could be needed for financial estimates, no major flaws were found.

Everyone agreed that the framework is strong and well-suited to Tamale's MSW problem and that it can be an invaluable resource for other cities facing comparable waste management goals.

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CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the summary of the findings of the study, conclusions, and recommendations which when implemented would enhance waste management and renewable energy generation in Tamale.

5.2 Summary of Findings

Based on the results and discussions of the four objectives in this study, it is evident that waste-to-energy (WtE) technology holds significant promise for addressing waste management challenges in the Tamale metropolis. Each objective offers unique insights into various aspects of the study; waste characterization, stakeholder preferences for WtE technologies, social acceptance, and WtE integration strategies.

For the first objective, the study focused on the characterization of Municipal Solid Waste (MSW), which gives insights into the composition of waste, with organic matter emerging as a significant component. This underscores the potential for diverse WtE alternatives. Furthermore, the exploration of chemical characteristics and energy content underscored the suitability of thermal and/or biochemical conversion processes of the waste materials, as a calorific value of 28.9 MJ/kg was recorded for MSW in Tamale, which is optimal for energy generation. The second objective of the study employed a participatory approach to identify the most suitable WtE option for Tamale. Through stakeholder engagement informed by the analytical hierarchical process (AHP), anaerobic digestion (AD) emerged as the preferred method, emphasizing considerations of pollution potential, public health safety, and economic

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viability. This shows the importance of inclusive decision-making processes and the alignment of WtE solutions with broader sustainability goals.

In the third objective, the focus was on public perceptions towards WtE technology. Despite acknowledging the potential benefits, residents of Tamale express concerns about health impacts and environmental risks associated with WtE projects. This emphasizes the need for targeted education and awareness campaigns to address misconceptions and foster community support.

Finally, the fourth objective offers a practical model for integrating WtE technology into Tamale's existing waste management system. By identifying barriers and proposing implementation strategies, the study provides a roadmap for policymakers and stakeholders to navigate the complexities of WtE adoption. Moreover, it accentuates the role of public-private partnerships (PPPs) and capacity-building initiatives in overcoming challenges and realizing the full potential of WtE solutions.

5.2.1 Contribution to Knowledge

This study makes a significant contribution to the body of knowledge on waste-to-energy (WtE) adoption in developing urban settings, particularly within the context of Ghana’s waste management challenges. While previous research has explored WtE technologies primarily from a technical feasibility or environmental impact perspective, this study integrates waste characterization, stakeholder engagement, public perception, and policy integration into a comprehensive decision-making framework. The following key contributions emerge from the study:

1. Empirical Insights into Waste Composition and Energy Potential

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The study provides one of the first detailed characterizations of municipal solid waste (MSW) in Tamale, revealing that organic matter constitutes a major fraction, making it highly suitable for biochemical conversion processes such as anaerobic digestion (AD). The calorific value of 28.9 MJ/kg, which is optimal for energy recovery, adds a quantitative dimension to existing knowledge on waste-to-energy potential in Ghana, contributing to discussions on the viability of waste valorization strategies in sub-Saharan Africa.

2. Novel Application of the Analytical Hierarchy Process (AHP) in WtE Technology Selection

By employing the Analytical Hierarchy Process (AHP) in stakeholder-driven technology selection, this study presents an innovative participatory approach to WtE adoption. While previous studies have focused on techno-economic feasibility, this research integrates stakeholder preferences, revealing that anaerobic digestion (AD) is the most suitable option due to its low pollution potential, economic viability, and alignment with Ghana's sustainability agenda. This provides a replicable model for other cities facing similar waste management dilemmas.

3. Advancing Social Acceptance Research on WtE in Africa

Unlike many studies that focus on technical and financial viability, this research offers a nuanced understanding of public perceptions regarding WtE in Tamale. The study finds that while there is awareness of the benefits of WtE, concerns about environmental and health impacts remain a major barrier. This contributes to the limited body of literature on social acceptance of WtE technologies in Africa,

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emphasizing the role of targeted education and awareness campaigns in fostering community support.

4. Policy and Governance Contributions: A Model for WtE Integration

The study develops a practical framework for integrating WtE technologies into Ghana's existing waste management system, addressing critical barriers such as institutional coordination, regulatory gaps, and public-private partnership (PPP) development. Unlike existing models that assume top-down policy implementation, this study highlights the importance of multi-stakeholder collaboration, offering a policy roadmap tailored to the realities of developing urban centers.

5. Theoretical Advancements in Circular Economy and Industrial Ecology

By integrating Circular Economy (CE) and Industrial Ecology (IE) frameworks, the study strengthens the theoretical foundation of WtE research. It demonstrates how these theories can be operationalized in real-world waste management systems, particularly in low- and middle-income countries. This contributes to the ongoing academic debate on whether WtE aligns with circular economy principles, providing empirical evidence supporting its role in sustainable waste management.

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5.3. General Conclusion

The study results of the waste characterization exercise indicate that the MSW generated in the Tamale metropolitan area amounts to 176 tons/day, with a per capita waste generation rate of 0.47 kg/capita/day. From the characterization exercise, it was realized that organic waste constituted the major component of the waste mix at

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44.9%, followed by inert waste and miscellaneous and plastic waste, each at 20%. Paper, metal, glass, leather, and textile components accounted for the remaining 14.3%. Across the various waste streams, organic waste was found to be highest in the hospitality sector (62.3%) compared to households and markets at 44.9% and 13.1%, respectively. Notably, waste quantities from households contribute 70% of the total municipal solid waste (MSW) mix in the metropolis, comprising significant levels of biodegradables (54.9%) and non-biodegradables (45.1%). This finding strongly supports the potential for diverse WtE initiatives.

From the proximate and the ultimate analysis, the moisture content of MSW ranged between 5.4% and 12.6% across sources and varying residential income-classes. Volatile solids were found to range between 21.8% and 77.2%, while gross calorific values spanned from 7.9 MJ/kg to 28.9 MJ/kg. Energy content was significantly high in the households' waste, with an average of 6693.8 kcal/kg, followed by hotels/restaurants 2003.94 kcal/kg and 1883.62 kcal/kg in markets.

By inference, these findings suggest suitability for the implementation of either thermal and/or biochemical WtE conversion processes. While the waste exhibits promising characteristics for various WtE options, careful consideration of technology-specific optimization strategies is crucial. The analytical hierarchical process (AHP) was employed with a participatory approach to identify the most suitable WtE option for Tamale.

The results show that anaerobic digestion (AD) is the most preferred option, which aligns with similar findings from studies in different regions with similar economic

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climates. The preference for AD was based on considerations of pollution potential, public health safety, social acceptability, capital cost, operational and maintenance cost, and technical expertise. It was found that stakeholders prioritized environmental factors in the evaluation of WtE technologies. However, the sensitivity analysis showed that the "economy" factor could change the position of anaerobic digestion as the best method in the Metropolis, with a weight factor increase of over 85%.

In respect of public perceptions, while respondents of Tamale acknowledge the potential benefits of WtE, they also demonstrate inadequate understanding regarding the technical operations of WtE technology and its associated policies. This knowledge gap contributes to the observed concerns about risks associated with WtE, particularly in respect of “odor pollutants” and “health impacts”, which are among the most pressing issues raised by respondents. Consequently, there is a more negative attitude toward the construction of WtE plants in close proximity to residential areas, reflecting a clear manifestation of the Not-In-My-Backyard (NIMBY) syndrome, consistent with findings from previous studies. Additionally, the ANOVA and Multiple linear regression results indicate that urban residents possess a higher level of WtE awareness compared to their rural counterparts. Respondents aged between 46 and 70 exhibit greater recognition, awareness and understanding regarding WtE and related policies. Also, residents residing more than 5km away from a WtE plant demonstrate relatively lower awareness levels, while residents within 5km show promising levels of recognition, awareness, and understanding of WtE.

Furthermore, the findings suggest that increased age and higher education correlate with higher acceptance levels, while greater distance from a WtE plant and rural

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residence are associated with lower acceptance levels. Multiple linear regression analysis reveals that awareness of environmental issues and resources does not significantly impact residents' attitudes toward WtE. However, perceived risks and benefits do have a significant positive influence on residents' attitudes, with perceived risks demonstrating a stronger correlation with public attitude than perceived benefits. Therefore, enhanced and targeted publicity efforts are required to foster the development of WtE in Tamale. This study not only provided valuable insights but also guided the development of a WtE-centered ISWM framework, utilizing anaerobic digestion as the selected WtE alternative based on stakeholder input. If adopted by the Tamale Metropolitan Assembly, this framework could significantly accelerate progress toward achieving SDGs 7, 11, and 12, thereby paving the way for tangible advancements toward a cleaner, more sustainable future for Tamale. It could also serve as a model for sustainable waste management practices in other developing regions.

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5.4 Recommendations

Based on the findings of this study, the following recommendations are presented for action:

- Based on the study's findings, it is recommended that city authorities such as local government prioritize energy generation efforts in residential areas, especially within low-income communities, as they produce most of the biodegradable waste in this sector. Additionally, the hospitality sector should also receive attention, as it recorded the highest organic waste fraction among the three sectors considered in the study; residential, markets, and hospitality. The significant proportion of biodegradables in the waste mix, coupled with

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the appreciable waste generation rate and calorific value, makes the MSW in Tamale particularly suitable for WtE options such as anaerobic digestion.

- To foster the development of WtE, government intervention is imperative. Enhanced publicity efforts and sensitization campaigns focused on the perceived benefits and risks associated with WtE are needed from the National commission for civic education (NCCE) and the information service department of the metropolitan assembly to educate residents, particularly those in rural areas, individuals under 35 years old, and those with lower levels of education residing farther from WtE plants.

- It is recommended for the ministry of sanitation together with the local government ministry to implement a long-term monitoring program to track fluctuations in Tamale's waste composition over time. This data is crucial for ensuring the continued suitability of the chosen WtE technology (anaerobic digestion in this case) and identifying the need for potential adjustments.

- To achieve our goal of optimizing WtE conversion, we recommend that Tamale metropolitan assembly partner with the University for Development Studies to initiate research and pilot programs on innovative waste segregation strategies at both household and commercial levels. Enhanced segregation can improve anaerobic digestion efficiency, potentially opening avenues for further WtE technologies.

- It is recommended to implement a pilot an AD-WtE project within the Tamale metropolis, closely monitoring its performance, operational efficiency, and

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environmental impacts. Insights gained from this project will be invaluable for scaling up and replicating successful initiatives.

- Future research should focus on Optimizing pre-treatment and segregation strategies to enhance the efficiency of anaerobic digestion and explore other WtE options such as gasification and pyrolysis.

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APPENDICES

Appendix 1: Specifications considered for the selection of waste-to-energy Technologies

Option	Process type	Reaction Temp (°C)	Feedstock type	Moisture (%)	Pre-processing	Energy content	Product	Application	Environmental Issues
Incineration	Thermal	700 – 1400	Biological & Synthetic	25 - 30	Fine sorting	2 MJ (electricity)	Heat & Ash	1. Heat & power 2. Bottom ash as aggregate and filler material	1. Ash discharge. 2. Flue gases
Gasification	Thermal	500 – 1300	Organic MSW	< 15	Shredding & drying	2 MJ (electricity)	Syngas & char	1. Fuel and heat	1.toxic gasses 2. Char discharge
Anaerobic digestion	Biochemical	25 – 60	Organic MSW	75	Wet pulper & Sorting	0.04 – 0.09 MJ (electricity)	Methane & digestate	1. Heat, 2. Gas fuel, 3. Bio-	Pungent Odour

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								fertilizer	
Landfill gas	Biochemical	25 – 55	Organic MSW	30 – 70	Sorting	0.003 m^3/min (LFG)	Methane	1. Heat & power	1. Odour 2.Leachate 3. GHG Emissions

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APPENDIX 2: Mean scores of RAU Towards WtE

Question	Question	Mean value
Q14	MSW is adequately disposed of in Tamale?	2.55
Q15	You are familiar with the concept of waste-to-energy technology	3.16
Q16	You know WtE may cause environmental pollution	2.06
Q17	You know the national policies about WtE	3.96

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APPENDIX 3: Analysis of significant differences in waste generation among different income classes

Source	SS	df	MS	F	Prob > F
Between groups	1115.723	2	557.861	5.90	0.0038
Within groups	9166.927	97	94.504		
Total	10282.649	99	103.865		

Source: Field work, 2024

APPENDIX 4: Bartlett's test for homogeneity of variances

Chi-Squared (χ^2)	**Prob > χ^2**
0.0888	0.957

Source: Field work, 2024

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APPENDIX 5 :Comparison of waste generation among different income classes

Comparison	Mean Difference	p-value
Low Income vs. Middle Income	-1.90388	1.000
Low Income vs. High Income	6.57389	0.013
Middle Income vs. High Income	8.47777	0.010

Source: Field work, 2024

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APPENDIX 6:

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FACULTY OF NATURAL RESOURCES AND ENVIRONMENT

DEPARTMENT OF ENVIRONMENT AND SUSTAINABILITY SCIENCES

NYANKPALA, TAMALE.

PROGRAMME OF STUDY: Ph.D. Environmental Management and Sustainability

Topic: SELECTION OF THE MOST SUITABLE WASTE-TO-ENERGY TECHNOLOGY FOR MUNICIPAL SOLID WASTE MANAGEMENT IN TAMALE.

Dear participant,

This is an expert survey and your participation is voluntary. the information from this survey will be used to determine the preference of experts and/ or consultants for the technologies evaluated. This study forms part of the requirement for a doctoral degree in environmental management and sustainability that I am pursuing at the university for development studies.

The purpose of this survey is to gather expert opinions and recommendations regarding the selection of the most suitable Waste-to-energy technology for municipal solid waste management in Tamale. Your input will contribute to the development of sustainable waste management strategies in the region.

Thank you in advance for your valuable contribution to this survey. Your expertise will play a crucial role in shaping sustainable waste management practices in Tamale. If you have any questions or concerns, please do not hesitate to contact me @ +233543159388 / tahiru.abdulwahab21@uds.edu.gh.

Best regards,

Kindly note that your information will be kept confidential and will be available to only the researchers.

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Component one: weighting of sustainability indicators of waste-to-energy Technology.

Please assess and prioritize the **Sustainability Indicators** on the right side of the table below, in relation to the **Sustainability Indicators** on the left side, when selecting the most suitable WtE (Waste-to-Energy) technologies for Tamale. Assign a rating of nine (9) to indicate an extremely important indicator and a rating of one (1) to indicate equal importance.

SUSTAINABILITY INDICATORS FOR SELECTING OPTIMAL WtE TECHNOLOGY FOR TAMALE																		
	Extremely		Very strongly		Strongly		Slightly		Equal		Slightly		Strongly		Very strongly		Extremely	
Environment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technical
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environ

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Economic																		ment
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	social
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technical
Technical	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environment

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Social	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environment
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technical

Component two: weighting of **subcriteria of environmental** indicators of waste-to-energy Technology.

Please assess and prioritize the **subcriteria of Environment** on the right side of the table below, in relation to the **subcriteria of Environment** on the left side, when selecting the most suitable WtE (Waste-to-Energy) technologies for Tamale. Assign a rating of nine (9) to indicate an extremely important indicator and a rating of one (1) to indicate equal importance.

SUBCRITERIA - ENVIRONMENTAL INDICATORS FOR WASTE-TO-ENERGY (WTE) TECHNOLOGIES.

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	Extremely		Very strongly		Strongly		Slightly		Equal		Slightly		Strongly		Very strongly		Extremely	
Climate Change Impact	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Pollution Potential
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Public and Occupational safety
Pollution Potential	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Climate Change Impact
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Public and Occupational Safety
Public and Occupational Safety	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Pollution Potential
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Climate Change Impact

Component three: weighting of **subcriteria of technical** indicators of waste-to-energy Technology.

Please assess and prioritize the **subcriteria of Technical** on the right side of the table below, in relation to the **subcriteria of Technical** on the left side, when selecting the most suitable WtE (Waste-to-Energy) technologies for Tamale. Assign a rating of nine (9) to indicate an extremely important indicator and a rating of one (1) to indicate equal importance.

SUBCRITERIA - TECHNICAL INDICATORS FOR WASTE-TO-ENERGY (WTE) TECHNOLOGIES.

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	Extremely		Very strongly		Strongly		Slightly		Equal		Slightly		Strongly		Very strongly		Extremely	
Energy Generating Potential	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Waste Quality & Quantity
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Sophistication of Technology
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Availability of Skills
Waste Quality & Quantity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Energy Generating Potential
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Sophistication of Technology
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Availability of Skills
Availability of Skills	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	Sophistication of Technology

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	9	**8**	**7**	**6**	**5 5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	Waste Quality & Quantity
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	Energy Generating Potential
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Availability of Skills
Sophistication of Technology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Waste Quality & Quantity
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Energy Generating Potential

Component four: weighting of **subcriteria of economic** indicators of waste-to-energy Technology.

Please assess and prioritize the **subcriteria of Economy** on the right side of the table below, in relation to the **subcriteria of Economy** on the left side, when selecting the most suitable WtE (Waste-to-Energy) technologies for Tamale. Assign a rating of nine (9) to indicate an extremely important indicator and a rating of one (1) to indicate equal importance.

SUBCRITERIA - ECONOMIC INDICATORS FOR WASTE-TO-ENERGY (WTE) TECHNOLOGIES.																		
	Extremely		Very strongly		Strongly		Slightly		Equal		Slightly		Strongly		Very strongly		Extremely	

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Job Creation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Capital Cost
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Operation and Maintenance Cost
Capital Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Job Creation
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Operation and Maintenance Cost
Operation and Maintenance Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Capital Cost
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Job Creation

Component five: weighting of **subcriteria of social** indicators of waste-to-energy Technology.

Please assess and prioritize the **subcriteria of Social** on the right side of the table below, in relation to the **subcriteria of Social** on the left side, when selecting the most suitable WtE (Waste-to-Energy) technologies for Tamale. Assign a rating of nine (9) to indicate an extremely important indicator and a rating of one (1) to indicate equal importance.

SUBCRITERIA - SOCIAL INDICATORS FOR WASTE-TO-ENERGY (WTE) TECHNOLOGIES.																		
	Extremely		Very strongly		Strongly		Slightly		Equal		Slightly		Strongly		Very strongly		Extremely	

Social Acceptance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Impact on land and culture*
Impact on land and culture	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social Acceptance

Component six: Ranking of waste-to-energy (WtE) alternatives.

Please rank the waste-to-energy technologies by indicating how each technology is affected by every sustainability sub-criterion provided. Use a scale of 1 to 10, with 1 being the lowest and 10 being the highest. Kindly provide your ranking for each of the 12 sub-criteria for each technology included in this survey, based on your opinion.

	WtE Technologies				
	Sub-Criteria (sustainability)	Incineration	Gasification	Anaerobic digestion	LFG
1	Climate Change Impact				
2	Public and Occupational Safety				
3	Pollution Potential				
4	Energy Generating Potential				
5	Waste Quality & Quantity				
6	Sophistication of Technology				
7	Availability of Skills				
8	Job Creation				

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9	Capital Cost				
10	Operation and Maintenance Cost				
11	Social Acceptance				
13	Impact on land and culture				

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Section 1: Demographic Characteristics of Respondents.

1. Gender:

   a) Male, b) Female

2. Age:

   a) 18-25, b) 26-35 c) 36-45 d) 46-55 e) 56 and above

3. Educational level: a) No formal education b) Primary education c) Secondary education

   d) Tertiary education

4. Marital status:

   a) Single b) Married c) Divorced d) Widowed

5. Residence
   a) Urban b) Rural c) Tourist
6. Distance to WtE plant
   a) Near b) Far c) N/A
7. Family employed in environment-related career
   a) Yes b) No
8. Annual income
   a) <Ghc20k b) Ghc20k-50k c) Ghc 50k-100k d) > Ghc100k
9. Household size
   (insert………..)

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Section 2: Respondents' Perception of Waste-To-Energy Technologies

Instruction: Please mark the column that best represents your response to each statement

Question	I strongly agree	agree	Neutral	disagree	I strongly disagree
Public awareness of the Environmental Issues associated with WtE					
10. To what extent do you agree or disagree with the statement: 'You are concerned about environmental pollution issues?'					
11. To what extent do you agree or disagree with the statement: You care about the shortage of resources and energy?					
Public Awareness Towards WtE					
12. To what extent do you agree or disagree with the statement: You know how the MSW is disposed					
13. To what extent do you agree or disagree with the statement: You know waste-to-energy technology					
14. To what extent do you agree or disagree with the statement: You know WtE may cause environmental pollution					
15. To what extent do you agree or disagree with the statement: You know the national policies about WtE					

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Perceived Risk of WtE					
16. To what extent do you agree or disagree with the statement: WtE may emit air pollutants					
17. To what extent do you agree or disagree with the statement: WtE may discharge waste liquid					
18. To what extent do you agree or disagree with the statement: WtE may produce solid waste					
19. To what extent do you agree or disagree with the statement: WtE may generate noise pollution					
20. To what extent do you agree or disagree with the statement: WtE may produce obvious odor pollutants					
21. To what extent do you agree or disagree with the statement: WtE will impact the health of residents					
22. The transport process OF MSW has environmental impacts					
23. The storage process has environmental impacts					
24. The MSW disposal process has environmental impacts					
Perceived Benefits of WTE					
25. WtE can solve the waste siege					
26. WtE can provide jobs					
27. WtE can improve public health					

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28. WtE have significant social benefits					
29. WtE have significant environmental					
30. WtE have significant economic benefits					
31. WtE can increase the income of local residents					
32. WtE can improve local environmental quality					
33. WtE can reduce the consumption of fossil fuel					
34. WtE can promote economic development					
Public Attitude Towards WtE					
35. To what extent do you agree or disagree with the statement: You prefer electricity from WtE rather than fossil fuel					
36. To what extent do you agree or disagree with the statement: You support WtE construction in Tamale metropolis					
37. To what extent do you agree or disagree with the statement: You think WtE has a bright prospect					
38. To what extent do you agree or disagree with the statement: You think WtE is the best way to dispose of waste					
39. To what extent do you agree or disagree with the statement: you oppose the construction of WtE plant in your backyard (NIMBY)?					

Section 3: Policy and Governance (Stakeholders)

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40. Are there any existing policies or regulations addressing waste-to-energy integration into the management of waste in the metropolis?

A. Yes b. No

41. If yes, please mention the policies or regulations.

………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………

42. How effective do you believe these policies or regulations are?

a) Very effective b. Moderately effective c. Ineffective d. Not sure

43. In your opinion, what policy changes or improvements are needed to enhance waste-to-energy efforts in the metropolis?

………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………

44. How important do you think it is to integrate waste-to-energy into municipal solid waste management strategies?

a. Very important b. Moderately important c. Not very important

d) Not important at all

45. In your opinion, what additional support or measures could help enhance the implementation and adoption of waste-to-energy in the metropolis?

………………………………………………………………………………………
………………………………………………………………………………………
…………………………

46. What are the key challenges you face in implementing waste-to-energy technologies in the metropolis ?

………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
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Section 4: Barriers to WtE Adoption in the Tamale Metropolis

Instruction: Please mark the column that best represents your response to each statement

Question **Barriers to WtE Adoption in the Tamale Metropolis**	**Agree**	**Disagree**
47. WtE has high initial cost		
48. WtE is not environmentally friendly		
49. WtE is not a good source of energy		
50. The waste in the metropolis can not yield much of energy		
51. Problem of waste segregation		
52. Lack of political will		
53. WtE suffers social acceptance		

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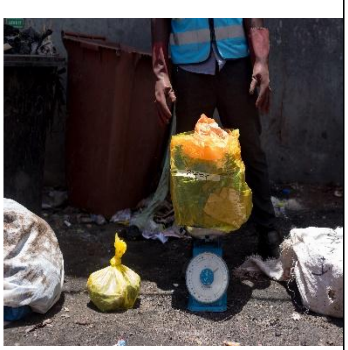
APPENDIX 7:



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