


# [ ASSESSING WASTE TO ENERGY OPTIONS, IN THE CASE OF MALAWI UNIVERSITY OF SCIENCE AND TECHNOLOGY]

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## DECLARATION

I *Esther Mulipa* declare that this research project represents my own work and that it has never been submitted to this institution or any other institution for any academic purpose. All sources of information have been appropriately acknowledged.

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Date ___19,July 2021_____

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## ABSTRACT

The Malawi University of Science and Technology, just like many other public institutions in Malawi, is faced with energy deficit as well as waste management challenges. The institution's electricity bills are so huge and unsustainable, in addition to challenges related to unreliable utility power supplies. The university is also faced with waste management problems which are becoming severe as the population keeps on rising. Unsafe waste handling, such as open burning, presents health as well as environmental risks. Therefore, this study focused on determining the potential for converting waste to energy at the university campus. The study objectives were: to assess the energy needs of MUST; to quantify waste generated at MUST; to characterize waste generated at MUST; and to analyze waste-to-energy technology options for MUST by using the Multi-Criteria Decision Analysis (MCDA) Approach. In order to meet study objectives, the energy needs of MUST were assessed using existing energy audit data. Furthermore, waste composition and quantification were undertaken and different waste-to-energy technologies were assessed using the MCDA. The study results show that MUST solid waste generation and composition by weight in terms of organic waste, recyclables, and others accounts for 77%, 23%, and 0% respectively. The study also found that about 685.5 Kgs of fecal matter flows into the wastewater (sewage system) every day. Anaerobic digestion emerged as the most suitable waste-to-energy technology for MUST, while briquetting was the second most suitable option. Gasification & Pyrolysis, Incineration with Energy Recovery, and Landfill with Gas Extraction technologies rank low, mainly due to their associated capital costs, operation and maintenance costs, and lack of expertise.

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## LIST OF ABBREVIATION

| | |
|---|---|
| WTE | wastes to energy |
| GHG | house gases |
| MUST | Malawi university of Science and Technology |
| MCDA | Multi criteria Dimension Analysis |
| ESCOM | Electricity Supply Corporation of Malawi |
| MGDS | The Malawi Growth and Development Strategy |

# 1.0 INTRODUCTION

Malawi, just like many other developing countries, has a huge energy access deficit, a situation that affects the socio-economic development of the country (Taulo, Gondwe, & Sebitosi, 2015); (Borgenstein, Li, Santana, Wade & Wanless, 2019). The Malawi Growth and Development Strategy III (MGDS III) identifies energy as one of the key priority areas that can spur development. As such, it needs adequate investment (GoM, 2019a); (Deloitte, 2017). The Malawi 2063 also recognizes that industrialization has stagnated in the country due to a lack of energy.

Currently, only 11% of the population has access to electricity in the country and only 4% of the rural population is connected to the grid (World Bank, 2019) (Borgenstein, Li, Santana, Wade & Wanless, 2019). It is estimated that 99% of the 361 MW of electricity generated in the country is hydro and mainly from the shire river (GoM, 2019a); (Girdis & Hoskote, 2005). Hydropower generation is further threatened by hydrological variability as the country continues to experience the effects of climate change (World Bank, 2019). In addition, the country is a net oil importer (Girdis & Hoskote, 2005); (Deloitte, 2017). As such, more foreign currency is spent on fuel imports.

With no alternative sources of energy, the country continues to rely on biomass (Halle & Burgess, 2006) that accounts for 89% of the energy needs (GoM, 2019a). This contributes to the high rates of deforestation experienced in many parts of the country (Borgenstein, Li, Santana, Wade & Wanless, 2019). Moreover, the biomass industry is associated with unsustainable and inefficient production and utilization (GoM, 2019a). It is estimated that about 7.5 million tonnes of wood are harvested annually, yet the forests can sustainably supply only 3.7 million tonnes (Deloitte, 2017). Widespread deforestation leads to a scarcity of fuelwood (Harcourt, Akande, & Olorunnisola, 2018). Therefore, there is a need to use forests sustainably.

Malawi is working to increase the capacity of higher learning education where enrollment stands at about 36,000 (GoM, 2019b). MUST was established in order to increase the capacity of higher learning education. However, challenges still remain due to inadequate resources, a situation which limits the university's ability to expand. Currently, it is estimated that less than 30% of the students who qualify for higher education enroll in public universities (GoM, 2019b). Energy access enables the use of modern information and communication technologies (ICT) (Welland, 2017); (UNDESA, 2014) in universities and may help power Open Distance Learning for increased access to higher learning education (GoM, 2019b).

Education institutions, including MUST, have not been spared by the challenge of accessing reliable, sustainable, and affordable energy. The budget of the university is dominated by utility bills, especially electricity and water. Therefore, exploring waste-to-energy options in educational institutions is very crucial at a time when waste management challenges are also emerging. Currently, waste accounts for only 5% of the biomass used as energy in Malawi (Deloitte, 2017). However, with more research and investment, this waste can be exploited and help meet the energy needs of educational institutions. Therefore, this study focused on determining waste generation potential and waste-to-energy options at Malawi University of Science and Technology in Malawi.

## 1.1. Research Background

The Malawi University of Science and Technology was established by an Act of Parliament Number 31 of 2012 with the goal of promoting the development, adaptation, transfer, and application of science, technology, and innovation for Malawi's macro and microeconomic development. MUST is a public university located in the Thyolo district, in the southern part of Malawi. It was established on 17 December 2012 and it opened its doors in March 2014. Though still young, the university is faced with many challenges, including inadequate funding, huge energy and water bills.

Energy is directly linked to education as it supports many essential activities in educational institutions (UNDESA, 2014). Therefore, having reliable, sustainable and affordable energy

supplies is so crucial for educational institutions. Currently, on average, the university spends MK107, 445,134. 15 (i.e., 131, 000 USD) per year, which is diverted from vital activities such as equipping science laboratories. As the university expands to meet the growing national demand (GoM, 2019b), the problem of waste management is also growing, thereby requiring urgent action by investing in sustainable solutions.

The global generation of solid waste is growing (WasteAid and ICCM, 2020) and this is not an exception for Malawi as well as MUST as the population size expands. Huge quantities of waste generated are usually difficult and more expensive to handle, especially in urban areas where space is scarce (Barré, 2014). The accumulated waste presents socio-economic and environmental challenges to communities, including heightened flood and health risks (WasteAid and ICCM, 2020). Waste collection in most parts of urban Malawi is almost nonexistent (Barré, 2014) and MUST is not spared from this problem as it relies on self-collection and disposal of solid waste. Currently, waste is considered as a valuable resource, yet it presents many entrepreneurial opportunities (Barré, 2014).



Figure 1: Improper solid waste disposal that presents environmental and health risks; Source: (WasteAid and ICCM, 2020)

Waste to Energy (WtE) is a very broad term that is used to describe processes that convert waste into energy, or an energy-carrying product (WSP, 2013). Waste-to-Energy consists of any waste treatment technique that creates energy in the form of electricity, heat or transport fuels (e.g., diesel) from a waste source (WEC, 2013). Waste-based biomass is already being used as an alternative source of energy for cooking and heating by low-income households in Malawi (Deloitte, 2017), but it is mostly consumed unprocessed. The most advanced WtE techniques, among others, include anaerobic digestion, gasification, pyrolysis, and landfill with energy recovery (WSP, 2013) (Harcourt et al., 2018). However, less advanced WtE technologies such as briquetting and pelleting are also widely used in developing countries, including Malawi. Waste-to-Energy technologies can help meet the ever-growing demand for energy (Nosherwani, 2020), especially at MUST where the population is expected to keep on rising.

Table 1 Waste-to-Energy Technologies.

| NO | Waste-to-Energy (treatment) Technologies | Description |
|---|---|---|
| 1. | Anaerobic digestion | Anaerobic digestion is a biochemical process in which microorganisms consume organic waste materials in the absence of oxygen (Deshan Botheju & Rune Bakke).<br>The process results in three primary end products: methane, carbon dioxide and digestate, which is a solid residue similar in form to soil (Clare Lukehurst et al). Composition of biogas 50– 75%, CH4, 25–50% CO2 and 1–15% of other gases (Nosherwani, 2020). |

| | | |
|---|---|---|
| 2. | Gasification | Gasification takes place in a restricted oxygen atmosphere, where waste is converted to a synthesis gas (syngas) that can be combusted or used in a gas engine or turbine (WSP, 2013). Gasification of waste fractions is not yet sufficiently developed in comparison to combustion |
| | | (WEC, 2013). Gasification is widely used in developing countries (Onchieku et al. 2011; TERI, 2010). |
| 3 | Incineration (with energy recovery) | Initially, the objective of waste incineration was to reduce waste before final disposal as it is capable of effectively reducing waste volume up to 90%. However, waste combustion enables the production of hot flue gas having a temperature range of 800-1000 °C that can be used to produce electricity (Nosherwani, 2020). |
| 4. | Pyrolysis | Pyrolysis is a thermal conversion process where waste is heated in the absence of oxygen which leads to the production of solid char, pyrolysis oil and pyrolysis gas (WSP, 2013). |
| 5. | Landfill with energy recovery | Unsanitary landfills are characterized by uncontrolled combustion and greenhouse gas emissions due to the production of methane. However, through sanitary landfills, Land Fill Gas (LFG) generated can be extracted and utilized for generating power and biofuel for vehicles, among others (Nosherwani, 2020). |
| | Briquetting | This can be described as the process of converting biomass into high density (Harcourt et al., 2018) that helps make waste usable friendly. |

Proper waste management demands a better understanding of the composition and characteristics of waste flowing into the waste streams (Akande and Olorunnisola, 2018). Waste composition and characteristics are different geographically (Ozcan, Guvenc, Guvenc, & Demir, 2016) and change due to changes in consumer behavior and technological advancements (Ozcan et al., 2016). Therefore, waste composition and characterization studies need to be undertaken in a specified area and periodically in order to understand the

generated. Understanding waste composition and characteristics also enables planners to determine suitable techniques for treating waste.

Universities play a crucial role in teaching and learning and are burdened with the social responsibility of educating the nation about sustainable solid waste management (Owojori, Edokpayi, Mulaudzi, & Odiyo, 2020). However, one of the thoughtful issues in solid waste management is determining the amount and composition of waste generated in academic institutions (Owojori et al., 2020), partly due to a lack of awareness by the top management team. This study was aimed at analyzing the waste generated at MUST and at determining the most suitable waste-to-energy options at MUST while considering the local situation.

## 1.2. Problem Statement

Malawi University of Science and Technology, have no access to waste collection services provided by the city council. As such, the institution relies on self-waste collection, treatment (burning) and disposal. However, as the population increases, it is anticipated that waste management will be a major challenge for the university. As such, there is a need to put plans in place for sustainable waste management. However, proper waste management plans demand a better understanding of waste in terms of its characteristics and quantities, which is still lacking. Currently, burning the of waste is the technique that MUST employs to reduce the volumes of waste generated. However, this kind of waste treatment is not environmentally friendly as it is blamed for GHG emissions. Therefore, exploring waste-to energy techniques for waste management needs to be done. However, this also creates the need for the university to be equipped with information regarding energy needs, waste compositions and volumes in order to identify the right waste-to-energy techniques.

## 1.3. Main Objective

The main objective of this study was to determine the best waste to energy technology depending on the energy needs, waste characteristics and quantities generated at MUST.

## 1.4. Specific Objectives

- To assess the energy needs of MUST
- To quantify waste generated at MUST
- To characterize waste generated at MUST
- To analyze waste-to-energy technology options for MUST by using the Multi-Criteria Decision Analysis (MCDA) Approach.

## 1.5. Research Questions

- What are the energy needs at the MUST?
- What are the quantities of liquid and solid waste generated at MUST?
- What are the characteristics of solid waste generated at MUST?
- What are suitable waste to energy technologies for MUST?

## 1.6. Significance of Study

The significance of this study is that MUST, as an institution, needs to operate sustainably as its population keeps on growing. Waste generation is highly linked to the size of the population. Therefore, a rise in waste generation will keep on rising, thereby demanding sustainable solutions for waste management at the campus. In addition, energy demand will

upsurge, thereby requiring MUST to identify alternative sources of energy for different uses. Therefore, this study helps to explore the potential of waste-to-energy at MUST through an understanding of energy needs, waste characteristics and quantities.

## 1.7. Location of Study

The study was conducted over a period of 2 weeks, from 16 April to 29 April 2021, across the campus of Malawi University of Science and Technology, which includes the administration block, library block, classrooms, hostels, and cafeteria. The samples were taken from various sampling zones on campus.

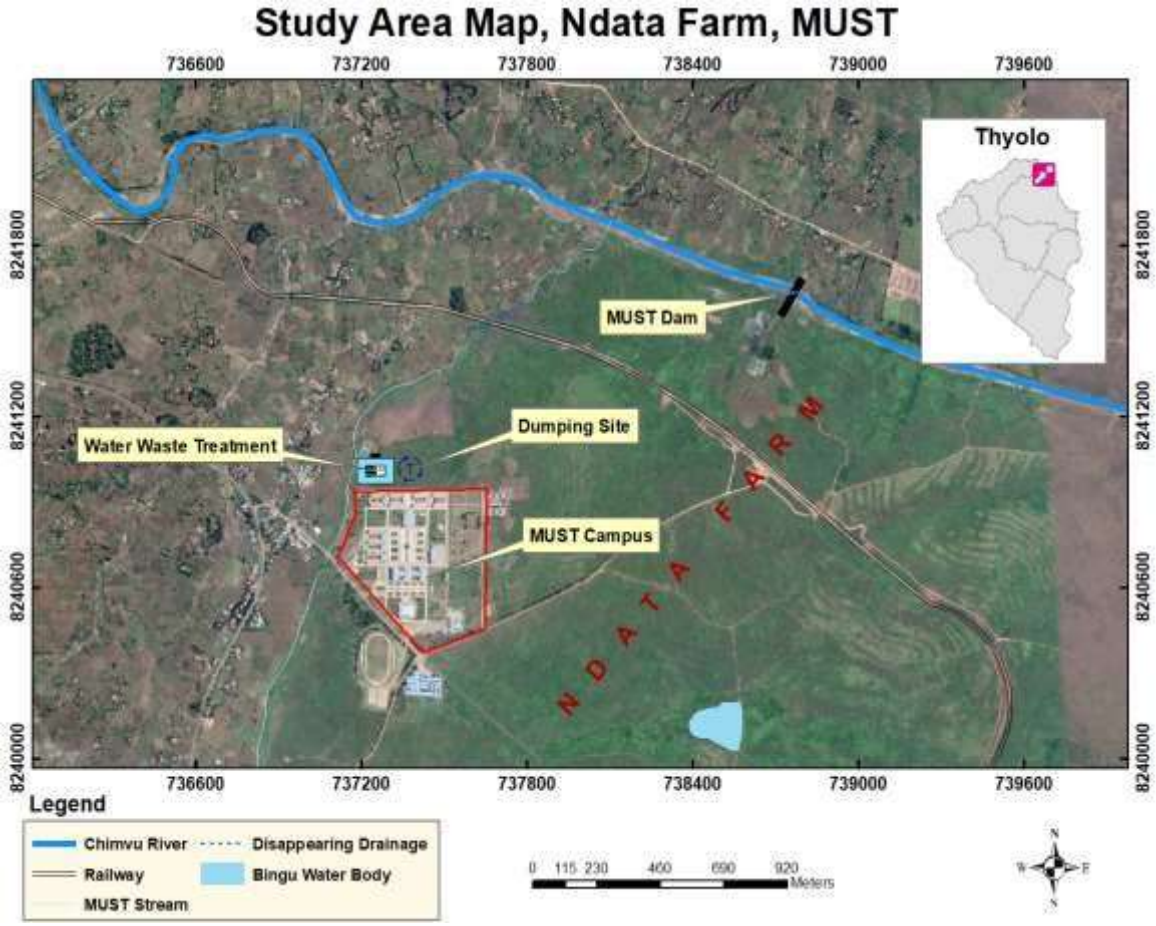



Figure 2: Study Location- Malawi University of Science and Technology

CHAPTER 2

# 2.0 LITERATURE REVIEW

## 2.1. Current Energy Status in Malawi

The Electricity Supply Corporation of Malawi (ESCOM) Limited is the only electrical power supplier in the country. it is a publicly owned company which was established by an Act of Parliament in 1957, which was revised in 1963 and then in 1998.

In Malawi, only 11% of the population has access to electricity, where urban and rural populations have 46% and 4% electricity access rates respectively. (World Bank, 2019). Low water levels in the Shire River due to drought are affecting electric power generation. As a result, the country experiences frequent blackouts, especially during the dry seasons. (Ministry of Water Development and Irrigation, 2013). So far, electricity generation company ENGENCO has been extending distribution lines and encouraging the use of solar power to minimize the energy crisis, but still, we need sustainable energy systems to reduce the problem of energy insecurity) MW (William Liabunya, chief executive officer of ENGENCO). The national energy mix shows that biomass is the main source of energy in Malawi, accounting for about 88.5% of the national energy demand. (UNEP, 2013). Overdependence on biomass contributes to high rates of deforestation, which is estimated to be at 2.8% per annum in the country. (UNEP, 2013; GoM, 2017). One of the challenges the country faces is being able to meet the energy needs of the various sectors in the country. Energy supply deficiencies are common, which result in interruptions to processes that require energy as an input. Just like any other industry, high energy costs affect the operations of the Malawi Tourism Industry. There is a need to provide alternative sources of energy, such as biogas. However, adoption of biogas technology is very low in Malawi.

## 2.2. Current Energy status

Malawi University of Science and Technology relies on the electricity supply from ESCOM, since the electricity supply from ESCOM is from hydropower sources, which are not reliable because the demand is high and it is intermittent. The institution is experiencing different issues with electrical supply, including blackouts, and during blackouts, the institution uses a diesel generator, which is not environmentally sustainable. Diesel generators emit carbon dioxide, nitrogen oxide, particulate matter, and other hazardous exhaust into the atmosphere. Those concerned about environmental sustainability might find that a natural gas generator is a better option since it is a cleaner-burning fuel. Because the overall need for the energy given to MUST is less than the energy consumed, supplemental energy must be introduced to match the need. This is significant because, as the population of MUST institutions grows, so will the energy problem.

## 2.3. Waste generation

According to the U.S. Energy Information Administration (EIA), the world's energy demand will increase by 30% by the year 2025. Currently, the leading source of energy in the world is fossil fuel, which is a non-renewable and limited natural resource. Many developing countries, like Malawi, face significant challenges in dealing with rising levels of waste. Malawi is at increasing risk from the dangers of accumulated waste. For example, in 2019, the capital city, Lilongwe, was producing approximately 250 metric tonnes of waste per day (Kamakanda, 2019).

In Malawi, waste management is also a big problem and the cost of waste management is very high. Alarmingly, current waste collection services can handle only a small percentage of waste (around 30%), so the city, like many other areas in Malawi, faces a growing problem of accumulated waste (Barre, 2014). It is estimated that the cost of waste management will increase from $205.4 billion to about $375.5 billion in 2025 per year. In low-income countries, waste collection services constitute the bulk of a municipality's

budget for managing solid waste, which is between 80% and 90%. (The World Bank, 2012). Therefore, there is a need for sustainable solutions to waste management. In Malawi, universities and public places generate huge quantities of organic waste.

## 2.4. Sustainable Waste Management

Solid Waste Management is defined as the control, generation, storage, collection, transfer, transport, processing and disposal of solid waste consistent with the best practices of public health, economics, financial, engineering, administrative, legal and environmental considerations (Jamal, 2002). Waste management involves the use of a number of concepts which, among others, include waste management hierarchy (WMH) (UNEP, 2013). This WMH concept is normally presented diagrammatically and it indicates an order of preference for action in managing waste. (UNEP, 2015). The concept's concern with waste management is the need to divert waste from landfill to other uses as much as possible through different interventions, which include waste generation prevention, reducing waste generation, reusing waste, recycling waste, energy recovery from waste, and finally disposing of waste.

The goal of sustainable waste management is to reduce the number of natural resources consumed, confirm that any materials that are taken from nature are reused as many times as possible, and that waste created is kept to a minimum. The Drivers of waste management around the world are: the market for recyclable and reusable waste is growing; public health as waste is a breeding ground for rodents and disease-causing micro-organisms; and environmental protection as greenhouse gases such as methane and carbon dioxide emitted from waste contribute to global warming. (UNEP, 2015). Nevertheless, the improper handling and disposal of solid waste constitutes a serious problem; it contributes to the high morbidity and mortality rate in many developing countries (Martin, 2004). Poor solid waste management is common in Malawi (indeed in most developing countries), and is partly a result of inadequate financing, institutional will and capacity (Maganga 2013; Barre 2014). Poor waste management reduces the quality of life by

providing food and breeding conditions for vermin and disease vectors, producing odor, diminishing aesthetics and contaminating surface and ground water (Hoornweg and Bhada-Tata 2012). A basic requirement for the successful implementation of waste-to-energy technology is the existence of an advanced waste management system that helps to improve the separate collection and treatment of different separated waste streams (RPG Group Project Proposal: Waste-to-Energy Technology, Policy and Investment Perspective. Raymond Tech Australia, 5 July 2020).

## 2.5. Waste Characterization

Many higher education institutions use waste management activities as a starting point for their sustainability initiatives. Characteristics and understanding the composition of a campus's generated waste is the first step toward developing successful and effective waste management strategies across university campuses.

Waste characterization is a scientific approach that helps to collect precise data about waste characteristics. The-Ecological Solid-Waste-Management-Act, Section 17, defines waste characterization as "the identification of constituent materials which comprise solid waste generated and disposed of within an area. Basically, wastes are grouped into two groups, which are biodegradable wastes and non-biodegradable wastes. (Boma Qcubec, n.d). The Waste characterization helps to determine the components of waste generated. Waste generated can be biodegradable or non-biodegradable. Biodegradable waste means any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, and paper and paperboard (cf. Landfill directive)" (EEA, 2009).

Biodegradable municipal solid waste is the fraction of Municipal Solid Waste (MSW) that can undergo biological decomposition. Examples of biodegradable waste are food waste, wood, paper, cardboard and textiles. Non-biodegradable wastes are those that cannot be decomposed or dissolved by natural agents and they remain on the earth for thousands of years without any degradation, for example, plastics and glasses. Waste characterization

data is needed for planning purposes, as planners need to have knowledge of the contents of waste flowing into waste streams.

### 2.6. Source Separation of university Solid Waste

Source separation of waste at an institution is the simplest method for characterizing waste. Therefore, the institution needs to collect plastics, bottles, cans and food waste separately as part of an integrated waste management plan. (DoEA, 2018). Source separation of waste is done by having a number of bins, each bin for a specific type of waste. For instance, two bins can be used, where one bin is for organic waste and the other for inorganic waste. (Graunke & Wilkie, 2008).

### 2.7. Solid Waste Quantification

Having knowledge about the quantity of waste generated before implementing a biogas project is necessary. Usually, volume and mass are the units used for measuring the amount of waste. (NCST, 2014). Biogas project implementers also need to have knowledge of the seasonal availability of waste.

### 2.8. University Waste-to-Energy Case studies

Wastes produced at the University of California campus are used to generate campus energy. The main thrust of the research of Ruihong Zhang, professor in the Department of Biological and Agricultural Engineering at the University of California, Davis, has been to attempt to solve two important current problems at the same time: the shortage of power and the excess of waste. The plant was named the UC Davis Renewable Energy Anaerobic Digester. The system uses a fermentation process through which bacteria devour the waste and produce methane and carbon dioxide, in other words, biogas. The plant was designed to convert 50 tons of waste into 12,000 kWh of energy each day. In addition to producing renewable energy, since it is installed on a former landfill, which naturally produces a large

quantity of methane, the plant also combines the biogas produced by the bacteria with the methane from the former landfill. The result is the capacity to generate 5.6 million kWh per year of clean energy. In addition, by converting the gases into energy, the plant is expected to reduce greenhouse gas emissions by 13,500 tons per year. UC Davis will earn 100% of the green energy and carbon credits and receive all of the electricity generated. Three waste-to-energy projects at the University of Cincinnati are: waste cooking oil-to biodiesel, waste paper-to-fuel pellets and food waste-to-biogas. The implementation of these waste-to-energy (WTE) projects would lead to the improvement of campus sustainability by minimizing waste management efforts and reducing GHG emissions via the displacement of fossil fuel usage. The technical and economic aspects of their implementation were assessed and the corresponding GHG reduction was estimated. The results showed that on-site implementation of these projects would: (1) divert 3682L (974 gallons) of waste cooking oil to 3712L (982 gallons) of biodiesel; (2) produce 138tonnes of fuel pellets from 133tonnes of waste paper (with the addition of 20.75tonnes of plastics) to replace 121tonnes of coal; and (3) produce biogas that would be enough to replace 12,767 cubic meters of natural gas every year from 146tonnes of food waste. (Jwasman 2015).

# CHAPTER 3

## 3.0 METHODOLOGY

### 3.1. Analyzing energy needs of MUST

In order to determine suitable waste-to-energy options for MUST, there is a need to understand the energy needs of the university. Therefore, data on energy needs and demand was collected from different offices. Existing energy audit data generated by the university during past studies was also used to analyze MUST energy needs.

### 3.2. Quantifying Solid Organic Waste Generated at MUST

**Materials and Instruments**: Buckets or containers of known volumes; weighing instruments; gloves, face masks and gumboots; and a mat or large paper for handling waste.

**Methods**: Quantifying solid waste was done at the point of source (MUST campus) rather than at the dump site. The process involves physical weighing of waste using a weighing instrument. The volume of waste generated was done using a container of a known volume. Measuring the weight and volume of waste generated by MUST was done for a period of 5 days in order to determine waste generation variability in a week.

### 3.3. Waste Water Quantification

The researcher was specifically quantifying black water, i.e., waste water from toilets. Usually, one person produces 0.5kg of feces per day. Therefore, the total amount of fecal matter can be calculated by multiplying with the number of people at MUST campus. The total amount of black water discharged per day will constitute the fecal matter plus the amount of water used for flushing the toilets.

### 3.4. Characterizing Solid Waste Generated at MUST

**Materials and Instruments**: Smaller containers for sorting waste; Container of a known volume; weighing instruments; gloves, face masks and gumboots; and large plastic paper for sorting waste.

**Methods**: Usually, more generalized field procedures based on common sense and random sampling techniques have evolved for determining composition. There is a general consensus that a sample size of approximately 100kgs is adequate enough for the determination of the composition of waste (UNEP, 2005). Therefore, the researcher obtained 100kgs of waste to be considered for characterization. The study involved the separating of waste into different categories, including food waste, paper and cardboard, leather, glass, plastics and clothing waste, among others. Separated waste was measured to determine the volume and weight of each waste component. MUST started to encourage source separation of waste at the campus, therefore it was simple work in waste characterization.

### 3.5. Analyze waste-to-energy technological options using Multi-Criteria Decision Analysis (MCDA).

The researcher, based on waste quantification and characterization data generated for MUST, analyze suitable technologies that can be employed by MUST using the MCDA model. Among other factors to be considered include suitability of the waste resource; cost of the technology; sustainability of the technology;

# CHAPTER 4

## 4.0 RESULTS AND DISCUSSION

### 4.1. power demand/needs assessment of must

The researchers used existing data on energy demand at the university that was collected by the MUST. Data used was collected from the library, administration, cafeteria, classrooms, hostels and sewer treatment facility at the campus. Electricity at MUST is mainly used to power lights, air conditioners, fans, pumps, motors and appliances. Load by block analysis shows that administration, cafeteria and sewer treatment facilities rank high, accounting for 22%, 22% and 20% respectively (Fig 3). The average hourly load curve shows that load peaks between 7-8am from 70kw to 440kw when cooking and learning activities start at the campus. Then the load reduces to 225kw at 5-6pm when learning activities stop and cooking activities are still in progress. The load reduces further back to 70kw at 9-10pm when all cooking activities have ceased (Figure 4). Therefore, the load curve shows that MUST can adopt alternative sources of energy that target specific buildings, uses and time of the day. For instance, solar energy generated can help meet the load in the administrative block during the day, while waste energy can fuel cooking energy needs.

Table 2: MUST Load by Area/Block.

| NO. | Area/Block | Power Usage | Load in KW |
|---|---|---|---|
| 1. | Library | Lighting, air conditioning + appliances | 43.8 |
| 2. | Administration | Lighting, air conditioning + appliances | 165.6 |

| | | | |
|---|---|---|---|
| 3. | Cafeteria | Appliances, ceiling Fans+ lights | 162.7 |
| 4. | Classrooms | Ceiling Fans, lights + appliances. | 109.6 |
| 5. | Hostels | Lighting, appliances | 113.4 |
| 6. | Sewer Treatment | Pumps + motors | 144 |

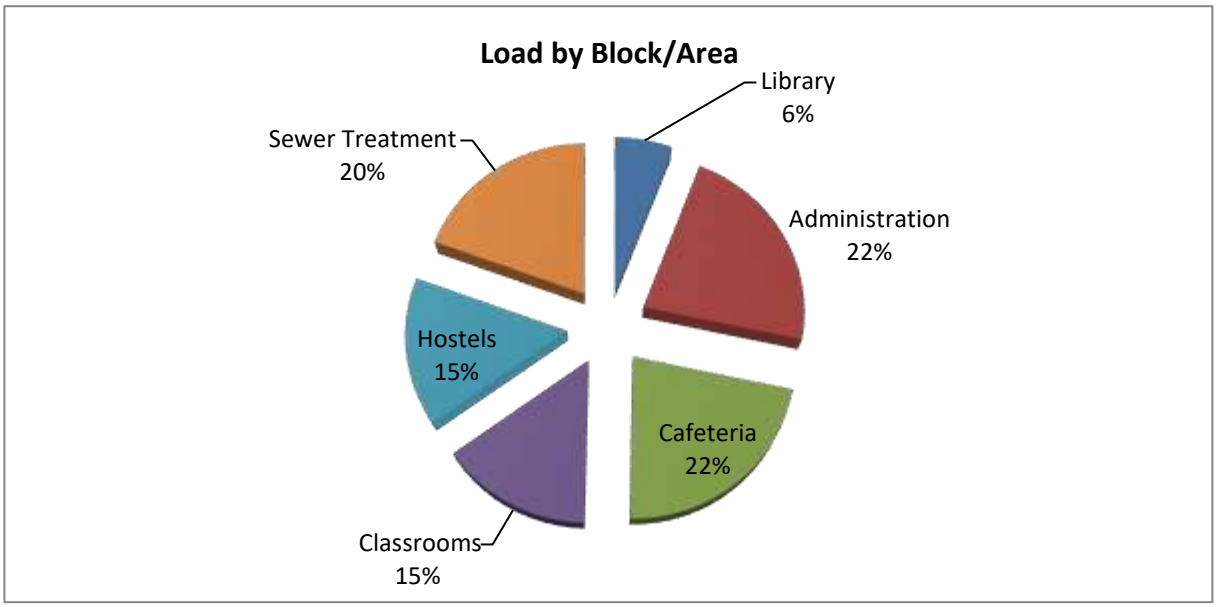



Figure 3: MUST Average Hourly Load Curve for Admin, Classrooms and Cafeteria Blocks

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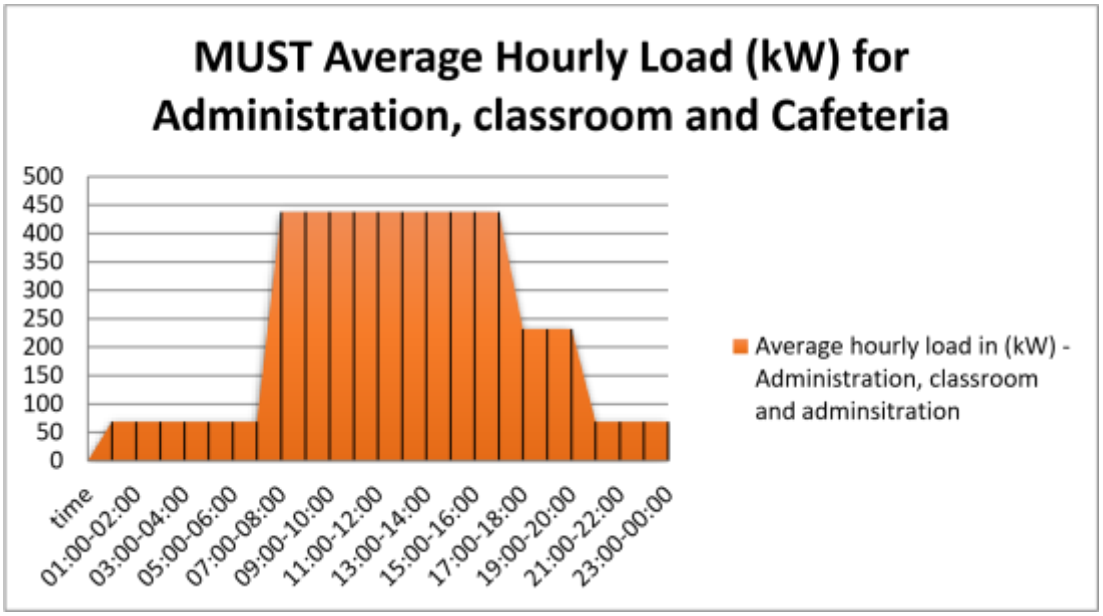



Figure 4: MUST average hourly load for administration, classrooms and cafeteria

## 4.2. AVERAGE WASTES COMPOSITION ANALYSIS

### 4.2.1 Waste Composition by Blocks

The waste composition and quantification studies were done for a period of five days in order to determine daily waste generation variation. Samples were collected from each hall for analysis, thereby providing an opportunity to determine the waste characteristics and quantities generated by each hall on the campus. Waste quantification involves determining its volume and weight. The characterization of the waste was based on grouping waste into organics, recyclables (plastics, paper, cardboard, metal, glass) and others.

The results show that organic waste, though having a higher percentage of weight, tends to have a smaller volume. Organic waste is also mainly generated from halls 1-8 and the cafeteria, where it accounts for 76% by weight (i.e., 32% by volume) and 98% by weight

(i.e., 78% by volume) respectively. Classrooms, administrative and library blocks waste generation is dominated by recyclables, which account for 83% weight (97% volume), 50% weight (91% by volume) and 100% (by volume and weight) respectively. Therefore, organic waste can effectively be intercepted from the cafeteria and halls 1-8 for composting and energy recovery, while recyclables can easily be obtained from classrooms, administrative and library blocks (see Tables 3-7 and Figures 6-10).



Figure 5: Waste generated at MUST

Table 3: Waste Characteristics and Quantities for HALLS 1-8 at MUST

| composition | Monday | | Tuesday | | Wednesday | | Thursday | | Friday | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) |
| recyclable wastes | 48.4 | 740 | 38.4 | 690 | 37.4 | 400 | 27.6 | 658 | 53.3 | 978 |
| organic wastes | 161.6 | 368 | 109.9 | 180 | 119 | 696 | 98.8 | 171.8 | 156.3 | 270 |
| others | 1.0 | 12 | 0.6 | 6 | 0 | 0 | 0 | 0 | 2.3 | 35 |

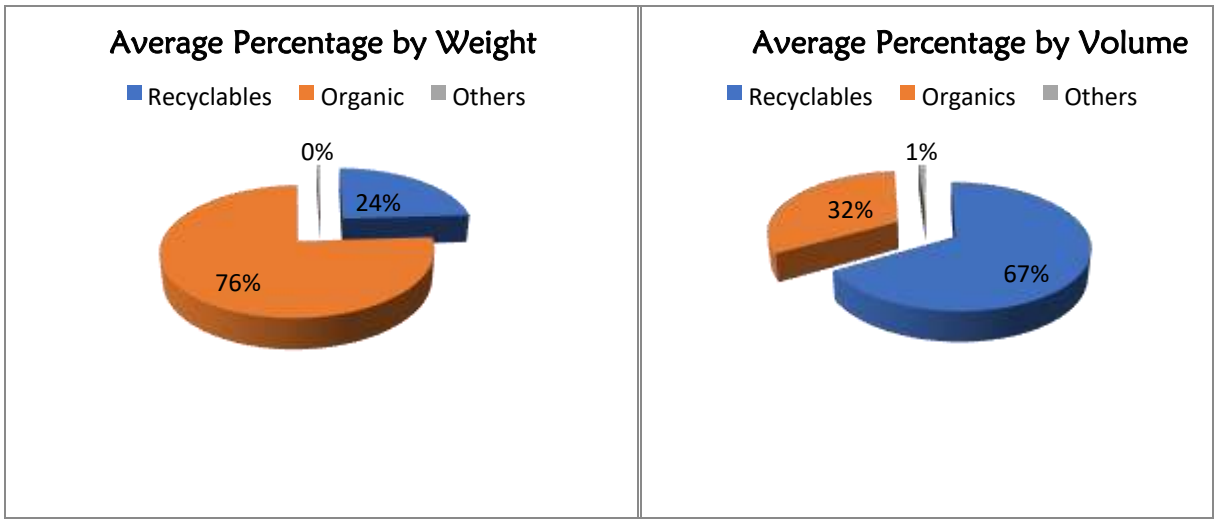


Figure 6: Average waste weight and volume for HALLS 1-8 at MUST.

Table 4: Classrooms Waste Generation and Composition.

| composition | Monday | | Tuesday | | Wednesday | | Thursday | | Friday | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) |
| recyclable wastes | 5.7 | 100 | 3.2 | 50 | 2.5 | 75 | 2.9 | 52 | 4.3 | 70 |
| organic wastes | 0.3 | 2 | 2.5 | 5 | 0 | 0 | 0.6 | 1 | 0 | 0.3 |
| others | 0.4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

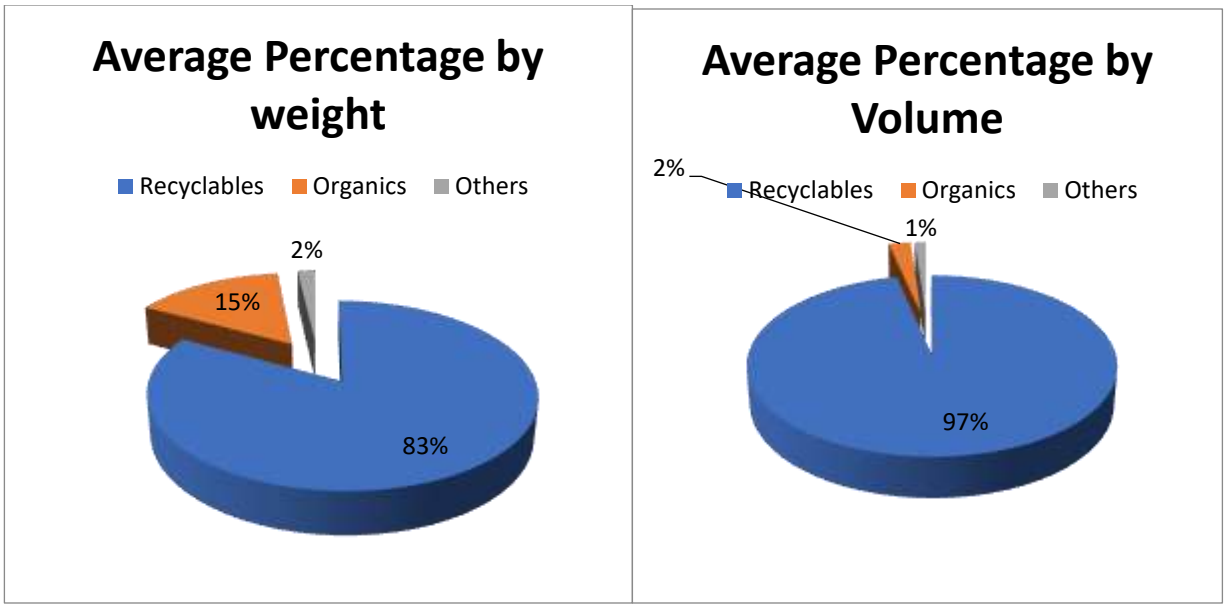



Figure 7: Classrooms Waste Generation and Composition by weight and volume.

Table 5: Administration Block Waste Generation and Composition

| composition | Monday | | Tuesday | | Wednesday | | Thursday | | Friday | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) |
| recyclable wastes | 4.5 | 80 | 3.5 | 55 | 3 | 60 | 4 | 70 | 3.8 | 68 |
| organic wastes | 0.5 | 2 | 6 | 10 | 4.2 | 7 | 2.4 | 4 | 6 | 10 |
| others | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

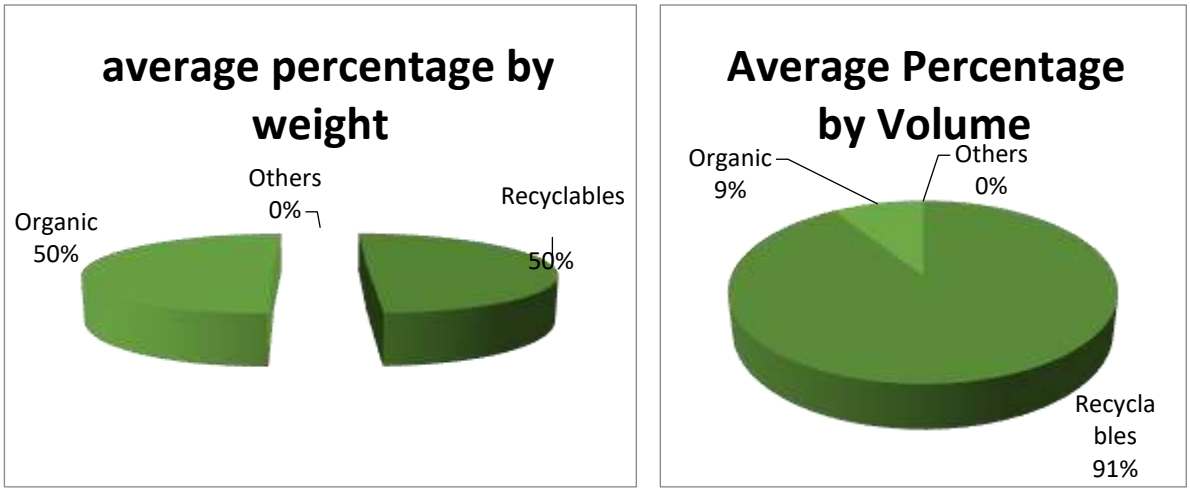



Figure 8: Administration Block Waste Generation and Composition by

Weight and Volume.

Table 6: Library Block Waste Generation and Composition

| composition | Monday | | Tuesday | | Wednesday | | Thursday | | Friday | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) |
| recyclable wastes | 1.7 | 30 | 1.1 | 20 | 0.2 | 10 | 0.7 | 13 | 1.2 | 20 |
| organic wastes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| others | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

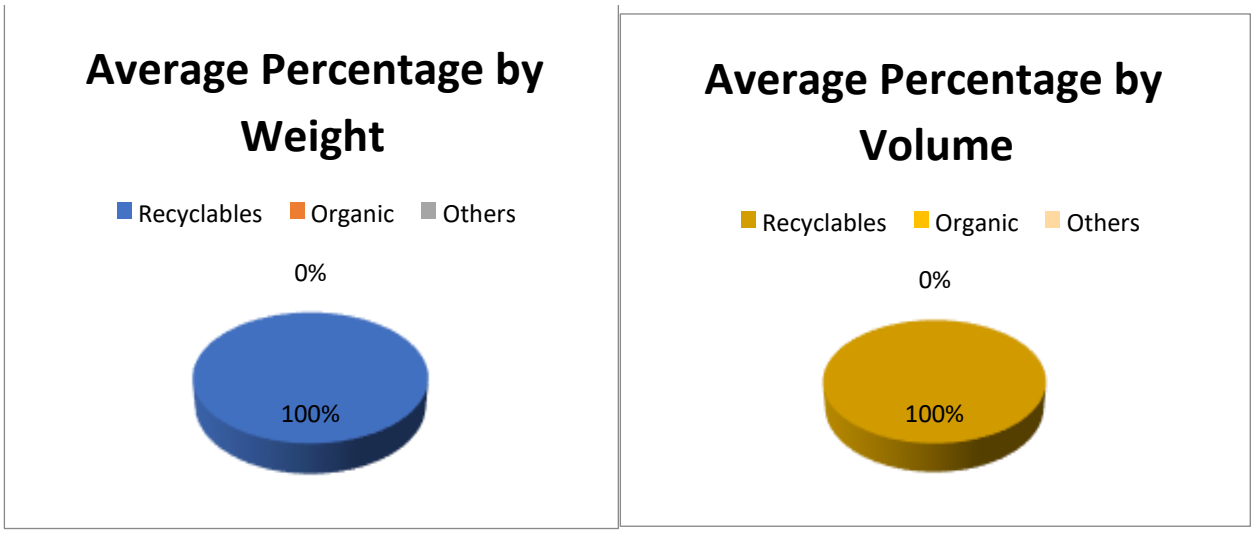



Figure 9: Library Block Waste Generation and Composition by weight and volume

Table 7: Cafeteria Block Waste Generation and Composition

| composition | Monday | | Tuesday | | Wednesday | | Thursday | | Friday | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) |
| recyclable wastes | 0.9 | 17 | 1.0 | 20 | 0.6 | 12 | 1.4 | 25 | 0.8 | 15 |
| organic wastes | 42.7 | 70 | 18 | 30 | 60 | 100 | 42.7 | 70 | 25 | 45 |
| others | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

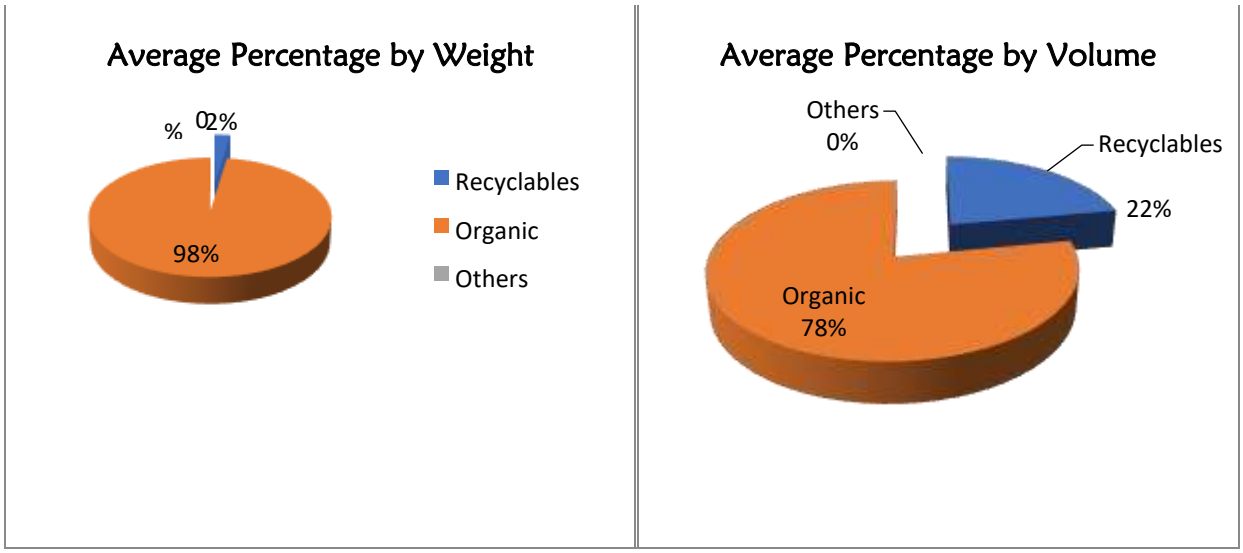


Figure 10: Cafeteria Block Waste Generation and Composition by Weight and Volume.

### 4.2 Accumulative Waste Generation for MUST

Accumulatively, MUST waste generation and composition shows that organic waste constitutes the largest constituent of the total waste generated. Organic waste, recyclables and others account for 77%, 23% and 0% of the waste flowing into MUST waste streams. However, it must also be noted that, by volume, recyclables rank first at 67% and second to organic waste at 32%. Therefore, if the university's primary intervention for waste management at the campus is to reduce volume, then recyclables must be the target first (See Tab. 8 and Fig. 11).

| composition | Monday | | Tuesday | | Wednesday | | Thursday | | Friday | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) | Weight (KGs) | Volume (L) |
| recyclable wastes | 61.2 | 967 | 47.2 | 835 | 43.7 | 557 | 36.6 | 818 | 63.4 | 1,151 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| organic wastes | 205.1 | 442 | 136.4 | 225 | 183.2 | 803 | 144.5 | 246.8 | 187.3 | 325.3 |
| others | 1.4 | 16 | 0.6 | 6 | 0 | 0 | 0 | 0 | 2.3 | 35 |

Table 8: Accumulative Waste Generation and Characteristics for MUST.

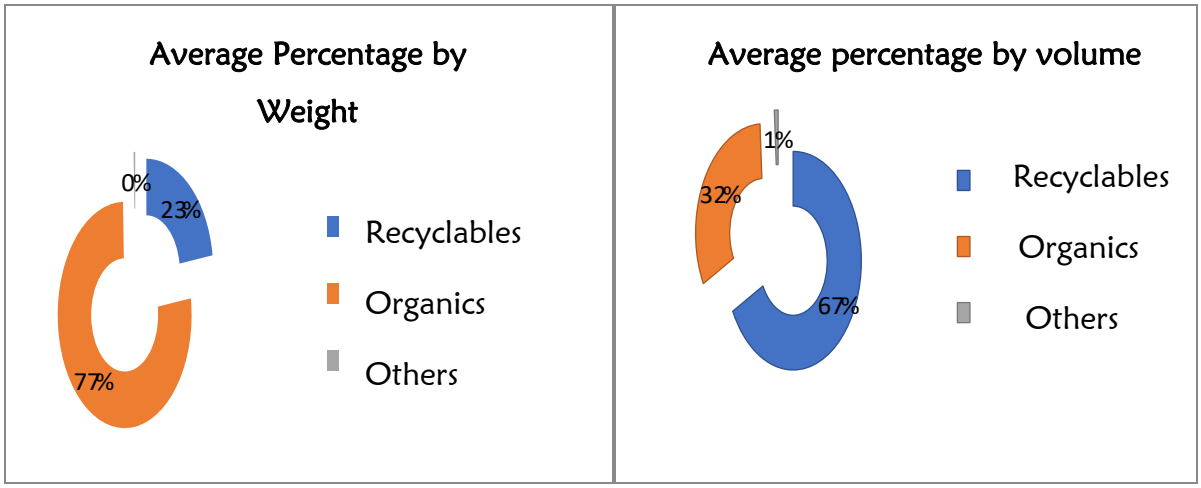



Figure 11: Accumulative Waste Generation and Characteristics for MUST.

### 4.3. Human Waste Generated by MUST

Usually, waste water that comes from the toilet, known as black water, contains many potentially disease-causing organisms and also contains more nutrients. The water from the sink or shower is usually called greywater. It contains fewer bacteria and lower amounts of nutrients when compared with black water. Energy recovery from waste water that involves anaerobic digestion must focus on blackwater as it contains the much-needed nutrients for AD. Using average sewage generated by an individual person, the amount of sewage generated by MUST campus can be estimated.

- MUST campus population: 2,742

- The average amount of feces (wet weight) generated per person per year is 250g/capita/day (Gao et al., 2002).

Therefore, 685.5 Kgs of fecal matter flows into the wastewater (sewage system) every day at the MUST main campus that can be harvested and used as feedstock for energy generation through AD.

## 4.4. Analyzing MUST WtE Options Using Multi Criteria Decision Analysis (MCDA)

The waste-to-energy options considered for this analysis were anaerobic digestion, briquetting, pyrolysis and gasification, incineration with energy recovery and landfill with gas extraction. Factors considered for this analysis were carefully selected in order to identify the most suitable WtE technologies for adoption by the MUST. These factors are waste resource suitability, capital cost, operation and maintenance, technology maturity, environmental sustainability, and policy & regulatory frameworks. The wastes considered for energy recovery include solid waste as well as wastewater (black water).

The score took consideration of the local context and showed AD as the best option to be considered considering that the organic resources (food waste and blackwater) are in abundance; the capital cost of the technology is lower; the technology is easy to operate and maintain; and the environmental benefits are much greater, among others, due to harvested bio-slurry that can replace inorganic fertilizer. Briquetting ranks second as the technology is cheap, easy to operate and maintain. However, briquetting is limited as it can be used to treat papers and cardboard only. Gasification & Pyrolysis, Incineration with Energy Recovery and Landfill with Gas Extraction technologies rank low, mainly due to their associated costs and lack of expertise to operate and maintain.

WtE Technology and Criteria for Analyzing MUST WtE Technology Options

| No. | WtE Technology Option | Criteria (5) | Description |
|---|---|---|---|
| 1. | Anaerobic Digestion | Resource suitability | Quality and quantity of the waste resources |
| 2. | Briquetting | Capital Cost | Initial investment cost required |
| 3. | Pyrolysis & Gasification | Operation and maintenance | How easy it is to operate and maintain the WtE technology, i.e., financially and availability of the local expertise. |
| 4. | Incineration with Energy Recovery | Policy and regulatory frameworks. | Availability of national and MUST policies and regulatory frameworks that support the WtE technology option. |
| 5. | Landfill with Gas Extraction | Environmental sustainability | The impact of technology on the environment and climate change. |

Rating of Waste-to-Energy Technology Options Using Weighting Method

| | | Criteria | | | | | Total Score |
|---|---|---|---|---|---|---|---|
| | Description | Resource Suitability | Capital Cost | Operation and Maintenance | Policy and Regulatory Frameworks | Environmental Sustainability | |
| | Weight out of 100 points | 30 | 25 | 20 | 13 | 12 | 100 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Minimum desired score for each criteria | 20 | 15 | 10 | 6 | 6 | 55 |
| Technology Options | 1. | AD | 22 | 18 | 14 | 6 | 9 | 69 |
| | 2. | Briquetting | 10 | 22 | 15 | 6 | 4 | 57 |
| | 3. | Gasification & Pyrolysis | 15 | 12 | 10 | 6 | 7 | 50 |
| | 4. | Incineration with ER | 14 | 10 | 10 | 6 | 7 | 47 |
| | 5. | Landfill with GE | 15 | 12 | 12 | 6 | 8 | 53 |

## 5.0 CONCLUSION AND RECOMMENDATION

Every day, the institution is literally squandering money by simply dumping waste at the dumpsite without any formal trash reduction, recycling, or composting on campus. Wastes can be put to good use in institutions. The amount and weight of garbage created here are depicted in the diagram above. It is feasible to employ garbage as a solution to the energy problem.

The importance of waste management that uses waste for energy production, reduces the demand for landfills, reduces the pressure for additional landfills, landfill sites, hazardous waste disposal capability, and reduces hazardous emissions. In addition to that, the utilization of waste technologies not only resolves the waste management issues but also generates energy that can be sold for profit. According to the research results, it is now up to MUST authorities as technology institutions to make smart investments by stopping burning waste instead of investing in reliable technologies that offer great solutions and make money and benefits out of trash.

## 6.0 ACKNOWLEGMENT

Firstly, I would like to express my sincere gratitude to my supervisor, Mr. Hope Chadimba, for his excellent support, helpful comments, and motivation. His guidance and comments helped me during all the time of research and writing this dissertation. My sincere thanks also go to Dr. Taulo for helping with the energy audit data. Finally, I would also like to thank Mr. Kazembe, the lab technician, who gave me access to use his personal equipment.

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