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# Solid Waste Composition and Waste-to-Energy Options at The Malawi University of Science and Technology in Malawi


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**Abstract** Lack of understanding of solid waste composition and generation rates is one of the major bottlenecks to the adoption of waste-to-energy technologies. Therefore, this study analyzed solid waste composition and generation rates at the Malawi University of Science and Technology. In addition, the study examined the potential waste-to-energy options for the university based on the available solid waste resources. The study involved collecting and analyzing 186.9kg of solid waste samples per day for a period of five days to determine solid waste composition and generation rates. A multi-Criteria Decision Analysis Model was used to evaluate the viability of anaerobic digestion, briquetting, pyrolysis, gasification, incineration with energy recovery, and landfill with gas extraction waste-to-energy technologies. The key factors considered in the analysis were feedstock availability, capital cost for developing the waste-to-energy technologies, operation and maintenance of the technologies, environmental sustainability opportunities presented by the technologies, and the availability of the policies and regulatory frameworks that motivate the development of the technologies. The study findings showed that organics, recyclables, and other types of waste accounted for 77%, 23%, and 0%, respectively. Anaerobic digestion, briquetting, gasification, and pyrolysis, landfill gas extraction, and incineration with energy recovery scores were 69%, 57%, 50%, 48%, and 47%, respectively. Therefore, anaerobic digestion emerged as the most suitable waste-to-energy option at the MUST. The university should adopt a policy that encourages onsite solid waste segregation, where organic solid waste can easily be extracted for anaerobic digestion.



**Keywords**: *Energy recovery; Circular Economy; Waste Characteristics; Waste Segregation; Multi-Criteria Decision Analysis.*

## 1. Background

Solid waste management is a major global challenge considering that it is not cheap and contributes to undesirable environmental impacts (Ferronato & Torretta, 2019; Taboada-González et al., 2010). Waste emits greenhouse gases (GHG) that are blamed for climate change and global warming (Hoang et al., 2017; Ferronato & Torretta, 2019; Taboada-González et al., 2010). In addition, solid waste may increase the risk of flooding in urban areas by blocking water drainage systems.

Waste is inevitable; therefore, solid waste will continue to be generated. Finding sustainable solutions is crucial if the undesirable consequences of poor solid waste management are to avoided (Pham Phu et al., 2021). However, to exploit the waste resource for socio-economic development there is a need for reliable data, which can be used during decision making process by planners in the urban settings. Consequently, there is growing interest in solid waste related research around the globe (Phuong et al., 2021; Yenice et al., 2011; Taboada-González et al., 2010).

Waste-to-energy (WtE) is one of the key components of the Circular Economy (CE) concept, which is a sustainable development strategy that is being proposed to address environmental degradation and resource scarcity. CE's 3R principles are waste reduction, reuse, and recycling (Heshmati, 2017; Ekins et al., 2019). In a CE, waste is regarded as a valuable resource that can be used for different economic uses at a time when urban settings are becoming resource constrained (Miezah et al., 2015; Moya et al., 2017).

WtE technologies are increasingly being adopted around the globe, especially in urban settings, as they enable cities to solve multiple challenges, such as, sanitation, climate change, and energy poverty (Moya et al., 2017). Currently, waste collection is very poor in urban Malawi, just like in many other developing countries, because the local authorities lack adequate resources (Uche-soria & Rodr, 2019; Moya et al., 2017). Therefore, waste remains uncollected and dumped in open space, a situation that creates environmental and health risks for the population (Ferronato & Torretta, 2019).

The Government of Malawi (GoM), Non-Governmental Organizations (NGOs), Community-Based Organizations (CBOs), and other stakeholders implement water and sanitation related projects to prevent the outbreak of water-borne diseases. However, the waste-to-energy option is overlooked, yet it presents an opportunity for addressing multiple challenges related to sanitation, climate change and energy access.

One of the major bottlenecks to the exploitation of waste as a valuable energy resource is a lack of research. In addition, most local governments as well as organizations do not keep records of waste generation in terms of composition and quantities (Taboada-González et al., 2010). Lack of this data makes it more difficult for the city or community planners to determine the suitable WtE technology for treating waste.

Generally, WtE options are dependent on solid waste compositions, as some components of solid waste are not suitable for certain conversion technologies (Miezah et al., 2015). In addition, solid waste studies have to be undertaken continuously as waste generation rate and compositions do change as a result of socio-economic developments taking place in a particular community (Pham Phu et al., 2021; Hoang et al., 2017; Phuong et al., 2021; Yenice et al., 2011). With increased economic activities and changes in people's lifestyles, it should be anticipated that waste generation cannot remain the same.

The processes for WtE are grouped into two main process categories, which are thermochemical and biochemical. Combustion, gasification, pyrolysis, carbonization, and catalytic liquefaction are examples of thermochemical processes. On the other hand, Anaerobic Digestion (AD), ethanol fermentation, and methane production in landfills are regarded as biochemical processes (Sharma et al., 2014; Uche-soria & Rodr, 2019). For optimum WtE production, there are processes that require specific waste types; hence, waste should be sorted. For instance, AD requires organic or biodegradable components of solid waste. Therefore, the solid waste generated must be segregated at the point of generation to remove inorganic solid waste. Deliberate policies that promote solid waste segregation should adopted. Moreover, it will be easier for entrepreneurs to collect specific types of solid waste for recycling or energy recovery. Depending on the technology adopted, it is possible to generate energy in the form of heat, electricity, and fuels (gaseous and liquid) (Faaij, 2006; Uche-soria & Rodr, 2019).

The Malawi University of Science and Technology (MUST) is not immune to waste management challenges. The University is always under pressure from the government to increase the enrollment of students, yet the growth of the critical infrastructure does not match the population increase at the campus (Uche-soria & Rodr, 2019). Thus, waste generation increases, yet waste handling facilities remain the same. This kind of unsustainable waste management will present major challenges for the University, including health risks and environmental degradation (Hoang et al, 2017; Uche-soria & Rodr, 2019). The university must explore sustainable solutions to address waste management challenges. In the process, more research will be needed to guide the decision-making process by the management and planners (Miezah et al., 2015). In this case, waste characterization and WtE-related studies have to be undertaken in order to provide the much-needed statistics that will enable the university to make proper decisions (Yenice et al., 2011; Phuong et al., 2021; Taboada-González et al., 2010). Among others, waste generation and composition data help planners identify the appropriate technologies for treating solid waste (Phuong et al., 2021). Therefore, the objectives of this study were to determine the composition of solid waste that is generated at MUST and to analyze WtE options for the university using the Multi Criteria Decision Analysis (MCDA) method by considering the technology enablers and barriers.

## 2. Materials and Methods

### 2.1 Study Area

The study was conducted at MUST, which is one of the six public universities in Malawi. The university was established by Act of Parliament Number 31 of 2012 and enrolled its first cohort of students in April 2014. The university is in Thyolo District, Malawi, and has a population of 2700 students. Figure 1 shows the location of the university.

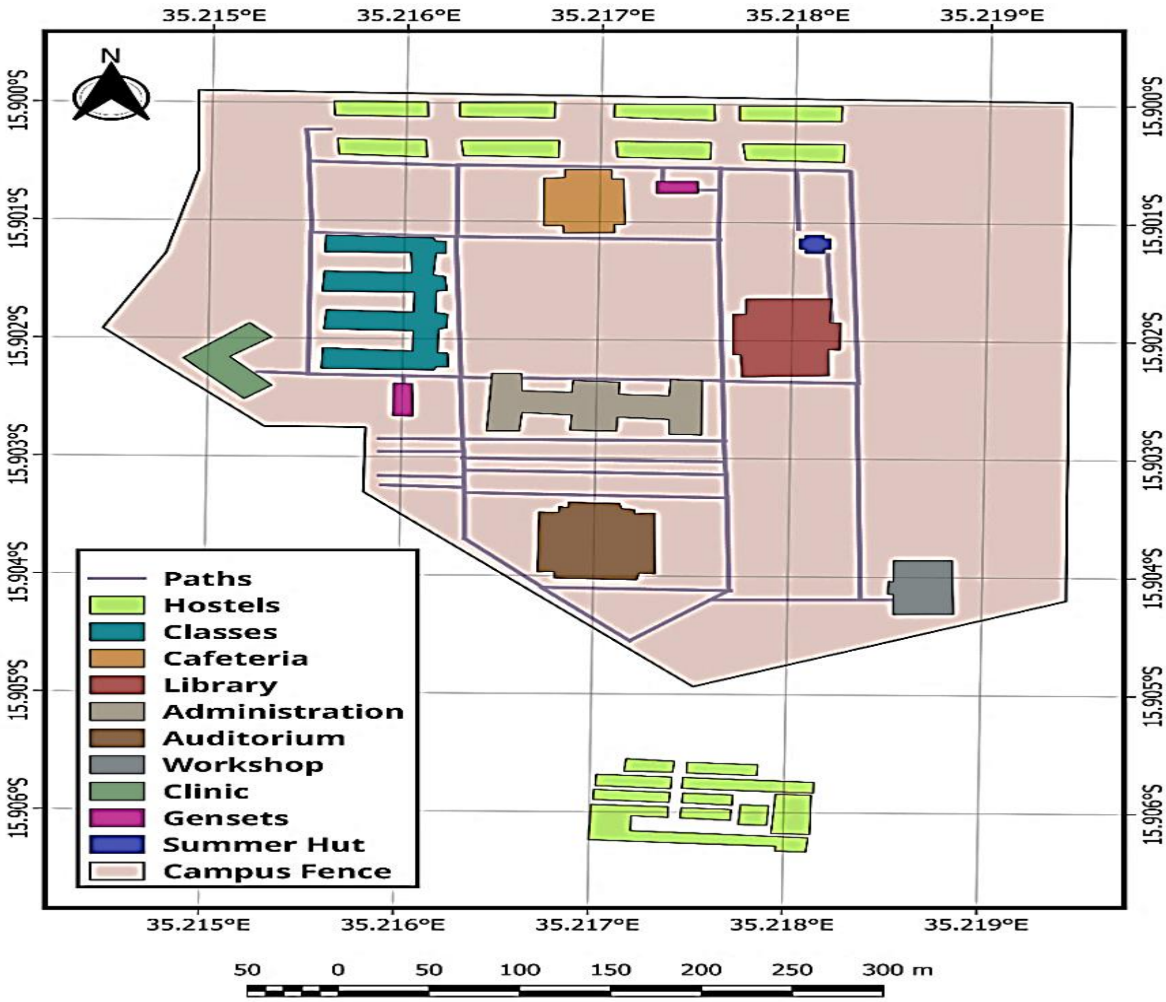


*Figure 1: Location of MUST Campus.*

### 2.2 Solid Waste Composition Analysis

#### 2.2.1 Sample Collection

Usually, solid waste sample sizes of between 100 and 1000 increase the accuracy of results (Gawaikar and Deshpande, 2006). However, due to the COVID-19 pandemic, the university was operating partially, and as a result, less waste was being generated. On average, the study collected a sample of 186.9kg per day for analysis from different blocks at the MUST. Waste characterization can be done either at the point of generation, at the dump site, or while in transit. In this case, the study considered waste characterization at the point of generation. Therefore, solid waste was intercepted for analysis before being collected and disposed of by the cleaners at the campus. Proper arrangements were made with cleaners so that all the waste generated was made available for the study.

The collected solid waste samples were transported to a sorting center that was established within the campus for analysis. To understand the solid waste flow at the campus from different areas, the study divided the campus into five main sections: the hostels (Halls 1–8), administration block, classroom blocks, library block, and cafeteria.

### 2.2.1 Materials

Materials and equipment used in this study were gloves, face masks, and gumboots for safety purposes; plastic containers (60 liters) for handling waste during characterization; a weighing instrument for measuring weights of solid waste; and a plastic sheet that was used for waste segregation.

### 2.2.2 Procedure

The characterization of the solid waste involved determining the components of the solid waste generated. In this case, solid waste was sorted into different categories and their weights determined. Solid waste samples were placed on the plastic sheet, and hand sorting of the waste was done to segregate the waste into different groups. Table 1 shows the categorization method of the solid waste that was used during this study.

*Table 1: Solid Waste Grouping Method*

| Waste categorization | Description |
|---|---|
| Organic Waste | Food waste, garden waste and any biodegradable waste |
| Recyclable Waste | Plastics, metals, paper, cardboards, and glass |
| Others | Mixed waste that is difficult to segregate |

After segregating the waste, each component was weighed using a digital weighing instrument, and then the percentage of each component was determined. The waste characterization study was conducted for a period of five days, starting from Monday to Friday. The quantitative data was analyzed using the Excel statistical package. Figure 2 shows the segregated organic waste at a waste handling site at MUST.

*Figure 2: Segregated organic waste.*

### 2.1.Evaluating MUST WtE Options Using Multi Criteria Decision Analysis (MCDA)

MCDA comprises various classes of methods, techniques, and tools with different degrees of complexity that explicitly consider multiple objectives and attributes in the decision-making process (Dean, 2022). MCDA is concerned about choosing options using several, and often conflicting, criteria to achieve the pre-considered preferred results (DuncanRangel et al., 2009; Ward et al., 2016). One key element of MCDA is the option, which is an alternative course of action or solution that is proposed to address a perceived problem (Dean, 2022; DuncanRangel et al., 2009).

The WtE options proposed for MUST were AD, Incineration with Energy Recovery, Briquetting, Pyrolysis and Gasification, and Landfill with Gas Extraction. Based on the objectives and criteria, these options were measured by the scoring method in order to determine whether they met the stated objectives (Ward et al., 2016). The objective of this study considered identifying the most suitable WtE for the MUST by considering the following factors: raw material (feedstock) availability, which is also dependent on solid waste quantities and compositions generated by the university; capital cost that the university will require in order to develop the technology; the ability to operate and maintain the identified WtE technologies, which is dependent on the availability of technical expertise and technologies; national and university policy and regulatory frameworks that support specific technologies; and environmental sustainability opportunities that are presented by the specific WtE technologies at the campus and the surrounding communities (Ward et al., 2016; Vilutienė & Zavadskas, 2003).

The suitable technology for the university should be easy to sustain in the long term as the population of the university expands. In addition, the technology should be able to bring more benefits to the MUST community in terms of energy, sanitation and the environment.

## 3. Results and Discussions

### 3.1 Wastes Quantification and Composition Analysis

Based on blocks at the campus, the study found that organic solid waste quantities generated per day by weight for hostels, classrooms, the administration block, the library, and the cafeteria were 129 kg, 0.68kg, 3.82kg, 0 kg, and 37.68kg, respectively. On the other hand, statistics showed that hostels, classrooms, the administration block, the library, and the cafeteria generate 41.02kg, 3.72kg, 3.76kg, 0.98 kg, and 0.94kg of recyclables per day, respectively. Other types of waste (i.e., mixed waste) quantities generated from the blocks were 0.78kg, 0.08kg, 0kg, 0 kg, and 0kg, respectively. Figure 3 shows percentages of organic, recyclables and mixed waste generated from different blocks.

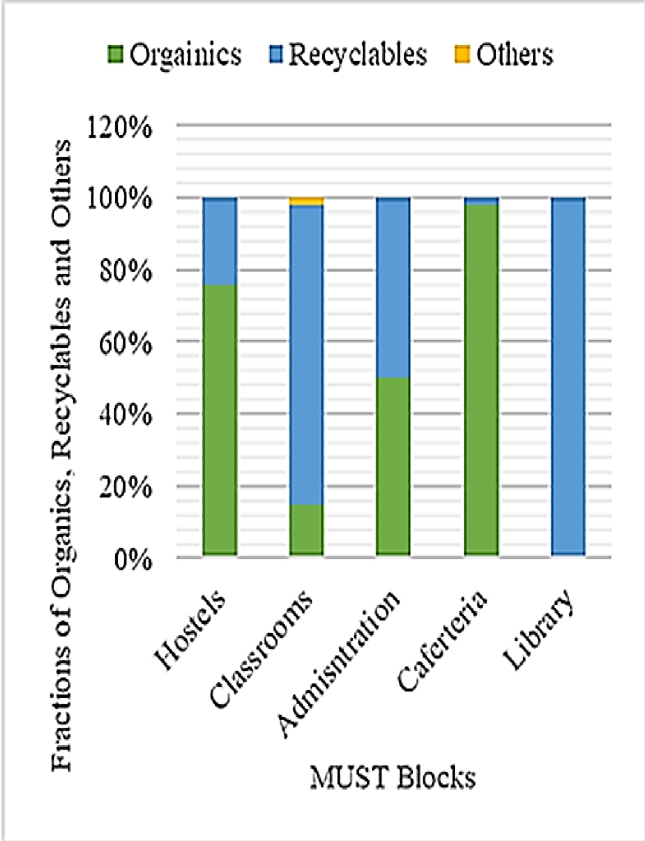


*Figure 3: Solid Waste Generation from Different Blocks.*

Accumulatively, the study found that quantities of organics, recyclables and others generated by the MUST were 171.3kg, 50.42kg and 0.86kg, respectively. Figure 4 shows the accumulative percentages of organic, recyclable, and mixed waste at the MUST.

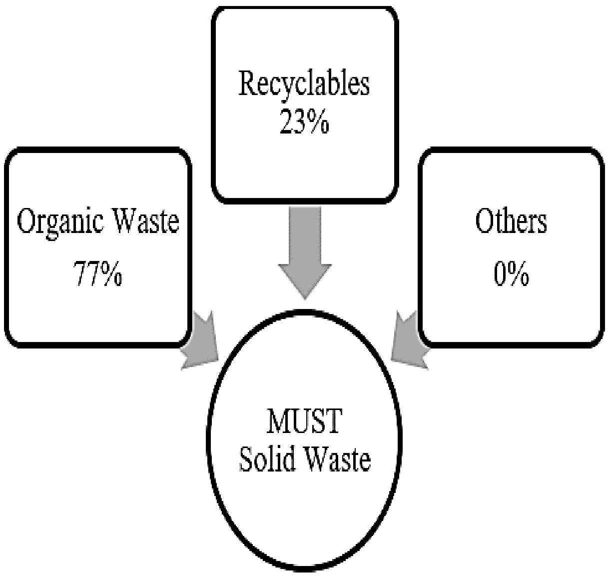


*Figure 4: Solid Waste Generation at MUST Campus.*

Organic waste accounts for the largest share of the solid waste generated by the MUST. Most of this biodegradable waste is generated in hostels, considering that many students take their meals to their hostel rooms. The study also found that the library generates zero organic waste. This is justified considering that the library at MUST has rules in place that prevent taking food, drinks, and water into the library. The hostels also emerged as the largest generators of recyclables. However, it should be expected that these statistics will continue to change as the University expands and other areas, such as the MUST Industrial Park and engineering workshops start to operate.

### 3.1. Solid Waste Characterization Study Findings in Comparison with Other Similar Studies.

A comparison of the solid waste composition generated by different universities around the globe showed different results (Table 2). This was anticipated considering that solid waste generation varies with the socio-economic status of the communities (Pham Phu et al., 2021; Phuong et al., 2021; Yenice et al., 2011). Usually, solid waste generated in developing countries has a higher fraction of organic waste (i.e., >50%) (Chamdimba et al., 2021). MUST has yet to operationalize its engineering workshops and industrial parks; as a result, the generation rate of recyclables, such as metals, plastics, and papers, is still limited at present. Therefore, organic waste, at 77%, accounts for the largest share of the solid waste generated. This alone signifies that entrepreneurs should focus on biodegradable waste if they are to exploit the waste resource generated at the MUST.

*Table 2: A Comparison of MUST Solid Waste with other Universities Around the Globe.*

| | **This Study Findings** | **(Budihardjo et al., 2021)** | **(Ugwu et al., 2020)** | **(Báreková, & Franeková, 2015)** | **(Ishak et al., 2015)** | **(Tiew & Watanabe, 2011)** | **(Starovoytova, 2018)** |
|---|---|---|---|---|---|---|---|
| Organic | 77% | 50.5% | 34.29% | 28% | 48% | 54% | 37% |
| Recyclables | 23% | 49.5% | 65.71% | 38% | 46% | 31% | 63% |
| Others | 0% | - | - | 24% | 5.81% | 15% | 0% |

The statistical analysis of the solid waste generation in universities based on the literature reviewed showed that the organic and recyclable generation had a mean of 46.97 and 45.17, respectively, and a variance of 264.13 and 250.49, respectively. Organic waste generated in universities around the world, accounting for 46.97% on average, is much lower when compared to that of MUST at 77%. On the other hand, the observed variations in mixed waste can be attributed to waste handling practices adopted by different universities. It should be expected that universities with a policy that promotes solid waste segregation generate less mixed solid waste.

### 3.2. Analyzing MUST WtE Options using Multi-Criteria Decision Analysis (MCDA).

The scores showed that AD is the best option to be considered at MUST because the organic waste is abundant, the capital cost for the technology is lower, the technology is easy to operate and maintain, and the environmental benefits are much greater. The MUST planners should priorities the development of the appropriate infrastructure for advancing AD technology. The technology will enable the university to generate biogas fuel for cooking and heating. In addition, the bioslurry, which is produced as a byproduct of the AD process, can be sold to farmers and landscapers.

AD is the most favored WtE option at MUST not only because of the abundant organic solid waste (feedstock) but also because the technology is mature. Biogas has been used in Malawi for many years. These AD plants, especially fixed-dome types of digesters, have mostly been developed by NGOs for rural communities. With this background, the University is expected to have the required expertise to develop, operate, and maintain the technologies in the long term. In addition, the prefabricated digesters are becoming cheaper and more reliable, so the required capital cost to develop the technology is reducing rapidly.

Briquetting ranks as the second most suitable WtE option as the technology is cheaper and it is easy to operate and maintain. However, briquetting is limited in that it can only be used to treat papers and cardboards generated by the university. Briquetting, which is one of the oldest technologies for converting solid waste into usable form. The University continues to generate huge quantities of paper waste that can be densified and used for heating and cooking. The technology is simple and cheaper, thus making it easier to operate and maintain. Already, several CBOs and entrepreneurs in Malawi are producing briquettes from different types of feedstocks, such as, sawdust, rice husks, and paper waste. Table 3 shows scores of different WtE options.

*Table 3: 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 criterion | 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 | Landfill with GE | 15 | 10 | 9 | 6 | 8 | 48 |
| | 5. | Incineration with ER | 14 | 10 | 10 | 6 | 7 | 47 |

Gasification and Pyrolysis, incinerators with energy recovery, and landfills with gas extraction technologies were ranked very low, mainly due to high capital costs and a lack of expertise to operate and maintain them. These technologies have been in existence for centuries; however, they have not been fully exploited partly because the fundamental principles underpinning their operation are still vague, particularly with regards to the type of material suitable as feedstock(Mohammadi & Anukam, 2022). Globally, extensive studies have been undertaken on gasification and pyrolysis technologies over the last decade; however, there are still pending research-related issues that require further improvements. An analysis of WtE technologies by EPA (2021) and Bary at al. (2021) also shows that pyrolysis and gasification represent a significant financial investment compared with direct biosolid land application alternatives and that there are several challenges and data gaps associated with these technologies. For instance, the mechanisms involved in the feedstock conversion process are still under debate (Mohammadi & Anukam, 2022). Therefore, very few countries, such as, Sweden, Germany, Canada, the United States, India, and China, have managed to commercialize these technologies (Luo et al., 2018). Adoption of these technologies by the university will present so many risks and be costly due to uncertainties.

Landfill with gas extraction and incineration with energy recovery scores are the lowest, mainly because the technology is not yet mature in the country and the required capital cost is very high. Generally, the University lacks the required technical expertise to develop, operate, and maintain the technologies. Moreover, huge capital costs will remain a bottleneck to the adoption of such technologies. However, these technologies have the capacity to treat larger quantities and different types of solid waste than AD and briquetting.

## 4. Conclusions

Solid waste quantification and composition studies at the MUST show that organic waste accounts for the largest share. This is a common characteristic of solid waste generation in developing countries. An analysis of WtE options for the University using the MDCA model that considers feedstock availability (based on the university's solid waste composition), capital costs, operation and maintenance, environmental sustainability, and policy and regulatory frameworks shows that AD is the most favored option, while briquetting is the second most favored option. Pyrolysis, gasification, landfill gas extraction, and incineration with energy recovery are less favored as the technologies require more research.

## 5. Recommendations

- To make sure that different forms of solid waste can be easily separated and exploited as a resource, MUST needs to promote source separation of solid waste.
- Organic solid waste composition at 77% is an opportunity for the University to consider generating biomethane and bioslurry through AD.
- Briquetting should also be explored, considering that it is less complex and does not require large capital costs to develop. Briquetting machines can easily be fabricated locally, and their operation and maintenance costs are much lower.
- Gasification, pyrolysis, incineration with energy recovery, and landfill gas extraction should be the university's primary research focuses because they are still in their infancy.

## 6. Further Study Area

More research is needed to assess the actual recoverable energy from the waste resource generated at the MUST. In this case, each WtE technology must be evaluated to determine the recoverable energy based on the waste resource available. In addition, further studies will also be needed on the implementation of an onsite solid waste segregation policy, where behavior change is demanded.

## Author Contribution

**Hope Chamdimba** participated in the study design, data analysis and writing the manuscript. **Esther Mulipa** was involved in data collection and writing the manuscript. **Austin Nyirenda** and **Francis Chagunda** were involved in writing the manuscript.

## Declaration of conflict of interest

The authors of this review paper certify that they have no affiliations with or involvement in any non-financial or financial interest in the subject matter or materials discussed in this paper.

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