MAKERERE UNIVERSITY



MAKERERE UNIVERSITY BUSINESS SCHOOL

ASSESSMENT OF WASTE TO ENERGY POTENTIAL OF UNIVERSITIES: A CASE OF ORGANIC WASTE AT MAKERERE UNIVERSITY BUSINESS SCHOOL

BY

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A DISSERTATION SUBMITTED TO MAKERERE UNIVERSITY BUSINESS SCHOOL (FACULTY OF GRADUATE STUDIES AND RESEARCH) IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF ENERGY ECONOMICS AND GOVERNANCE OF MAKERERE UNIVERSITY

PLAN A

NOVEMBER, 2025

DECLARATION

I **Muyinda Bridgette Mirembe**, hereby declare that this dissertation is my original work and has never been published nor presented to any institution for an award of a degree.

Signed..... Date.....9/11/2025.....

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APPROVAL

This is to certify that the research entailed in this dissertation has been conducted under our guidance as academic supervisors.

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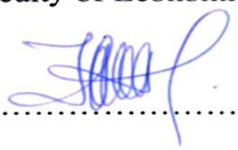

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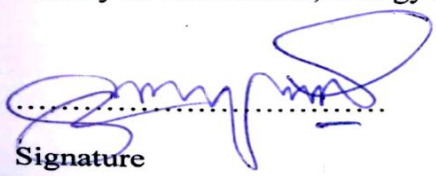

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DEDICATION

I dedicate this work to the Almighty God, my Creator, and wellspring of wisdom. I also honor my parents, Dr. Edith Basalirwa Mwebaza and Dr. Moses Basalirwa Muyinda, who have inspired me to work diligently toward my goals. My supervisors and my friends, thank you for your untiring support and motivation throughout my studies.

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ACRONYMS

MUBS	Makerere University Business School
WtE	Waste to Energy
KCCA	Kampala City Council Authority
MSW	Municipal Solid Waste
GHG	Green House Gas
CO_2	Carbon dioxide
H_2	Hydrogen
CH_4	Methane
CE	Circular Economy
LHV	Lower Heating Value
HRT	Hydraulic Retention Time
MJ	Mega Joules

ABSTRACT

The rapid growth of municipal solid waste poses significant environmental and socioeconomic challenges, particularly in urban centres of Sub-Saharan Africa where waste collection and management systems remain inadequate. University campuses, which generate substantial quantities of organic waste, present unique opportunities for waste-to-energy (WtE) solutions that align with circular economy principles and national renewable energy targets. This study assessed the organic waste-to-energy potential of Makerere University Business School (MUBS) by quantifying waste streams, estimating their energy yields, and evaluating the economic viability of biogas and briquette production.

Using a mixed descriptive–experimental design, waste was collected and analyzed over five months at five high-output sites across the MUBS campus. Results showed that the university generates approximately 147.7 tonnes of organic waste annually, composed mainly of food waste (63%) and grass/leaves (37%). Energy potential analysis indicated an annual yield of 450,761 MJ, with grass waste offering higher calorific value. Laboratory conversion trials demonstrated annual outputs of 1,627.6 m^3 of biogas from grass waste, 1,014.9 m^3 of biogas from food waste, and 85.9 tonnes of briquettes from grass waste. Economic feasibility analysis revealed positive net present values of UGX 10.45 million for biogas from food waste, UGX 67.7 million for biogas from grass waste and UGX 41.08 million for briquettes, with internal rates of return exceeding 25%, and benefit–cost ratios of 1.2 for briquettes,1.4 for biogas from grass waste and 1.1 for biogas from food waste, confirming profitability. Sensitivity tests further underscored the importance of feedstock availability and energy yields in determining cost efficiency.

The findings establish that campus organic waste can be harnessed to support energy diversification, reduce disposal costs, and mitigate greenhouse gas emissions, positioning universities as models for sustainable waste management. The study recommends investment in integrated WtE systems, prioritizing briquette production for cost efficiency while promoting biogas for energy diversification, thereby advancing Uganda's renewable energy and climate resilience agenda.

CHAPTER ONE

INTRODUCTION

1.0 Background to the Study

Rapidly rising solid waste volumes pose serious threats to ecosystems, public health, and economies worldwide. In 2023, global municipal solid waste reached about 2.24 billion tonnes and is forecast to grow by nearly 70 percent by 2050 if no new measures are taken (World Bank, 2023). Only around one-fifth of this is recycled; most is landfilled or incinerated, worsening pollution and depleting resources (Sharma & Jain, 2020). In Sub-Saharan Africa, urbanization and limited waste infrastructure mean collection rates range from 25 to 70 percent, averaging just 57 percent, with the remainder accumulating in informal dumps that threaten water supplies and community health (Muheirwe et al., 2023).

In Kampala, the city authority collects roughly 28,000 tonnes of waste each month only about 40 percent of the total generated while the balance is often dumped illegally (KCCA, 2023). Daily waste output stood at 3,206 tonnes in 2015 and is projected to rise to 4,739 tonnes by 2030, driven by population growth (GGGI, 2018). Approximately 78 percent of Kampala's refuse is biodegradable, produced at an average rate of 0.55 kg per person per day; however, only 43.7 percent of that is officially collected (Tibihika et al., 2020). University campuses contribute significantly to this organic stream up to 73 percent of landfill content yet their biodegradable waste remains largely untapped for energy recovery (GGGI, 2018).

The consequences of inadequate waste management range from contaminated groundwater to fatal landfill collapses. The August 2024 Kiteezi disaster, which claimed 24 lives, highlights the urgency for sustainable solutions (Daily Monitor, 2024). Similar tragedies in India (2005), Malaysia (2017), and Albania (2020) further illustrate the global scale of the problem (Kumar &

Gupta, 2006; Lee & Hwang, 2018). Overfilled landfills not only emit greenhouse gases but also leach toxins, undermining both environmental integrity and human well-being.

Waste-to-Energy (WtE) technologies such as anaerobic digestion, gasification, pyrolysis, and incineration offer a pathway to convert waste into electricity, heat, or fuels, reducing landfill reliance while supporting renewable energy targets (Lombardi et al., 2022; Ghisellini et al., 2022). Universities, which generate diverse waste streams including food scraps, paper, plastics, and hazardous materials, represent ideal settings for piloting WtE solutions (Tangwanichagapong et al., 2020). In Uganda, higher-education institutions already grapple with large volumes of organic waste from dining halls and academic activities, suggesting significant potential for biogas and briquette production (MUCCRI, 2015).

This study sought to evaluate the quantity and composition of organic waste at Makerere University Business School, and assess the feasibility of converting it into viable energy forms, such as electricity, biogas, and briquettes. By aligning with Uganda's renewable energy targets and the principles of a circular economy, the research proposed practical solutions for effective institutional waste management, contributing to the broader objectives of environmental sustainability.

1.1 Problem Statement

Kampala's waste management system is under severe strain. Of the approximately 28,000 tonnes of municipal solid waste generated each month, less than half is formally collected, leaving the remainder to be burned, buried, or dumped in unauthorized locations (KCCA, 2023). In Nakawa Division alone, daily generation peaks at 240 tonnes, yet only 40 percent enters the official collection stream, exacerbating air pollution, contaminating water sources, and heightening

public-health risks through the proliferation of disease vectors (KCCA, 2023). The catastrophic collapse of the Kiteezi landfill in August 2024, which claimed 24 lives and displaced hundreds of nearby residents, tragically underscores the human and environmental toll of inadequate disposal infrastructure (Daily Monitor, 2024).

Recognizing these challenges, Ugandan authorities and private partners have launched pilot Waste-to-Energy initiatives. The Ddundu project, a collaboration between the government and RIC Energy, aims to convert municipal refuse into 20 MW of baseload power (Nile Post, 2024). In western Uganda, community-level briquette ventures have seen promising uptake with adoption rates of 58.2 percent in Isingiro, 50.6 percent in Masindi, and 66.7 percent in Mbarara demonstrating the feasibility of transforming organic residues into solid fuels (Nakiganda et al., 2023). Within higher-education institutions, efforts such as color-coded recycling bins and partnerships with private waste collectors signal growing commitment, yet low awareness of the "5Rs" (refuse, reform, reduce, reuse, recycle) and poor waste-sorting practices persist (Tibihika et al., 2020; Owojori et al., 2020).

Mixed waste streams not only inflate disposal costs as private firms must transport refuse to distant Mukono and Mityana Road landfills but also squander valuable organic fractions that could feed biogas digesters or briquette presses (Daily Monitor, 2024). Drawing on the Circular Economy model which links access to cleaner energy sources with socio-economic advancement this study sought to quantify and characterize university organic waste streams to reveal untapped WtE opportunities, thereby alleviating landfill burdens and aligning campus operations with Uganda's Renewable Energy Policy (2007) (Ategeka, 2017).

1.2 Purpose of the Study

The primary aim of this research was to conduct a comprehensive assessment of organic solid-waste streams at Makerere University Business School and to evaluate the technical and economic feasibility of deploying Waste-to-Energy solutions specifically biogas digesters, briquette presses, and small-scale combustion or gasification units. By characterizing campus waste generation patterns, estimating calorific values, and analyzing cost–benefit scenarios, the study sought to furnish actionable recommendations for institutional stakeholders, aligning with national renewable energy targets and circular-economy principles.

1.3 General Objective

This study aimed to examine the energy potential of organic solid waste in universities

1.3.1 Specific Objectives

i. To quantify and classify the organic solid waste in universities
ii. To estimate the energy worth of the organic solid waste generated in universities
iii. To examine the economic feasibility of converting university organic waste into energy

1.4 Research Questions

i. What is the quantity and composition of organic waste generated in universities?
ii. What is the estimated energy potential of the organic waste in universities?
iii. Is organic waste-to-energy conversion in universities economically viable?

1.5 Scope of the Study

1.5.1 Content Scope

This study focused on quantifying waste, estimating the energy potential, and analyzing the economic feasibility of WtE solutions in universities. Through literature review and case studies, practical approaches were identified and evaluated.

1.5.2 Geographical Scope

The study focused on Makerere University Business School (MUBS) in Kampala, Uganda, a leading institution with approximately 13,000 students and 900 staff. The study featured five key waste collection points at the MUBS's main campus namely: Small Gate Mast, ADB Building, Berlin Hall, MUBS Guest House, and the Dining Hall. These sites were expected to provide robust data due to their high waste output. Given that students across Ugandan universities share similar socio-cultural backgrounds, their waste management behaviors are likely consistent, which made MUBS a representative case study.

1.6 Time Scope

The research spanned ten months, from November, 2024 to August, 2025, with data collection occurring over five months (November, February, March, April, and May) during an active academic semester. This timeframe ensured the capture of typical waste generation patterns influenced by student and staff activities.

1.7 Significance of the Study

By generating rigorous empirical data on campus-level waste volumes and energy potential, this study equips MUBS administrators and the Ministry of Energy and Mineral Development with evidence-based recommendations to integrate organic Waste-to-Energy systems into institutional

operations. Demonstrating tangible cost savings through reduced landfill tipping fees, lowered fuel procurement expenses, and possible revenue from electricity or briquette sales strengthens the financial case for on-site biogas and briquetting facilities. Environmentally, diverting biodegradable waste from landfills to controlled conversion processes decreases CO_2-equivalent emissions, mitigates leachate formation, and reduces open dumping, contributing to national greenhouse-gas mitigation commitments under Kigali Declaration, an outcome of the World Climate Research Programme (WCRP) open science conference of October, 2023 (WCRP, 2024). Socially, positioning MUBS as a campus "living laboratory" for sustainable waste management fosters student and staff engagement in clean-energy practices, enhances hands-on learning opportunities, and catalyzes behavioral shifts toward the "5Rs" (refuse, reform, reduce, reuse, recycle). The findings also guide investors and development partners by clarifying feedstock supply reliability and projected returns, thereby facilitating strategic investments that support Uganda's Renewable Energy Policy (2007) and circular-economy ambitions.

1.8 Theoretical Framework

1.8.1 The Circular Economy Model and its Integration with Waste-to-Energy

The concept of the circular economy has gained significant traction in recent years as a means of addressing the growing global challenge of waste management and resource depletion. The circular economy model aims to transform the traditional linear "take-make-waste" approach to a more sustainable closed-loop system where the value of products, materials, and resources is maintained for as long as possible, and the generation of waste is minimized (Ranta & Saari, 2019).

The circular economy concept highlights the interdependence between resource use, waste, and energy production, emphasizing the need for a holistic approach that considers the entire life cycle

of materials and products (Pouikli, 2020). By incorporating waste-to-energy technologies into the circular economy model, the value of waste materials can be harnessed, and the overall efficiency of the system can be improved (Zanoletti et al., 2021).

Central tenets include designing out waste, keeping products and materials in use, and regenerating natural systems (Ellen MacArthur Foundation, 2020). In practice, this framework promotes valorizing campus refuse such as food scraps, paper, and plastics via technologies that convert these streams into biogas, briquettes, or compost, thereby reducing the reliance on fossil fuels and contributing to the overall sustainability of the system (Malinauskaitė et al., 2017).

For example, integrating anaerobic digestion facilities on site not only recovers methane for electricity or heating but also generates nutrient-rich digestate that can be returned to campus landscapes, embodying cradle-to-cradle principles (Lombardi et al., 2022; Zanoletti et al., 2021). By embedding CE strategies within university operations, Makerere University Business School (MUBS) can demonstrate how closed-loop waste management fosters resilience, reduces landfill reliance, and aligns with Uganda's Renewable Energy Policy (2007).

However, the integration of waste-to-energy technologies into the circular economy is not without its challenges. For example, the availability of certain critical raw materials like biodegradable waste may not be sufficient to meet the growing demand, which could hinder the ability to fully implement circular economy practices (Kullmann et al., 2022). Furthermore, the environmental impacts of some waste-to-energy technologies, such as air pollution or the potential release of hazardous substances, must be carefully considered and addressed through rigorous regulations and technological advancements to ensure the sustainability of the circular economy model (Mora et al., 2021).



Figure 1: 5Rs Circular Economy

Source: (Meshram, 2024)

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

Solid waste management (SWM) in Ugandan and East African universities is a pressing challenge, driven by substantial waste generation from large student and staff populations, diverse campus activities, and limited infrastructure (Okot-Okumu et al., 2019). These institutions produce significant volumes of organic waste, plastics, paper, and electronic waste, yet rely heavily on unsustainable practices such as open burning, dumping, and landfilling, which contribute to environmental pollution, soil degradation, and health risks like waterborne diseases and water contamination (Kihila et al., 2021; Mugerwa, 2023). The lack of robust circular economy frameworks further intensifies these issues, with minimal recycling or energy recovery (Tesfaye et al., 2023). This review synthesizes literature, exploring solid wastes in universities, waste management practices, segregation challenges, barriers to Waste-to-Energy (WtE) adoption, non-WtE approaches, economic feasibility of WtE solutions, and emerging trends in Ugandan and East African contexts. By analyzing regional studies, this review highlights gaps in waste characterization, energy potential, and economic analysis, underscoring MUBS's contribution to sustainable waste management.

2.1 Waste Management Practices in Ugandan and East African Institutions

East African institutions predominantly use linear waste management models, focusing on collection, transportation, and disposal, with minimal circular approaches like recycling or energy recovery. Okot-Okumu (2019) found that in Ugandan urban councils, including universities, only 40–50% of waste is collected, with the rest openly dumped or burned, leading to soil and water contamination, underscoring the need for precise waste quantification at MUBS to avoid similar

inefficiencies. Mugerwa (2023) reported that Makerere University generates waste comprising 60% organic material, 20% plastics, and 15% paper, but only 10% is recycled due to poor segregation, providing a baseline for MUBS to classify waste types and volumes accurately. The absence of detailed waste composition data across institutions hinders targeted management, a gap MUBS aims to address through systematic profiling.

In Tanzania, Oberlin and Szántó (2021) noted that a Dar es Salaam university's composting initiative processed only 5% of organic waste due to inadequate infrastructure. Kihila et al. (2021) found that the University of Nairobi generates 0.6 kg of waste per person daily, with 50% organic, but low segregation rates (15%) limit accurate classification, emphasizing the importance of robust quantification systems. Nshimiyimana et al. (2022) in Rwanda reported that Kigali's universities produce 0.5–1 kg of waste per person daily, with 55% organic, but inconsistent collection data hampers classification, a challenge MUBS must overcome.

Tesfaye et al. (2023) in Ethiopia noted that Addis Ababa's universities generate 65% biodegradable waste, yet only 20% is diverted from landfills due to poor waste tracking, supporting MUBS's focus on detailed waste characterization. Katusiime et al. (2024) at Kyambogo University reported 45% organic waste, but lack of classification leads to open dumping, reinforcing the need for MUBS's objective. Mugume et al. (2023) found that Kampala's technical institutes generate 50% organic waste, with only 5% quantified for composting, indicating a regional gap in waste profiling. Niyongabo et al. (2023) in Burundi reported that Gitega's universities lack waste composition data, with 70% landfilled, necessitating studies like MUBS's. In South Sudan, Loro et al. (2024) noted that the University of Juba generates 0.7 kg of waste per person daily, with 60% organic, but lacks quantification systems, further highlighting MUBS's relevance in providing granular waste data to inform management strategies.

2.2 Challenges in Waste Segregation

Waste segregation is pivotal for the MUBS study's first and second objectives quantifying and classifying waste and evaluating energy potential as poor segregation complicates waste characterization and reduces WtE efficiency. Ojok et al. (2023) found that in Kampala, only 15% of institutional waste is segregated, with mixed waste streams due to limited awareness, inadequate bins, and lack of training, hindering accurate waste typing critical for MUBS's classification efforts. Namanya and Kiggundu (2022) reported that at Kyambogo University, only 12% of waste is segregated, with students using single bins, impacting the ability to classify organic fractions for WtE technologies like anaerobic digestion. Gelan (2023) noted that in Addis Ababa, 70% of institutional waste is unsegregated, reducing the potential for energy recovery from organic waste, a challenge MUBS must address to ensure viable WtE inputs.

In Kenya, Mutisya et al. (2024) found that Nairobi's technical colleges have segregation rates below 10%, with cultural attitudes viewing waste handling as low-status, complicating waste classification accuracy and affecting MUBS's goal of precise waste typing. Nuwematsiko et al. (2020) in Kampala noted that economic incentives, like selling recyclables, drive segregation near universities. Rukondo et al. (2023) in Mbarara reported 8% segregation rates, with mixed waste increasing costs and reducing energy potential, a barrier MUBS aims to overcome. Uwamahoro et al. (2022) in Rwanda found that the University of Rwanda has a 10% segregation rate, with students unaware of sorting protocols, affecting waste characterization efforts relevant to MUBS. Ndayisaba et al. (2023) in Burundi noted that only 7% of university waste is segregated, limiting WtE feasibility, underscoring MUBS's need for segregation strategies. Nyirenda et al. (2023) in South Sudan reported 5% segregation at Juba's institutions, with mixed waste undermining energy recovery, a challenge MUBS's study addresses. In Tanzania, Mwakitalu et al. (2024) found that

mixed waste at the University of Dodoma increases landfill costs by 25%, highlighting the need for MUBS to improve segregation to support waste classification and WtE efficiency.

2.3 Barriers to Effective Waste-to-Energy Adoption

The Africa Report (2019) highlighted high capital costs, inadequate collection systems, and low calorific value of waste due to high moisture content as barriers across Africa. Nakiganda et al. (2024) noted that in Uganda, unsegregated institutional waste reduces WtE efficiency, particularly for anaerobic digestion, a key technology MUBS aims to assess, necessitating improved segregation practices. Amoah-Antwi et al. (2024) in Ghana found that anaerobic digestion is viable for organic waste but requires consistent segregation, a challenge at MUBS where mixed waste is prevalent, directly linking to the study's segregation focus.

In Ethiopia, Tesfaye et al. (2023) reported that the Reppie WtE plant's success relies on large-scale urban waste streams, not replicable in universities due to limited waste volumes and funding. Lohani et al. (2021) noted high costs and lack of expertise in Kathmandu's institutions, mirrored in East Africa, where universities must navigate similar constraints to achieve energy recovery. Ssekyanzi et al. (2024) highlighted Uganda's lack of power purchase agreements (PPAs), discouraging WtE investment, a factor MUBS's economic feasibility analysis (aims to address. Mungai et al. (2023) in Tanzania noted that universities lack technical capacity for WtE systems, with maintenance costs exceeding budgets. Ssekyanzi et al. (2023) found low WtE awareness in Kampala's institutions, reducing support for briquette production, a social barrier MUBS must overcome through awareness campaigns. Niyonzima et al. (2022) in Rwanda reported cultural resistance to handling organic waste, limiting biogas adoption. Kibet et al. (2023) in Kenya noted that Moi University's students are unaware of WtE, with only 3% of waste considered for energy

recovery, emphasizing the need for education at MUBS. Ochieng et al. (2023) in Kenya reported low community acceptance of WtE.

2.4 Non-WtE Approaches and Their Limitations

Non-WtE approaches provide context for the MUBS study's second and third objectives, as their limitations justify exploring WtE and analyzing its economic feasibility. Komakech et al. (2023) found that composting in Uganda's urban councils is limited by land constraints and low market demand, with only 25% of organic waste processed, reducing its viability as an alternative to WtE at MUBS, where energy recovery is prioritized. Okello et al. (2021) reported that Gulu University's composting pilot processed only 5% of waste due to space issues and negative perceptions, highlighting the need for MUBS to pursue WtE technologies like anaerobic digestion for organic waste. Niyonzima et al. (2022) in Rwanda noted that composting at the University of Rwanda is hindered by high labor costs, with 10% of organic waste composted, underscoring WtE's potential for MUBS. Mwesigye et al. (2023) in Fort Portal found that composting fails due to lack of funding, with 6% of waste diverted, supporting MUBS's focus on economically viable WtE. Nkurunziza et al. (2023) in Burundi reported that composting at Gitega's universities processes only 8% of waste, limited by market demand. In South Sudan, Deng et al. (2024) noted that composting at the University of Juba is minimal, with only 5% of waste processed, reinforcing the need for MUBS's energy-focused approach.

Recycling is constrained. Agbefe et al. (2021) found that in Ghana, only 10% of institutional waste is recycled, primarily by informal pickers, offering limited scalability compared to WtE, which MUBS aims to evaluate for economic feasibility. Mugerwa (2023) reported that Makerere University's recycling is informal, with most recyclables landfilled, a challenge MUBS addresses through WtE. Taremwa et al. (2024) in Mbarara noted 8% recycling rates, with limited

infrastructure, supporting MUBS's WtE focus. Wambua et al. (2023) in Kenya reported 5% plastic recycling in technical colleges, underscoring WtE's potential. Habimana et al. (2022) in Rwanda found 10% recycling at universities, limited by bin availability, reinforcing MUBS's energy recovery objectives. These limitations highlight the need for MUBS to assess WtE as a sustainable alternative, with economic metrics to ensure viability.

2.5 Economic Feasibility of Waste-to-Energy Solutions

The study's third objective analyzing WtE economic feasibility requires evaluating regional economic factors. The feasibility of WtE in universities hinges on waste availability, technology costs, and energy market conditions (Lombardi et al., 2022). Nakiganda et al. (2024) estimated anaerobic digestion in Uganda costs $50–70 per kW installed capacity, with high upfront costs deterring adoption, necessitating MUBS's LCOE analysis to identify cost-competitive options. Ssekyanzi et al. (2024) noted that Uganda's lack of subsidies and PPAs results in negative NPVs for WtE, emphasizing MUBS's need for models yielding positive IRR through gate fee savings and digestate valorization. Amoah-Antwi et al. (2024) found Ghana's anaerobic digestion achieved BCRs of 1.2–1.5 with subsidies, but without them, IRR drops below 10%, guiding MUBS's feasibility metrics to prioritize subsidy scenarios.

Global trends show WtE's potential to address waste and energy challenges, but developing nations face unique constraints (Olujobi et al., 2021). Fraunhofer ISE (2019) reported LCOE for small-scale biogas at $0.08–0.12/kWh and briquettes at $150–200/tonne, competitive with diesel and charcoal. Mukasa Tebandeke et al. (2019) found Ugandan campus WtE projects achieve payback periods of 3–7 years, with digestate sales boosting NPV, a model MUBS could replicate. Kaseva et al. (2023) noted that PPPs in Tanzania reduce WtE costs by 20%, improving BCR, a strategy MUBS could explore. Ochieng et al. (2023) highlighted that low community acceptance

in Kenya increases project risks, affecting IRR, a factor MUBS's stakeholder engagement must address. Awasthi et al. (2019) emphasized feedstock consistency as a profitability driver, aligning with MUBS's segregation focus. UNDP (2021) advocated feed-in tariffs and concessional loans to de-risk WtE investments, critical for MUBS's economic viability. These studies underscore MUBS's role in assessing WtE feasibility tailored to institutional contexts, ensuring economic sustainability.

2.6 Emerging Trends and Innovations

Emerging trends are crucial for all MUBS study objectives, as they suggest innovative approaches to waste quantification, energy recovery, and economic feasibility. Mugisha et al. (2023) reported that digital waste tracking in Kampala's colleges improved collection efficiency by 15%, aiding MUBS's waste quantification efforts by providing real-time data for classification. Omondi et al. (2024) found that vermicomposting at Kenyatta University reduced landfill waste by 30%, offering insights for managing organic waste to support WtE at MUBS, aligning with its energy potential objective. Kaseva et al. (2023) noted that public-private partnerships (PPPs) in Tanzania improved collection efficiency by 20%, relevant to MUBS's economic feasibility assessments of WtE implementation, as partnerships could reduce costs. Nuwagaba et al. (2022) reported that student-led clubs in Uganda increased recycling by 15%, supporting waste classification. Atuhaire et al. (2024) found that biodegradable bags in Arua reduced plastic use by 10%, aiding MUBS's efforts to classify non-organic waste and focus on organic fractions for WtE. Bekele et al. (2023) in Ethiopia reported 12% segregation improvements through waste audits, supporting MUBS's energy potential assessments by ensuring accurate waste typing. Gakuba et al. (2024) in Rwanda noted 18% collection efficiency gains via IoT systems, relevant to MUBS's management strategies for waste quantification. Kamau et al. (2023) in Kenya found that waste-to-art programs increased

plastic recovery by 8%, offering creative approaches to waste management that MUBS could adapt. Ndayizeye et al. (2024) in Burundi reported 10% segregation improvements through sorting workshops, supporting MUBS's focus on behavioral strategies to enhance WtE feasibility. In Tanzania, Massawe et al. (2023) noted that community waste banks increased recycling by 10%, a model MUBS could explore to support economic viability of waste management. These trends inform MUBS's objectives by providing innovative, context-specific solutions for sustainable waste management.

Summary

Existing literature shows that while East African universities generate large amounts of organic waste, poor segregation, weak institutional systems, and reliance on open dumping limit energy recovery and recycling. Waste-to-energy (WtE) technologies are recognized as promising, but their adoption is hindered by high capital costs, technical gaps, and lack of institutional models. Few studies have examined the economic feasibility of WtE specifically in university settings, and there is limited data on how segregation practices can be improved to support such systems.

This gap points to the need for MUBS to conduct detailed waste quantification and characterization, assess the energy potential of its organic waste through technologies like anaerobic digestion and briquetting, and evaluate their financial viability using measures such as LCOE and NPV. Furthermore, MUBS should pilot segregation improvement strategies, such as buy-back programs or targeted awareness campaigns, to secure reliable feedstock. In doing so, MUBS can provide a replicable institutional model for waste-to-energy adoption in Ugandan and East African universities.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

The chapter specifically covered the research design, methodology, study population, sampling process, data collecting, procedure, and research instruments, as well as data analysis techniques, validity and reliability and research ethics.

3.1 Research Design

This study employed a mixed descriptive-experimental quantitative design to systematically measure waste generation at Makerere University Business School (MUBS) and to evaluate its energy conversion potential. First, a descriptive component quantified daily and monthly waste flows by conducting systematic sampling at five high-output campus locations. Trained research assistants collected, sorted, and weighed refuse into defined categories using calibrated digital scales, ensuring three replicate measurements per site and per sampling event to enhance precision (Mohajan, 2020). This longitudinal sampling occurred in November, 2024 and February through May, 2025 and captured both term-time and vacation variations in waste production.

Second, an experimental component processed representative organic samples in laboratory settings to determine bioenergy yields. Batch anaerobic digestion trial equations were carried out in continuously stirred tank reactors (CSTRs) following Mukisa's (2016) protocols, varying hydraulic retention times to optimize methane output. Carbonization experiments utilized a muffle furnace at 350–450 °C to produce biochar, which were then equated into briquettes using binder ratios recommended by the Tanzania Industrial Research and Development Organization (2023). Energy outputs from combustion and methane production were calculated using standard biomass

conversion equations (Buswell & Boyle) and lower heating-value determinations (Nabaggala et al., 2018).

All quantitative data was subjected to statistical analysis including measures of central tendency, variance, using software such Microsoft excel. This robust design ensured accurate measurement, reproducibility, and rigorous evaluation of MUBS's waste-to-energy potential.

3.2 Study Population

For this investigation, the study population comprised the organic solid waste generated at five strategically selected dumping sites located within Makerere University Business School's (MUBS) main campus. These sites were purposively chosen based on their high waste generation rates and functional diversity, ensuring that waste streams representative of academic, commercial, and administrative activities were captured.

The selected sites are shown in **Table 1.** These locations provided a comprehensive view of the volume and composition of organic waste generated by students, staff, and visitors on campus. Weekly and monthly waste outputs at these points formed the basis for quantifying total waste generation and for analyzing the composition critical for evaluating the institution's waste-to-energy (WtE) potential. Sampling from these sites allowed the study to account for variations in waste production influenced by location-specific activities such as lectures, food service operations, and administrative functions.

3.3 Data Collection Methods

Primary data collection involved weekly waste capture at each site during scheduled visits. Each fraction was weighed to the nearest 0.1 kg using calibrated scales. Subsamples of organic refuse were simulated for moisture, volatile solids, and ash content according to ASTM standard

procedures (García Álvaro et al., 2023). Secondary data such as historical waste-management reports, equipment specifications, and market price lists was sourced from KCCA publications, MUBS facilities records, and peer-reviewed literature to complement primary findings.

Table 1: Waste dumping sites at MUBS

Site	Month					Total No. of drums collected	Value in kgs
	Week	**1**	**2**	**3**	**4**		
Small gate mast	Nov						
	Feb						
	Mar						
	Apr						
	May						
ADB	Nov						
	Feb						
	Mar						
	Apr						
	May						
Berlin hall	Nov						
	Feb						
	Mar						
	Apr						
	May						
Guest house	Nov						
	Feb						
	Mar						

	Apr						
	May						
Dining hall	Nov						
	Feb						
	Mar						
	Apr						
	May						

3.4 Data Analysis Techniques

Several mathematical and statistical approaches were utilized in this study to systematically evaluate the collected waste data and address the research objectives. The selected models were organized into three primary categories: measurement of waste quantities and composition, estimation of the energy potential embedded in the waste streams, and assessment of the economic viability of proposed waste-to-energy interventions. Each group of equations was carefully tailored to enhance the accuracy of analyzing waste characteristics, forecasting energy yields, and determining the financial sustainability of implementing waste-to-energy technologies at Makerere University Business School.

3.4.1 Assumptions of the study

The study was carried out based on a set of assumptions essential for its methodological rationality and efficiency, as shown in **Table *2***.

Table 2: Some of the assumptions taken in the study

Assumptions	Value	Reference
Economic life of the bio digester (years)	25	(MEMD, 2023)
Desired slurry concentration (%)	8	(Mukisa, 2016)
Discount rate (%)	5	(Dimson, 1989)
Total solid content of the feedstock (%)	10	(Barry, 2009; Steffen, 1998a)
Ultimate CH4 yield (m 3 CH4/kg VS added)	0.3	(Barry, 2009; Steffen, 1998a)
Hydraulic retention time (days)	14	(Barry, 2009; Steffen, 1998a)
Volatile solid content (%)	80	(Barry, 2009; Steffen, 1998a)

3.4.2 Waste quantification models to determine waste composition;

To estimate the amount and types of waste generated, standard municipal solid waste (MSW) quantification formulas were used. The total municipal solid waste energy potential was calculated using the following generalized formula in **Eq. (1)**.

$$M_{Ep} = T_{W,year} * \varepsilon * Q_{OR} * LHV \quad (1)$$

Where;

M_{Ep} is the solid waste energy potential (MJ/year); ε is the waste collection efficiency (%); Q_{OR} is the fraction of the organic waste content (%) and LHV is the lower heating value of the MSW, taken as 18.47MJ/kg for grass waste (Lelicińska-Serafin, 2024) and 4.30MJ/kg for food waste (McGaughy, 2024).

The total waste generated was calculated using **Eq. (2)**

$$W_{T=W_{org1}+W_{org2}}$$

(2)

Where;

- W_{org1} represents the organic waste component 1 collected (kg);
- W_{org2} represents the organic waste component 2 collected (kg).

3.4.3 Biomass energy conversion models for estimating energy yields

Production of biogas

The potential for biogas production from organic waste was determined using adapted versions of the Buswell and Boyle equations, relating the composition of the substrate to its methane generation potential. The daily fermentation slurry, denoted as S_d, was calculated using **Eq. (3)**. To achieve the desired low total solids content in the anaerobic digester slurry concentration S_D, which facilitates easier pumping in the CSTR digester, the required dilution water, W_s, was determined using **Eq. (4)**:

$$S_{d=\frac{V_D}{HRT}} \quad (3)$$

$$W_S = \frac{(TS-S_D)*S_d}{TS} \quad (4)$$

In this context, Ws denotes the amount of dilution water added to the slurry (kg), S_D refers to the target total solids (TS) concentration of the slurry (%), S_d represents the daily quantity of slurry introduced for fermentation (kg), TS indicates the total solids content of the feedstock (%), V_D stands for the digester volume (in kg), and HRT corresponds to the hydraulic retention time (days).

The daily solid input, symbolized as Sf, required for the digester system was determined using **Eq. (5)**.

$$S_f = S_d - W_S \quad (5)$$

The Organic Loading Rate (OLR), or the influent total volatile solids in the digester, was determined by the amount of volatile solids (VS) introduced, as outlined in **Eq. (6)** (Schön Michael, 2007).

$$OLR = S_O = \frac{V_{vs} * S_d}{V_D} \quad (6)$$

In this context, S_0 represents the influent total volatile solids (kg·VS·m^{-3}·V_D·day^{-1}), V_{vs} indicates the percentage of volatile solids, V_D refers to the volume of the anaerobic digester (m^3), HRT stands for the hydraulic retention time (days), and S_d represents the daily amount of fermentation slurry added (kg).

For high-rate anaerobic digestion systems, the recommended volatile solids loading rate is between 1.6 and 4.8 kg per m^3·VS·day. In contrast, for low-rate systems (which operate without heating and mixing), the recommended range is 0.5 to 1.6 kg per m^3·VS·day (Rittmann and McCarty, 2001).

The kinetic parameter K denotes the ratio of volatile solids concentration to the bacterial concentration in the digester. A lower K value leads to a higher percentage of waste being converted into biogas (Dennis & Burke, 2001). The value of K is determined using **Eq. (7)**, which shows that although digester temperature has little impact on K, there is an exponential relationship

with S_0.

$$K = 0.8 + 0.016_{e^{0.06 S_o}}$$

(7)

The methane production rate, represented as γ_0 (m^3 $CH_4 \cdot m^{-3}$ fermentor$\cdot day^{-1}$), was determined using **Eq. (8)**.

$$y_o = \frac{B_{O*S_O}}{HRT} * (1 - \frac{K}{(HRT* \mu_{m)-}\ 1+K})$$

(8)

In this case, B_0 refers to the ultimate methane (CH_4) yield, expressed in cubic meters of CH_4 per kilogram of volatile solids (m^3 CH_4/kg VS added), while μ_m represents the maximum specific microbial growth rate (day^{-1}). The value of μ_m is calculated using **Eq. (9)**, as outlined by Hashimoto and Chen (1981).

$$\mu_m = 0.013T - 0.129$$

(9)

Where T represents the digester temperature, which ranges from 20 to 60°C. If B_0, μ_m, S_0, and HRT remain constant, an increase in K leads to a decrease in the methane production rate γ_0.

Table 3: Identified feed stocks for biodigester systems

Feed stock	Total solid content of the feedstock (%)TS	Ultimate CH4 yield (m^3 CH4/kg VS added) B_0	Hydraulic retention time (days) HRT	Volatile solid content (%)V_{vs}
Cow dung	5-12	0.20-0.30	20-30	75-85
Whey	1-5	0.80-0.95	3-10	80-95
Leaves	80	0.10-0.30	3-10	90
Straw	70	0.35-0.45	10-50	95
Garden wastes	60-70	0.20-0.50	8-30	90
Grass	20-25	0.55	10	90
Grass silage	15-25	0.56	10	90
Fruit wastes	15-20	0.25-0.50	8-20	75
Food waste	10	0.50-0.60	10-20	80

Source: (Barry, 2009; Steffen, 1998a)

Production of briquettes

The preparation of biomass materials included steps such as sorting and cleaning the raw feedstock, drying, undergoing pyrolysis or carbonization, grinding, and screening. Carbonization is most efficient when carried out at temperatures ranging from 350°C to 450°C and usually requires 6 to 8 hours or 2 to 7 sun drying days (Biomass Briquetting Handbook, 2023). The produced biochar was then combined with a binder, according to a specified weight percentage (% wt) based on the material properties, to produce briquettes.

The total biochar production was calculated using **Eq. (10)**.

$$W_{BC} = T_{GW} * 60\% \quad (10)$$

Where:

T_{GW} is total waste generated in a week

W_{BC} is total biochar per week

The mix ratio considered for making the briquettes was 2:1:6 considering biochar, soil and water, respectively. The average weight of a single briquette was considered as 135grams (Bonsu et al.,2020).

The estimated number of briquettes was calculated using **Eq. (11).**

$$\frac{Mix\ total}{Unit\ weight} \tag{11}$$

The study assumed weight loss of 45% of the wet mixture after sun drying for 7 days. The yield in kg was therefore calculated using **Eq. (12).**

$$0.55\% * Mix\ total \tag{12}$$

The annual yield is calculated by multiplying the weekly yield through the weeks in a year.

$$Annual\ yield = Weekly\ yield * 52 \tag{13}$$

3.4.4 Economic Feasibility Analysis

The average Levelized Cost of Energy (LCOE) was calculated using the net present value method, which discounts the initial investment costs along with the cash flows from revenues and expenses throughout the plant's operational life to a common base date (Kost Christoph et al., 2013). The LCOE for biogas and briquette production was evaluated using **Eq. (14)**.

$$LCOE = \frac{I_O + \sum_{t=1}^{n} \frac{A_t}{(1+r)^t}}{\sum_{t=i}^{n} \frac{M_{t,el}}{(1+r)^t}} \tag{14}$$

Here, $L\ C\ O\ E$ denotes the Levelized Cost of Energy, expressed as UGX per cubic meter for biogas (UGX/m³) and UGX per kilogram for briquettes (UGX/kg). I_o refers to the initial investment costs (UGX), A_t represents the total annual costs incurred in year t (UGX), and M_{tel} is the amount of

energy produced in year t. Additionally, r stands for the discount rate (%), n is the plant's operational lifespan (in years), and t indicates the specific year of operation (1, 2, 3, …, n).

3.4.5 Cost-Benefit Analysis

Cost-benefit analysis (CBA) is a structured method used to assess the economic viability and overall value of an energy project. It systematically compared the projected costs and benefits over the project's lifespan, aiding in selecting the most advantageous energy option (Helm, 2021). In this context, CBA served as a valuable tool for evaluating the feasibility and benefits of producing biogas and briquettes from MUBS waste.

The operational lifetime of waste-to-energy technologies significantly influences their economic sustainability, particularly in institutional environments. Modern biogas systems, particularly those employing anaerobic digestion, generally operate for 15 to 25 years, depending on factors such as the quality of construction materials, regular maintenance practices, and operating conditions (MDPI, 2022). Conversely, briquette production systems have a typical lifespan of 8 to 12 years, with critical components like motors and presses needing periodic replacement or refurbishment (U.S. Forest Service, 2018).

In evaluating the economic viability of briquette-based cooking solutions in Uganda, the analysis took into account the following economic parameters:

Discounted Payback Period

The discounted payback period measured the time needed to recover the initial investment in briquette and biogas production, factoring in the savings from reduced fuel costs and other financial benefits (Boardman et al., 2018). In determining this period, both the upfront investment

costs and the projected fuel cost savings over the operational lifetime of the systems were taken into account.

$$PBP = \frac{Initial\ investment}{Annual\ net\ cash\ flow} \quad (15)$$

Net Present Value (NPV)

Net Present Value (NPV) is an important financial metric used to evaluate the profitability and economic feasibility of producing briquettes or biogas. It took into account the initial investment, operational and maintenance costs, and the discounted value of monetary savings achieved by shifting to alternative fuels. A positive NPV suggested that the project is economically worthwhile (Mishan & Quah, 2020). To compute the NPV, the cash flows generated from briquette and biogas production throughout the project's lifetime were estimated and discounted using an appropriate rate to determine their present value.

$$NPV = \sum \frac{B_t - C_t}{(1+r)^t} \quad (16)$$

Where:

B_t represents benefits realized in year t;

C_t denotes costs incurred in year t;

r is the discount rate (%);

t refers to the specific year or time period (in years).

The Benefit Cost Ratio (BCR)

The Benefit-Cost Ratio (BCR) is a key profitability measure used in cost-benefit analysis. It evaluated the financial viability of the cash flows generated by the project. The BCR was computed

by comparing the present value (PV) of benefits, which reflected the total worth of all benefits generated by the project, to the PV of costs, which reflected the total value of all costs associated with the project. A BCR greater than 1 suggests that the asset or project is expected to deliver a positive net value.

Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) is the discount rate at which the Net Present Value (NPV) of cash flows equals zero. It represents the rate of return that the asset or project generates. If the IRR exceeds the required rate of return, the project is deemed financially viable.

$$\sum \frac{B_t - C_t}{(1+IRR)^t} = 0 \quad (17)$$

A sensitivity analysis was conducted to assess how variations in key variables such as waste availability, energy prices, and the discount rate affect the economic feasibility of briquette and biogas production. This analysis helped to evaluate the investment risk and financial resilience of the project (Mishan & Quah, 2020).

3.5 Validity and Reliability

Ensuring the validity and reliability of research findings was critical for producing credible and actionable results. Validity refers to the extent to which the methods and instruments used in the study accurately capture the concept they are intended to measure, while reliability concerns the consistency of these measurements across time and repeated applications (Mohajan, 2020; Heale & Twycross, 2015).

In this study, several measures were employed to uphold both validity and reliability. For construct validity, waste sorting categories (organic, paper, plastics, and mixed) were clearly defined based

on established solid waste management guidelines by Tchobanoglous et al., (2014) to avoid misclassification. All experimental procedures such as moisture content analysis, volatile solids determination, and lower heating value measurements followed standardized methods (ASTM D3173, ASTM D3175, and ASTM D5865 protocols). Pilot tests were conducted prior to full-scale sampling to refine instruments and procedures.

To enhance internal validity, the study implemented systematic random sampling at each waste site, reducing the potential for selection bias. Consistent measurement protocols were applied across all sampling events, and calibration of weighing scales and laboratory equipment was performed regularly.

Reliability was addressed by training all research assistants uniformly in sample collection, sorting, and measurement techniques. Inter-rater reliability was checked by comparing the weights and categorizations made by different assistants across a set of test samples. Repeated measures sampling the same sites over multiple months ensured temporal reliability, capturing consistent patterns in waste generation and composition.

For analytical reliability, cross-validation techniques were employed in the statistical and economic modeling phases, including sensitivity analyses that test the stability of results under different assumptions and parameter changes. These rigorous practices collectively strengthened the dependability and credibility of the study findings.

3.6 Ethical Considerations

Ethical compliance was a fundamental pillar of this research. Before commencing field activities, the researcher sought and obtained ethical approval from Makerere University Business School's

Research Ethics Committee. Permission to access campus waste collection sites was formally requested from the university's Facilities and Estates Management Department.

Throughout the study, all data collection processes adhered to principles of respect, safety, and confidentiality. Although the primary subjects were waste streams rather than human participants, indirect ethical concerns related to health and dignity were carefully managed. Research assistants were equipped with appropriate Personal Protective Equipment (PPE) such as gloves, boots, and masks to minimize exposure to hazardous materials.

In addition, collaboration with private waste collection companies operating on campus was conducted transparently, with clear terms of engagement and acknowledgment of their contributions. No personal or identifiable information about workers, students, or staff members was collected or published. Any photographs or documentation of waste sites was anonymized to protect institutional privacy.

The research findings were reported honestly and objectively, with due acknowledgment of data sources, methods limitations, and any conflicts of interest, thereby upholding the highest ethical standards for academic inquiry.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

This chapter details the study's results, which align with its set objectives: the quantity and composition of waste generated in universities, the estimated energy potential of the waste in universities, and the economic viability of waste-to-energy conversion in universities.

4.1 Quantities, composition and energy potential of MUBS organic waste

4.1.1 Composition and quantities of waste

As per composition, the organic waste was mostly comprised of food waste and dry grass/leaves. Data was collected through observation and weighing for a period of 20 weeks during the 5 months of waste collection and the number of drums (sacks) collected per site were counted as shown in **Table 4**.

Table 4: Total number of sacks (drums) collected per site

Site	**Month**	**Number of sacks collected per week**				**Total number of drums**
	Week	**1**	**2**	**3**	**4**	
Small gate mast	**Nov**	45	0	55	50	675
	Feb	0	30	35	48	
	Mar	44	32	49	45	
	Apr	0	50	26	24	
	May	45	40	32	25	
ADB	**Nov**	9	0	40	38	348
	Feb	0	8	16	5	
	Mar	26	10	23	37	
	Apr	0	40	16	18	
	May	22	16	12	12	
Berlin hall	**Nov**	4	0	11	12	102
	Feb	0	2	2	5	
	Mar	4	4	6	8	

	Apr	0	9	7	8	
	May	7	4	4	5	
Guest house	**Nov**	8	0	25	10	339
	Feb	0	10	22	38	
	Mar	18	25	27	28	
	Apr	0	30	12	14	
	May	24	20	18	10	
Dining hall	**Nov**	3	0	10	17	150
	Feb	0	7	10	18	
	Mar	5	7	7	8	
	Apr	0	12	9	6	
	May	10	10	7	4	

From the study, small gate had the greatest number of drums collected, followed by ADB, Guest house, Dining hall and lastly Berlin Hall with total collections of 675, 348, 339, 150 and 102 respectively for the period of five months as shown in **Figure *2***. The large collection at the small gate mast can be attributed to the fact that it is the hub of all the canteens in the university and most students and staff eat from there. Since Berlin Hall only constitutes of staff offices, it generated the least number of drums.

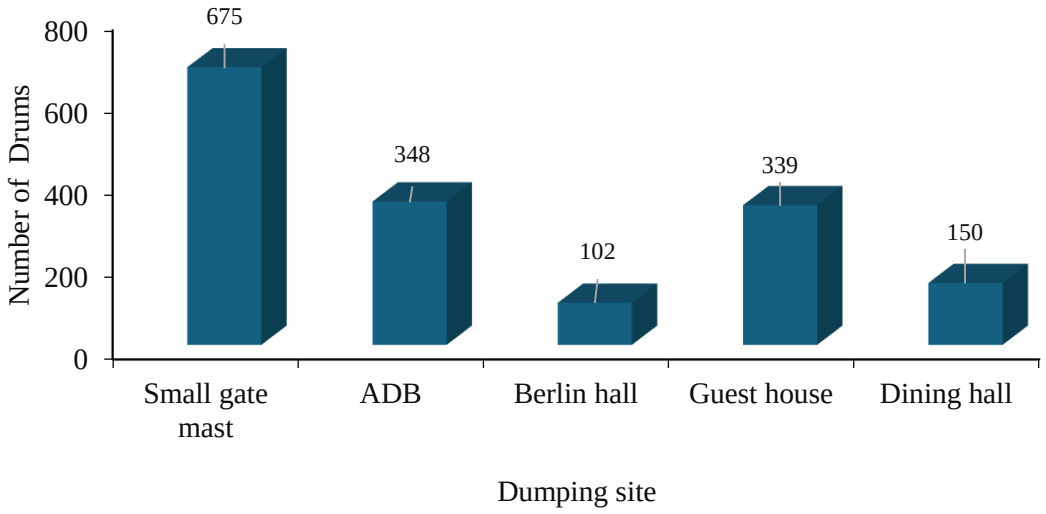

Figure 2: Number of drums collected per site for five months

During the data collection period, there were weeks where waste was not collected hence the zero drums recorded that week, but this was covered by the increased amount of waste collected in the following week. The composition of biowaste was analyzed through systematic visual examination of the collected samples. This method enabled a clearer assessment of the types and proportions of biowaste produced and provided important insights into waste handling practices across institutions.

To capture fluctuations in waste generation patterns, measurements were done weekly and a sample of four measurements were done per site, determining the average weight and standard deviation per site as shown in **Table 5**. The heaviest sacks were at the small gate mast with an average weight of 46.6 kg, followed by Dining hall at 46.54 kg, ADB at 32.5 kg, Guest house at 28.6kg and lastly Berlin Hall at 12.4 kg. This is greatly attributed to the fact that small gate mast and Dining hall are mainly comprised of food waste which is relatively heavier due to the high water content. ADB, Guest house and Berlin Hall are mainly comprised of grass waste that is majorly dry hence the differences in weight.

Table 5: Average weight of drums (sacks) per site

Site	**Total number of drums**	**Average weight (kg)**	**Total weight (kg)**
Small gate mast	675	46.6	31469.6
ADB	348	32.5	11296
Berlin hall	102	12.4	1261
Guest house	339	28.6	9705
Dining hall	150	46.54	6981

During the five-month period, the small gate mast dumping site collected the most amount of waste of 31,469.58 kg, followed by ADB, Guest House, Dining hall and Berlin Hall, generating 11,296 kg, 9,704.85 kg, 6,981.2 kg and 1,261.1 kg, respectively as shown in **Figure *3*.**

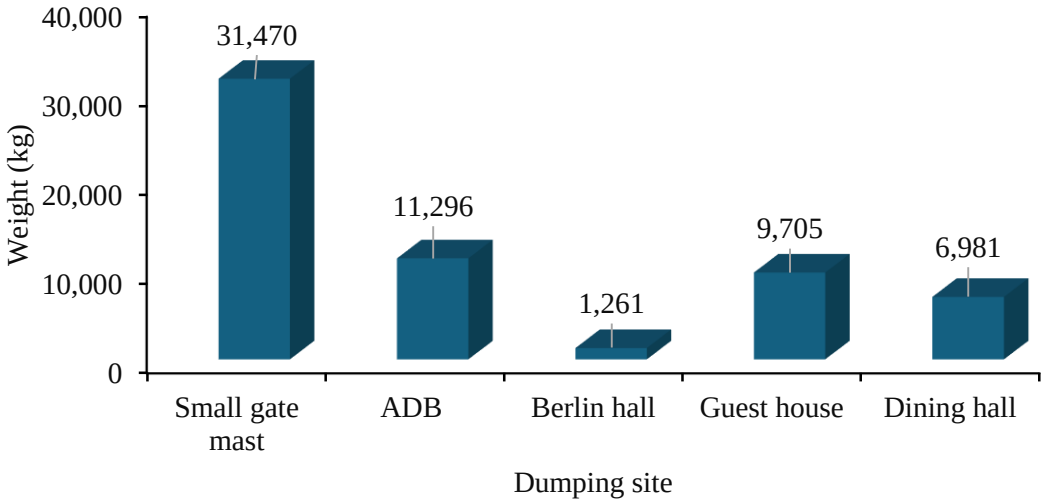

Figure 3: Waste collection weight per site for five months

As per **Eq. (2)** the total organic waste collected after calculation from the data collected is 60,712.73 kg giving us a total annual yield of 147,734.31 kg.

As per composition, the waste was separated into grass waste (dry grass and leaves), collected at three sites namely Guest house, ADB and Berlin Hall resulted into a total yield of 22,261.95 kg (37%) and 38,450.78kg (63%) of food waste collected at the small gate mast and dining hall for the five months as shown in **Figure 4.**

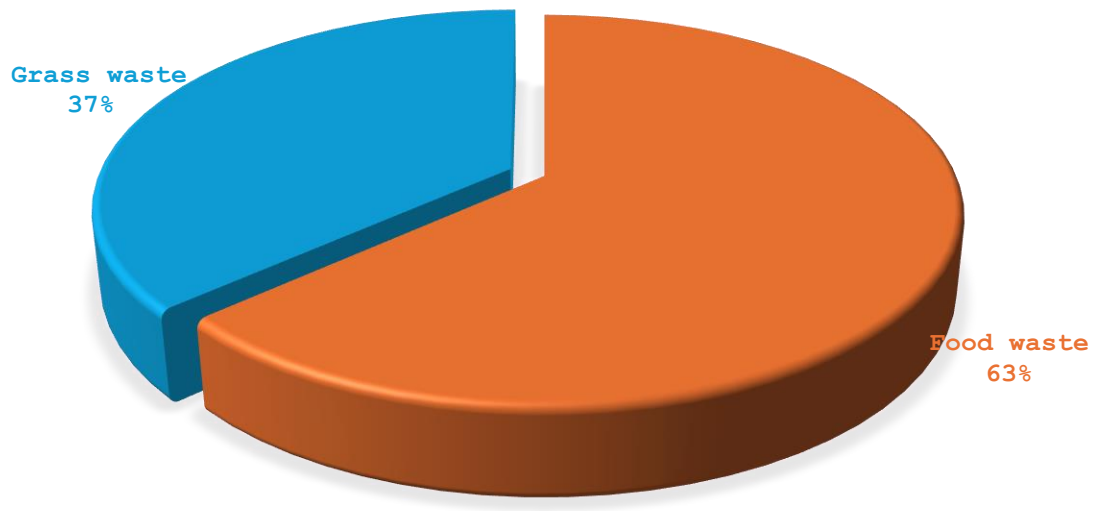

Figure 4: Percentage proportion of waste

Figure 5 illustrates the monthly variation in waste generation at MUBS between November and May. The results indicate considerable fluctuations, with peak values recorded in November (15,202.58 kg) and March (15,384.08 kg), while the lowest values were observed in February (9,697.15 kg) and April (10,035.33 kg).

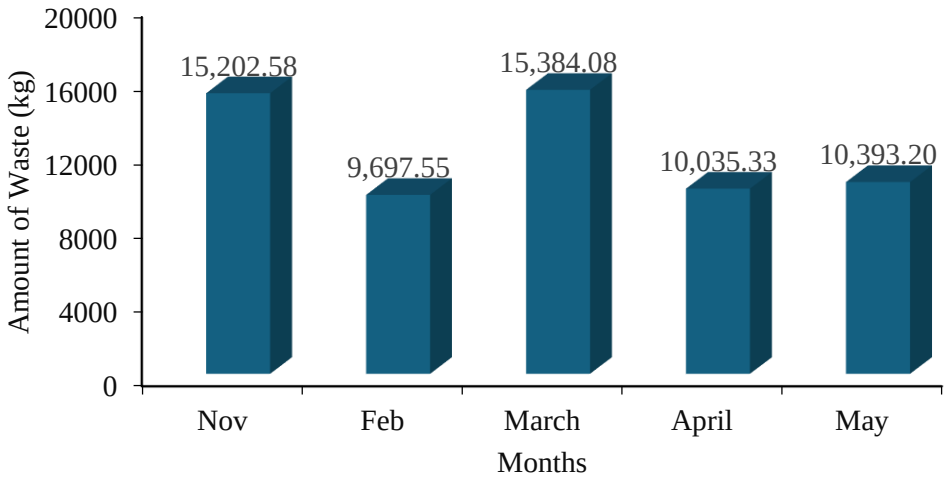

Figure 5: Waste generation per month

These variations can be explained by the cyclical nature of academic activities and seasonal dynamics. Higher waste volumes in November and March correspond to periods of increased student presence and heightened institutional activity, particularly at the start of semesters when enrollment is at its highest and food consumption rises in dining and canteen facilities.

Conversely, there were reduced waste quantities especially for food waste in February as it was just the beginning of the semester and April, when student numbers on campus declined especially during the exam period and food services operate at lower capacity. Seasonal influences also played a role, as the dry season typically produces less yard waste (e.g., dry grass and leaves) compared to wetter months.

Overall, the findings demonstrate that waste generation at MUBS is not constant but highly sensitive to institutional schedules and seasonal factors. This has important implications for waste-to-energy planning, as system design and feedstock availability must account for these variations to ensure reliability and sustainability.

4.1.2 Energy Potential of the waste

Using **Eq. (1),** we can estimate the total energy potential from the waste collected by MUBS to be 100,581.4MJ/year from food waste and 350,179.7MJ/year from grass waste as shown in **Table 6.**

Table 6: Calculation of energy potential

Parameter	**Food waste**	**Grass waste**
TW (kg/year)	93,564.1	54,169.65
E (%)	0.25	0.35
QOR (%)	1	1
LHV (MJ/kg)	4.30	18.47
MEP (MJ/year)	100,581.4	350,179.7

This is visibly shown in Error! Reference source not found. That the grass waste has a higher energy potential than food waste as it has a greater yield and higher LHV.

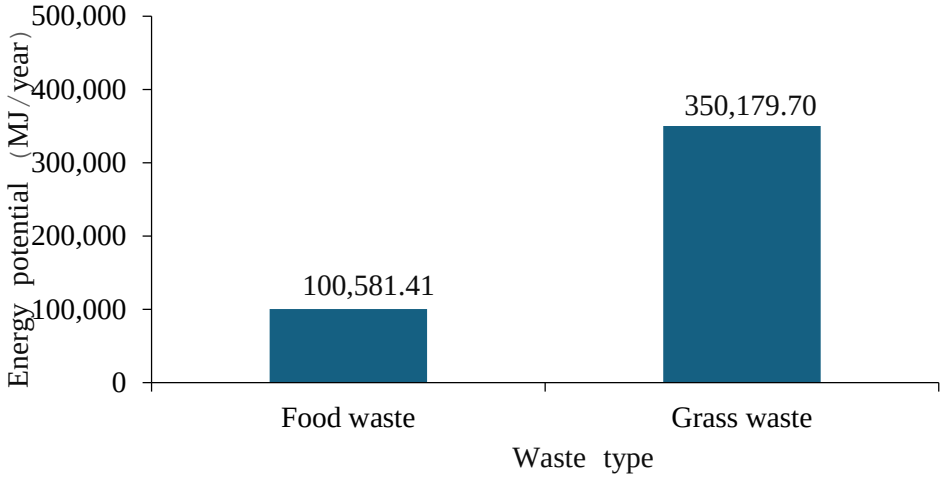

Figure 6: Energy potential by waste type

The generation of over 60.7 tons of waste in five months (**Figure 3**), which translates into an estimated annual energy potential of 450,761 MJ/year (**Table 6**), underscored the viability of adopting waste-to-energy systems such as biogas or briquette production in universities as this energy potential is enough to facilitate these activities. This finding aligns with the broader objective of estimating the energy potential of waste from universities. This can significantly improve university sanitation, reduce energy costs, and contribute to sustainable development by implementing integrated waste management strategies that recover energy and materials from their waste streams, as well as reduced air pollution since MUBS burns most of the grass waste to reduce the increased cost of waste collection after the Kitezi incident.

4.2 Biomass energy conversion models for estimating energy yields

Production of biogas from food waste

The study employed municipal solid wastes due to its suitability for high-rate anaerobic digestion, falling within the 1.6 to 4.8 kg per m 3. $V S \cdot d a y$ (Rittmann & McCarty, 2001). Using **Eq. (3) – (5)**, daily feedstock of 0.39m^3, slurry dilution water of 0.08m^3, and daily amount of solid influent 0.32m^3 were evaluated. The analysis results from the study considered hydraulic retention time of 14 days, the digester system of fermentation chamber volume of 5.52m^3 and the total solid content of 10%, for the food waste (Barry, 2009). Using **Eq. (6)**, the daily organic loading rate of $0.06 m^3 VS. m^{-3} VD. day^{-1}$ was evaluated for the feedstock. This mainly depends on the share of the volatile solids content.

With the use of **Eq. (4) and Eq. (5),** daily slurry dilution water (W_S) and daily solid influent (S_f) were calculated respectively, which indicated the amount of feedstock necessary to be incorporated into the biogas digester daily to achieve a particular biogas output, resulting to the ratio of daily slurry dilution water (W_S) to daily solid influent (S_f) of 1:4. Using **Eq. (7)** – **Eq. (9)** a methane yield per 14-day cycle of 23.36m^{3}CH$_4$ and a gas yield of 38.93m^3 generated an annual biogas yield of 1,014.9m$^{3.}$ A comprehensive assessment of these results is provided in **Table 7**.

Table 7: Production of biogas from food waste

Parameters	**Food waste**
Retention time (days) (HRT)	14.00
Digester Volume (m^3) (VD)	5.52
Daily feedstock (m^3/day) (Sd)	0.39
Total solids (TS) - (%).	10.00
Desired slurry concentration (SD) - (%)	8.00
slurry dilution water (Ws) - (m^3/day)	0.08
Daily amount of solid influent (Sf) - (m^3/day)	0.32

Ratio (W_s:S_f)	1:4
Volatile solid content (%) Vs	80.00
Organic loading rate (So)- ($m^3 VS.\ m^{-3} VD.\ day^{-1}$)	0.06
e	2.72
Kinetic parameter (K)	0.82
Ultimate CH4 yield (m^3 CH4/m^3 VS added) B_o	600.00
Temperature (Celicius)	25.00
µm (without heating)	0.20
Methane production rate (without heating) @ 25 degrees	1.67
Methane yield per cycle for 14-day cycle	23.36
Biogas yield per cycle for 14-day cycle (60% Methane)	38.93
Yield Per year	**1014.90**

Production of biogas from grass waste

Using **Eq. (3) – (5)**, daily feedstock of 0.74m^3, slurry dilution water of 0.50m^3, and daily amount of solid influent 0.24m^3 were evaluated. The analysis results from the study considered hydraulic retention time of 10 days, the digester system of fermentation chamber volume of 7.42m^3 and the total solid content of 25%, for the grass waste (Barry, 2009). Using **Eq. (6)**, the daily organic loading rate of $0.09 m^3 VS.\ m^{-3} VD.\ day^{-1}$ was evaluated for the feedstock. This mainly depends on the share of the volatile solids content.

With the use of **Eq. (4) and Eq. (5),** daily slurry dilution water (W_S) and daily solid influent (S_f) were calculated respectively, which indicated the amount of feedstock necessary to be incorporated into the biogas digester daily to achieve a particular biogas output, resulting to the ratio of daily slurry dilution water (W_S) to daily solid influent (S_f) of 1:4. Using **Eq. (7)** – **Eq. (9)** a methane yield per 10-day cycle of 37.46$m^3 CH_4$ and a gas yield of 62.43m^3 generated an annual biogas yield of 1,627.62m^3. A comprehensive assessment of these results is provided in

Table 8.

Table 8: Production of biogas from grass waste

Parameters	**Grass waste**
Retention time (days) (HRT)	10
Digester Volume (m^3) (VD)	7.42
Daily feedstock (m^3/day) (Sd)	0.74
Total solids (TS) - (%).	25
Desired slurry concentration (SD) - (%)	8
slurry dilution water (Ws) - (m^3/day)	0.50
Daily amount of solid influent (Sf) - (m3/day)	0.24
Ratio (W_s:S_f)	1:4
Volatile solid content (%) Vs	90
Organic loading rate (So)- ($m^3 VS.\ m^{-3} VD.\ day^{-1}$)	0.090
e	2.718
Kinetic parameter (K)	0.816
Ultimate CH4 yield (B_o) (m3 CH4/m3 VS added)	550
Temperature (Celicius)	25.00
µm (without heating)	0.196
Methane production rate (without heating) @ 25 degrees	2.676
Methane yield per cycle for 10-day cycle	37.46
Biogas yield per cycle for 10-day cycle (for 60% Methane)	62.43
Yield Per year	**1627.62**

Production of briquettes from grass waste

Using **Eq. (11)**, the weekly amount of biochar generated was 667.86 kg which generated a mix total of 3005.36 kg of biochar, binder and water in the estimated ratios of 2:1:6. On assumption that the weight of a briquette is 135grams (0.135 kg) and weight loss after sun drying for 7 days was 45% the weekly yield for briquettes using **Eq. (12)** and **Eq. (13)** was 1,625.95 kg, resulting into an annual yield of 85,953.39 kg after multiplying the weekly yield by the 52 weeks in a year, as seen in

***Table 9*.**

Table 9: Production of briquettes

Parameters	Value
Grass waste yield (kg)	22,261.95
Weekly yield (kg)	1,113.098
Mix ratio	2:1:6
Biochar yield	667.86
Binder (soil)	333.93
Water	2,003.58
Mix total (kg)	3,005.36
Weight of briquette (kg)	0.135
Dry mix total (kg)	1,652.95
No. of briquettes per week	12,244.07
Annual briquette yield (kg)	85,953.39

In conclusion, when converted into the same yield of kg/year, the study found out that of the total waste generated in MUBS, when converted to energy, more yields will be gained from production of biogas. The results indicated that biogas production provided greater overall energy yield compared to briquette production, highlighting its superior potential for energy recovery from MUBS waste. This suggests that universities should prioritize investment in biogas systems while supporting briquette production as a complementary strategy, thereby advancing sustainable waste management and energy self-sufficiency in higher education institutions.

4.3 Economic Feasibility Analysis

Levelized Cost of Energy for Biogas from food waste

From the study, the project required an initial investment of UGX. 24,460,040, with an annual operation and maintenance expenditure of UGX 30,884,249, a discount rate of 8%, and an annual gas yield of 1,014.9 m^3. Based on **Eq. (14),** the levelized cost of energy (LCOE) for biogas was calculated at UGX 32,521 per m^3 over a biodigester lifetime of 25 years. A detailed financial analysis is presented in Appendix 1.

In comparison, Nashua et al. (2025) evaluated the economic viability of biogas energy systems for households in Uganda and reported a value of UGX 14,565 per m^3, equivalent to approximately 98.557 m^3 of biogas, for a similar 25-year project lifetime. The disparity between the findings of this study and that of Nashua et al. (2025) can be attributed to differences in digester volume, type of feedstock, initial capital requirements, operational expenditures, and the annual cumulative biogas yield.

A sensitivity analysis was conducted by varying key parameters namely, initial capital cost, discount rate, annual waste collection cost, and annual biogas yield by ±50%. The results, illustrated in **Figure** *7*, demonstrate that each of these variables significantly influences the LCOE of biogas. Among them, the annual biogas yield emerged as the most critical factor: higher yields consistently led to lower LCOE values. This outcome is consistent with the observations of Al-Wahaibi et al. (2020), who emphasized that the economic viability of biogas production systems is strongly dependent on methane yield and its fluctuating economic value.

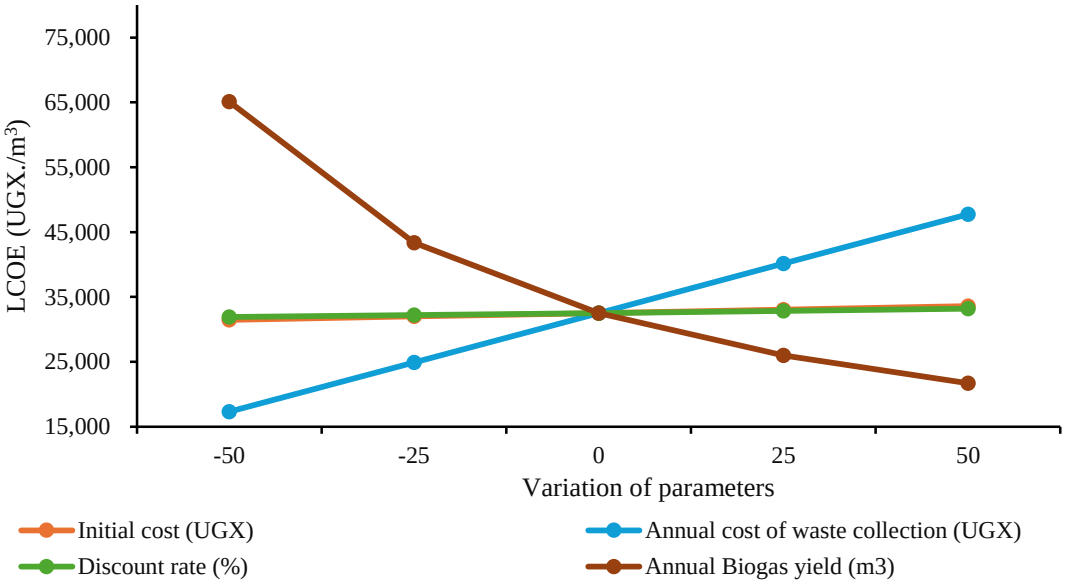

Figure 7: Variations in LCOE for biogas from food waste

Levelized Cost of Energy for Biogas from grass waste

From the study, the project required an initial investment of UGX. 24,460,040, with an annual operation and maintenance expenditure of UGX 30,884,249, a discount rate of 8%, and an annual gas yield of 1,627.62 m³. Based on **Eq. (14),** the levelized cost of energy (LCOE) for biogas was calculated at UGX 20,279 per m³ over a biodigester lifetime of 25 years.

In comparison, Nashua et al. (2025) evaluated the economic viability of biogas energy systems for households in Uganda and reported a value of UGX 14,565 per m³, equivalent to approximately 98.557 m³ of biogas, for a similar 25-year project lifetime. The disparity between the findings of this study and that of Nashua et al. (2025) can be attributed to differences in digester volume, type of feedstock, initial capital requirements, operational expenditures, and the annual cumulative biogas yield.

A sensitivity analysis was conducted by varying key parameters namely, initial capital cost, discount rate, annual waste collection cost, and annual biogas yield by ±50%. The results, illustrated in **Figure 78**, demonstrate that each of these variables significantly influences the LCOE of biogas. Among them, the annual biogas yield emerged as the most critical factor: higher yields consistently led to lower LCOE values. This outcome is consistent with the observations of Al-Wahaibi et al. (2020), who emphasized that the economic viability of biogas production systems is strongly dependent on methane yield and its fluctuating economic value.

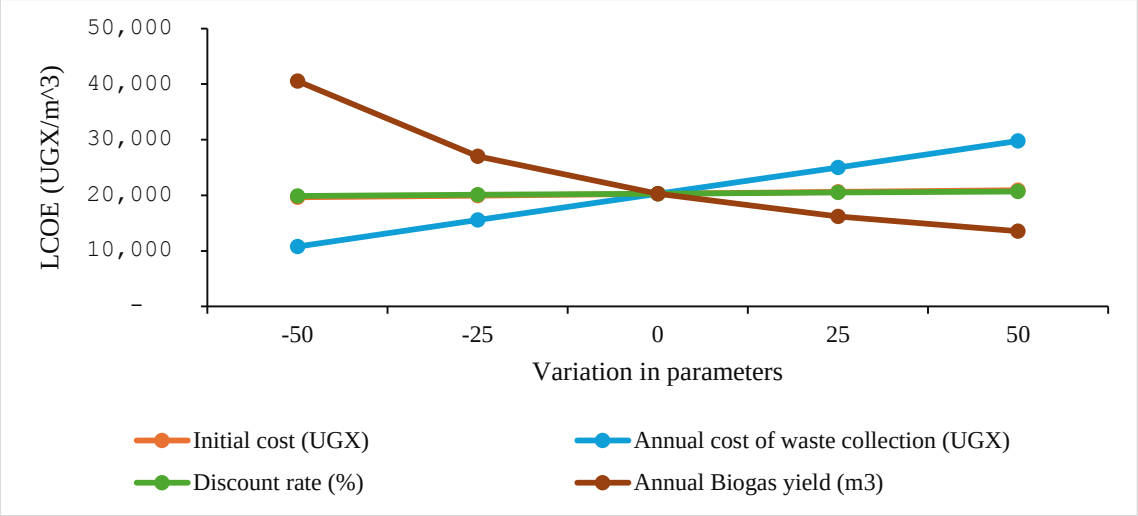

Figure 8: Variation in LCOE for biogas from grass waste

Levelized Cost of Energy for Briquettes

The study required an initial investment of UGX 50,700,000, with annual operation and maintenance (O&M) costs amounting to UGX 31,967,312, a discount rate of 8%, and an annual briquette output of 85,953.39 kg. Using **Eq. (14)**, the levelized cost of energy (LCOE) for briquette production was estimated at UGX 423 per kg over a system lifespan of 25 years.

To further evaluate economic viability, a sensitivity analysis was carried out by varying the initial capital cost, discount rate, annual waste collection cost, and annual briquette yield by ±50%. The outcomes, presented in **Figure 99**, confirm that each of these parameters exerts a notable influence on the LCOE of briquettes. Among these variables, however, the annual briquette yield proved to be the most decisive factor, as increased yields consistently resulted in lower LCOE values.

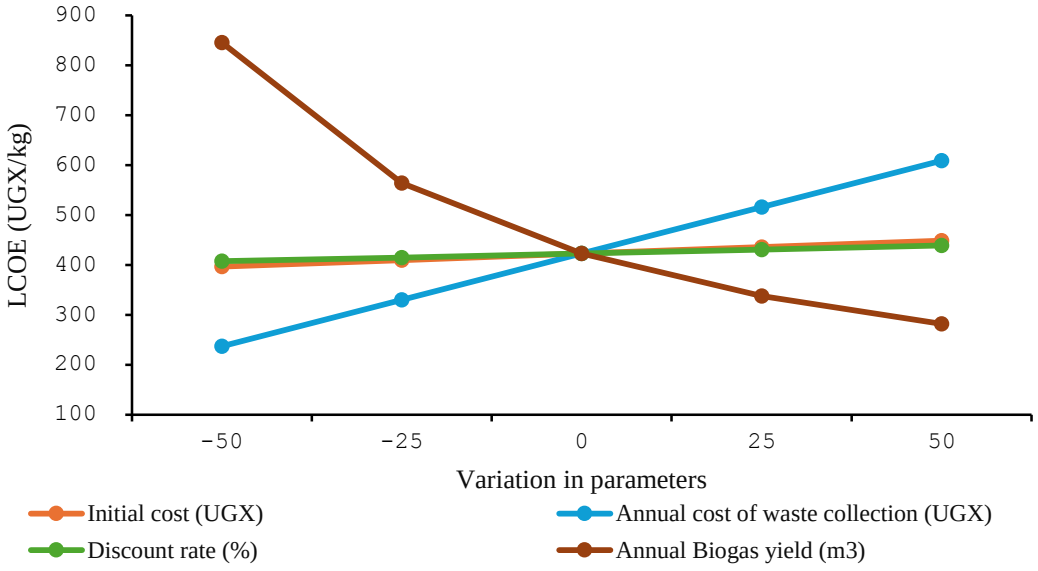

Figure 9 : Variations in LCOE for briquettes

Overall, the results suggest that while briquettes appear more cost-efficient per unit output, biogas remains an essential complementary pathway for waste-to-energy generation, particularly given its potential to provide clean and versatile energy for institutional use. It is therefore recommended that MUBS and similar universities prioritize briquette production for its cost efficiency, while simultaneously investing in biogas systems to ensure energy diversification, sustainability, and resilience.

Cost Benefit Analysis for Biogas from food waste

The economic viability of the proposed biogas system was also assessed through a cost–benefit analysis (CBA) using the project's initial investment cost of UGX 24,460,040, annual operation and maintenance (O&M) cost of UGX 30,884,249, and annual inflows of UGX 37,589,518, if we were to sell all output at 50,000 UGX/m^3 which is the current market price of biogas in Uganda. The analysis was carried out over a 25-year project lifetime at a discount rate of 8%.

The results indicate a net present value (NPV) of UGX 10,450,071.761, which is positive and therefore suggests that the project is economically feasible. The internal rate of return (IRR) was calculated at 27.35**%**, considerably higher than the applied discount rate of 8%. This implies that the project would remain viable even under less favorable financial conditions, highlighting its strong return potential.

The estimated payback period was 5 years and 4 months, which reflects a relatively short duration for the recovery of the initial capital investment. This enhances the attractiveness of the project to potential investors, as the financial risks are mitigated by the quick return on invested capital.

Finally, the benefit cost ratio (BCR) was computed as 1.1, exceeding the threshold value of 1.0. This result confirms that the expected benefits outweigh the associated costs, thereby reinforcing the economic viability of the system.

Cost Benefit Analysis for Biogas from grass waste

The economic viability of the proposed biogas system was also assessed through a cost–benefit analysis (CBA) using the project's initial investment cost of UGX 24,460,040, annual operation and maintenance (O&M) cost of UGX 30,884,249, and annual inflows of UGX 48,598,008, if we

were to sell all output at 50,000 UGX/m^3 which is the current market price of biogas in Uganda. The analysis was carried out over a 25-year project lifetime at a discount rate of 8%.

The results indicate a net present value (NPV) of UGX 67,734,344, which is positive and therefore suggests that the project is economically feasible. The internal rate of return (IRR) was calculated at 72.4**%**, considerably higher than the applied discount rate of 8%. This implies that the project would remain viable even under less favorable financial conditions, highlighting its strong return potential.

The estimated payback period was 1 year and 3 months, which reflects a relatively short duration for the recovery of the initial capital investment. This enhances the attractiveness of the project to potential investors, as the financial risks are mitigated by the quick return on invested capital.

Finally, the benefit cost ratio (BCR) was computed as 1.4, exceeding the threshold value of 1.0. This result confirms that the expected benefits outweigh the associated costs, thereby reinforcing the economic viability of the system.

Cost Benefit Analysis for Briquettes

For briquettes, the study entailed an initial investment cost of UGX 50,700,000, annual operation and maintenance (O&M) cost of UGX 31,967,312, and annual inflows of UGX 49,594,881 if we were to sell all the output produced at UGX 1000 per kg, which is the market price in Uganda. The analysis was carried out over a 25-year project lifetime at a discount rate of 8%.

The results indicate a net present value (NPV) of UGX 41,075,647.46, which is positive and therefore suggests that the project is economically feasible. The internal rate of return (IRR) was calculated at 34.75%, considerably higher than the applied discount rate of 8%. This implies that

the project would remain viable even under less favorable financial conditions, highlighting its strong return potential.

There was immediate recovery of the initial capital investment. This enhances the attractiveness of the project to potential investors, as the financial risks are mitigated by the quick return on invested capital.

Finally, the benefit cost ratio (BCR) was computed as 1.2, exceeding the threshold value of 1.0. This result confirms that the expected benefits outweigh the associated costs, thereby reinforcing the economic viability of the system.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study assessed the waste-to-energy potential of Makerere University Business School (MUBS). The conclusions are drawn according to the research objectives:

5.1.1 To quantify the amount and composition of waste generated at MUBS

The study established that MUBS generated 60,712.73 kg of waste within a five-month period, which, when annualized, amounts to approximately 145,710.54 kg per year. Analysis of the waste composition revealed that it was predominantly organic (approximately 100%), comprising mostly food residues, dry grass, and leaves. This dominance of organic matter not only underscores the high suitability of the waste stream for waste-to-energy technologies such as anaerobic digestion and briquetting but also points to a critical opportunity for the university to transition away from conventional waste disposal methods. The relatively negligible share of inorganic waste suggests that, with strengthened waste segregation practices, MUBS can maintain a clean and reliable feedstock supply for sustainable energy recovery. Moreover, these findings highlight the university's potential to serve as a model institution for other higher education facilities in Uganda, demonstrating how campus waste can be harnessed as a resource rather than a liability.

5.1.2 To determine the potential energy output from biogas and briquette production

From the quantified waste stream, the study estimated annual energy yields of 1,014.9 m^3 of biogas from food waste, 1,627.62 m^3 of biogas from grass waste and 85,953.39 kg of briquettes from grass waste. Both outputs represent substantial contributions to meeting campus energy demand and reducing dependence on traditional fuels such as charcoal and firewood. Biogas production emerged as particularly advantageous, given its ability to generate direct, clean, and versatile

energy suitable for cooking, heating, and electricity generation, thereby offering a sustainable substitute for fossil-based fuels in institutional settings. Briquettes, while less versatile, provide a stable and storable solid fuel that can effectively substitute for charcoal in households and campus kitchens, offering both economic and environmental benefits. When expressed in equivalent energy terms, the results highlight that biogas has a comparative advantage in energy conversion efficiency, while briquettes remain important in addressing energy accessibility and affordability. Collectively, these findings affirm that MUBS has the technical capacity to diversify its energy portfolio through multiple WtE technologies, contributing simultaneously to waste management, energy security, and environmental sustainability.

5.1.3 To evaluate the economic viability of waste to energy solutions

Economic analysis confirmed that both systems are financially feasible. Biogas from food waste recorded an LCOE of UGX 32,521 per m^3, with an NPV of UGX 10.45 million, an IRR of 27.3%, and a payback period of 5 years. Biogas from grass waste recorded an LCOE of UGX 20,279 per m^3, with an NPV of UGX 67.7 million, an IRR of 72.4%, and a payback period of 1 year. Briquettes achieved a lower LCOE of UGX 423 per kg and significantly stronger financial metrics (NPV of UGX 41 million, IRR of 34.75%).

5.2 Recommendations

5.2.1 Policy Recommendations

Firstly, financial support mechanisms should be set up. Currently, there is no dedicated financing to fund waste to energy conversion. Most of the interventions have been limited to pre-feasibility and feasibilities studies of the waste potential with no project implementation. Government and

development partners should provide subsidies, concessional loans, and tax incentives to reduce the high initial investment required for waste to energy conversion plants.

Secondly, there should be more promotion of the production and utilization of briquette. The Energy Policy 2023 does not set out the government's position on the production of briquettes. Policymakers should support briquette producers through the creation of structured markets, price incentives, and awareness campaigns highlighting briquettes as a sustainable alternative to charcoal.

Lastly, the government should fast track the development of waste management regulatory frameworks as highlighted in the Energy Policy 2023 (MEMD, 2023). Waste-to-energy (WtE) should be explicitly included in Uganda's renewable energy and circular economy frameworks to encourage adoption in universities and other large institutions. Stronger policies on waste segregation at source should be enforced in institutions to ensure consistent and clean feedstock for energy recovery.

5.2.2 Practical Recommendations

Adoption of waste to energy conversion plant at MUBS and other universities. Universities should prioritize installing a medium-scale biogas digester and briquette systems to utilize their predominantly organic waste stream, providing clean cooking and heating energy while lowering waste disposal costs.

Improved waste segregation practices. Universities should provide separate bins for organics, plastics, and recyclables, while training staff and students in proper segregation to maximize feedstock quality.

Capacity building. Technical training programs should be developed for staff and students on digester operation, briquette production, and system maintenance to ensure long-term sustainability. MUBS should serve as a pilot case, setting up small scale experimental plants to study the energy yield from waste and their economic viability. This will facilitate the sharing of lessons learned with other Ugandan and regional universities to encourage replication of WtE systems.

5.3 Limitations of the Study

Firstly, the timeframe of data collection was not broad enough. Waste generation data were collected over a five-month period, which may not fully capture seasonal variations in campus waste production.

Secondly, the study used some assumptions in technical parameters. Some values used in the calculations (e.g., methane content, calorific values, weight loss in briquettes) were based on literature rather than direct laboratory testing, which may introduce estimation errors. Furthermore, the financial evaluation assumed constant market prices for briquettes and biogas, yet in practice, price fluctuations could significantly affect profitability.

Thirdly, there was exclusion of environmental externalities. While energy potential and financial viability were analyzed, environmental impacts such as greenhouse gas reductions or air pollution displacement were not quantified.

Lastly, the study focused on MUBS, which may limit the direct applicability of findings to other universities with different waste streams, infrastructure, or resource conditions.

5.3 Further Areas of Research

Life-cycle environmental impacts

Future research should conduct detailed life-cycle assessments comparing the greenhouse gas reduction potential of biogas versus briquettes.

Integration with renewable energy systems

Studies could explore hybrid systems (e.g., solar-assisted anaerobic digestion or briquettes combined with improved cookstoves) to maximize efficiency and reliability.

Policy and market analysis

There is a need for research on the policy, financing, and market barriers that constrain briquette competitiveness and biogas adoption in institutional contexts.

Scaling models for universities

Comparative studies across multiple universities would help develop scalable frameworks for WtE adoption in higher education institutions in Uganda and beyond.

Technological innovations

Further research should test innovations in feedstock pre-treatment, digester design, and binder alternatives for briquettes to improve yields and reduce costs.

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APPENDIX 1



***Figure 10**: Waste collection at the Dining hall*



***Figure 11**: Waste collection at small gate mast*



Figure 12: Waste collection at ADB











Figure 13: Rubbish burning at the Dining hall

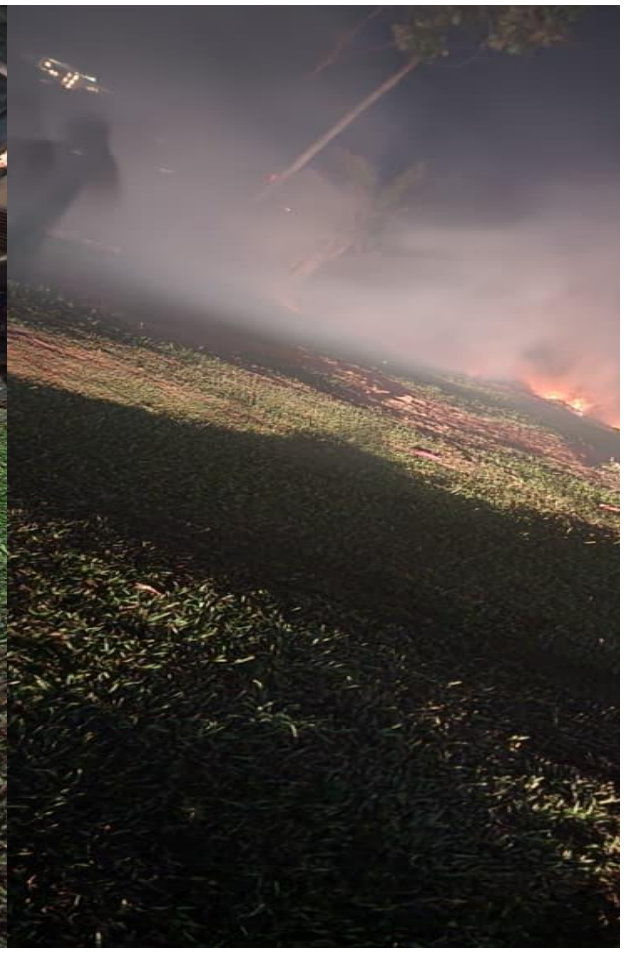

Figure 14: Rubbish burning at the pitch causing air pollution and wastage of waste