Waste-To-Energy Prospects of Municipal Solid Waste in Gazipur City Corporation

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This paper titled "Waste-To-Energy Prospects of Municipal Solid Waste in Gazipur City Corporation" submitted by Md. Tahsin Ahsan, Ridoy Ahammed has been accepted as partial attainment of the requisite for the degree, Bachelor of Science in Civil Engineering.

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Declaration of Candidate

It is hereby decalared that this thesis/project report, in whole part, has not been submitted elsewhere for the award of any Degree or Diploma.

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Dedication

To our loving family members and beloved teachers

for

the support, patience and most of all, faith they have shown in us.

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Without the help, love, and support of so many extraordinary people, this accomplishment would not have been possible. we are incredibly grateful.

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Abstract

Municipal solid waste (MSW) management is a pressing issue in urban areas and Gazipur City Corporation (GCC), the largest city corporation in Bangladesh, is no exception. This newly formed city corporation's population is expanding rapidly, and as a result, waste generation is significantly more than it is in other city corporations. Since there isn't a waste-to-energy (WTE) facility nearby, the current solid waste management (SWM) system is insufficient. The city corporation's present solid waste management strategy focuses primarily on the collection and disposal of waste, without taking other factors into account. GCC has a tremendous potential for using the waste-to-energy process to turn its waste into electricity because there is so much waste generated and disposed of every day. A study was done with the main goal of evaluating the waste generation, composition, moisture content, calorific value, and ash content of solid waste from households in the GCC due to the dearth of trustworthy data on waste characterization for the WTE process in this region. The study also took bazaar waste generation and composition into account.

100 kg of waste samples from five different zones were gathered in two cycles over the course of the dry season in order to achieve the suggested goals. The study found that organic waste (76.31%) predominated among other categories of waste, which included paper (5.73%), plastics (8.46%), glass (1.51%), metal (0.73%), rubber & leather (0.53%), textiles & wood (4.79%), and others (1.59%). The calorific value of MSW in the GCC was found to be 14.76 MJ/kg, with an average moisture content of 55%. 11.68% ash was found in the sample. Additionally, it was calculated that household waste in the GCC have a net electric potential of 18.9 MW. Anaerobic digestion (AD) can become an intriguing option in this region due to the presence of high percentage of organic waste and moisture content. After doing a techno-economic analysis of AD, it was determined that the projected plant's energy capacity was 11.61 MW, with a payback period of 5.26 years. It has been shown that putting AD into practice on a wide scale may both minimize waste and satisfy a sizeable percentage of the city's energy needs. Additionally, the weight of materials that can be recovered from trash created in the GCC totals 190.014 tons per day, and resource recovery has a potential revenue of 206.232 million BDT. As a

result, the waste produced in the GCC can be properly used, and the resource recovery and waste-to-energy processes can turn it into valuable assets.

Chapter 1: Introduction

1.1 General

Between 2015 and 2019, Bangladesh's economy grew by a strong 6-8% annually on average. Despite the difficulties caused by the COVID-19 epidemic, the nation was nevertheless able to grow at a positive rate of 3.5% in 2020 (UN, 2022). Bangladesh managed to navigate the COVID-19 epidemic despite the difficulties it presented by putting in place sound macroeconomic policies (Bangladesh Development Update, World Bank 2023 April). The number of individuals moving to urban regions has increased significantly as a consequence of socioeconomic advancements, with Bangladesh's urban population rising by more than 7% over the past ten years (UN, 2019). This increase in urban population can be ascribed to several factors, including the accessibility of better facilities for a better quality of life, which are primarily located in urban areas. These facilities include housing, electricity, water supply, sanitation, and more. These elements have been crucial in drawing people to metropolitan areas in search of improved living conditions and access to necessary services. Like many other places, Bangladesh's growing urban population has increased waste production as a result. The three most populous nations in Southeast Asia—India, Pakistan, and Bangladesh—have a combined population of 1.68 billion. Averaging 0.52 kg per person per day, South Asia produced 334 million tons of waste in total in 2016. Most communities in South Asia still practice open dumping, however there is a growing tendency toward creating hygienic landfills and encouraging recycling programs. The waste produced in the South Asia region is largely made up of organic waste. It is important to note that waste production in rural areas is far lower than in metropolitan areas, which lowers the average waste creation across the entire region (What a Waste 2.0, World Bank 2018).

An enormous amount of municipal solid waste (MSW) has been produced in Bangladesh as a result of the country's fast population increase and continued economic development, which has been linked to serious environmental problems (Bhuiyan, 2010; Afroz et al. 2010). Sustainable MSW management in Bangladesh is still a difficult problem and a recurring concern, despite the government's ongoing efforts (Islam, 2016). Early estimates from the 2000s indicated that metropolitan areas in Bangladesh were generating 58.4 million tons of solid waste annually, or roughly 16,015 tons per day (Bahauddin & Uddin, 2012). According to projections, this amount will rise to 47,000 tons per day, or 17.2 million tons annually, by 2025, primarily as a result of population growth and an increase in the rate at which waste is produced per person (Bahauddin & Uddin, 2012). The average per capita waste generation is found to be roughly 0.41 kg per capita per day when taking into account the population of the six largest city corporations in Bangladesh, namely Dhaka, Chittagong, Khulna, Sylhet, Rajshahi, and Barishal (Ahsan et al., 2014). According to a different study done in 2013, the urban population of 36.9 million people produced about 5,200,919 tons of municipal solid waste (MSW) annually, or 0.35 kg per person per day (Ashikuzzaman & Howlader, 2019). Waste-to-Energy (WTE) incineration is playing a significant role in producing renewable energy from discarded municipal solid waste (MSW) in order to meet the energy needs of urban populations and address the limited area available for new landfills. However, efficient electricity generation through incineration is hampered by MSW's low calorific value and high water content. In Bangladesh, there is a comparatively higher percentage of organic matter (74.6%) in MSW than there is of paper (9.1%) or plastic (3.5%) (Zakir Hossain et al., 2014).

With a population of about 2.67 million, Gazipur City Corporation (GCC) now retains the title of being the largest among the 12 city corporations in Bangladesh in terms of area (GCC, 2023). The GCC's overall waste generation rate was calculated to be 0.358 kg per person per day. The city corporation now only uses waste collection and disposal as solid waste management techniques.Multiple secondary dumping sites are dispersed throughout GCC in various zones. The waste is collected from these locations and transported to the final disposal site by GCC's conservancy department. The procedure is less efficient and more expensive because there isn't a waste separation between main and secondary disposal. As a result, the possibility of resource recovery is reduced because reusable and recyclable goods are not separated from solid waste. Data on the availability of resource recovery options particular to this city are missing from earlier work. This emphasizes the requirement for additional investigation and analysis to examine possibilities for putting resource recovery ideas into practice within Gazipur City Corporation.

1.2 Problem Statement and Objectives of the Study

As the largest city corporation, GCC is confronted with the daunting task of controlling the sharp increase in waste production brought on by population development. The city corporation authority is currently struggling to manage the massive volume of waste that is daily building up in two unsanitary landfills. A crucial chance to turn this enormous waste pile into useable resources is being lost because there isn't a waste-to-energy facility nearby. Municipal solid waste can be properly dealt with in the long run by creating a thorough management strategy and installing a waste-to-energy process in GCC. The following goals have been pursued in order to fulfill the main research goal:

1. To estimate the volume, composition and other characteristics of municipal solid waste (MSW) produced in the GCC.
2. To evaluate the GCC's MSW-based potential for resource recovery and energy production.
3. To find and assess appropriate waste-to-energy conversion technology for use in the GCC.

1.3 Scope and Limitations of the Study

Numerous research investigating the potential of waste-to-energy processes have been carried out in several major city corporations around the nation. Even though it is the largest city corporation in the nation, the one in question has not been the focus of any such inquiries. Unfortunately, there is presently no access to specific waste generation statistics for GCC commercial places, industries, institutions, and street sweeping operations. As a result, the only focus of this study is on the energy potential of waste generated from household and local bazaars. In order to get insight into the energy potential within GCC's waste heaps, the predicted waste generation data from this study is then contrasted with secondary data and earlier studies. The precise procedures, expenses, or design criteria connected with resource recovery methods, landfill site design, or other treatment choices are not thoroughly explored in this study. Instead, determining the energy potential within GCC and the viability of transforming its huge volume of waste into useful energy resources is the main goal.

1.4 Layout of the Thesis

The thesis is divided into seven in-depth chapters, including a literature review, results, an analysis of the current solid waste management system, and suggestions. A list of references has also been included.

Chapter 1 serves as an in-depth exploration of the background and objectives of the study.

Chapter 2 delves into the global and local aspects of the solid waste generation, composition, moisture content, calorific value, ash content, resource recovery found on the literature. In this chapter, extensive discussion about waste-to-energy process is provided. Details about the study area is also discussed here.

Chapter 3 presents a thorough methodology outlining all the procedures involved such as laboratory set up, taking measurements, standards and analysis of the test samples.

Chapter 4 focuses on the results and analysis of the experiments that were performed. It includes an examination of the composition, moisture contents, calorific value, ash content of municipal solid waste which are then compared with finding from previous studies.

Chapter 5 This chapter encompasses the conclusions drawn from experiments and analysis conducted for Waste-To-Energy option. It includes key findings and offer recommendations based on the study’s outcomes.

Chapter 2: Literature Review

2.1 General

According to common understanding, MSW includes all waste produced by the community but does not include sewage sludge, agricultural solid waste, or waste from industrial processes. Food wastes, yard wastes, containers and packaging, durable and non-durable items, and other inorganic wastes from residential, commercial, and institutional sources are all included in the U.S. Environmental Protection Agency's (EPA) definition of MSW. Appliances, books, clothing, newspapers, food scraps, cardboard boxes, paper products for offices and classrooms, wooden pallets, rubber tires, and cafeteria waste are a few examples of objects that fall into these categories. Municipal solid waste output is estimated to increase to 3.4 billion tonnes by 2050 from the current astonishing annual production level of 2.01 billion tonnes. Food and other organic waste make up just 32% of the total waste in high-income countries, whereas dry waste that may be recycled—including plastic, paper, cardboard, metal, and glass—makes up 51% of the waste. Food waste and green waste are produced in middle- and low-income countries at rates of 53% and 56%, respectively, with organic waste rising as economic development declines. Most waste nowadays is either dumped or disposed of in landfills around the world. In landfills, about 37% of waste is disposed of, and 8% of that is handled in sanitary landfills with landfill gas collection systems. 33 percent of waste is dumped openly, 19 percent is recycled or composted, and 11 percent is burned as the last resort. According to estimates, solid waste treatment and disposal operations in 2016 released over 1.6 billion tonnes of greenhouse gases equal to carbon dioxide (CO2) due to their size, content, and methods of management. Open dumping and landfill disposal without landfill gas collecting equipment are the main causes of this. Approximately 5% of world emissions come from these sources. By 2050, it is predicted that solid waste-related emissions will reach 2.6 billion tonnes of CO2-equivalent year absent improvements in the industry (What a Waste 2.0, World Bank).

2.2 Waste Generation

The generation and characterization of solid waste are among the key factors that impact the sustainability of the environment. (Ozcan et al., 2016). Population growth, urbanization, and economic development trigger the escalation of MSW generation (Kumar & Samadder,2017). Annually, the world produces a staggering 2.01 billion tonnes of municipal solid waste. On average, each person generates 0.74 kilograms of waste per day, but this number varies significantly, ranging from 0.11 to 4.54 kilograms. Although high-income countries represent only 16 percent of the world's population, they generate about 34 percent (683 million tonnes) of the world's waste. Experts predict that global waste will touch 3.40 billion tonnes by 2050 (What a Waste 2.0, World Bank). The amount and type of municipal solid waste produced by a community are closely associated with various socioeconomic factors. The medium socioeconomic groups generate the highest volume of solid waste (Khan et al., 2016). It is estimated that by 2050, daily per capita waste generation in high-income countries will increase by 19 percent, while low- and middle-income countries are expected to experience an increase of approximately 40 percent or more (What a Waste 2.0, World Bank). The prevailing factors affecting waste generation statistics are economic development and geographical latitude, which correspond to different climate conditions (Denafas et al.,2014). More waste is typically produced during the wet season due to the increased availability of vegetables, resulting in a higher volume of vegetable waste (Getahun et al., 2012).

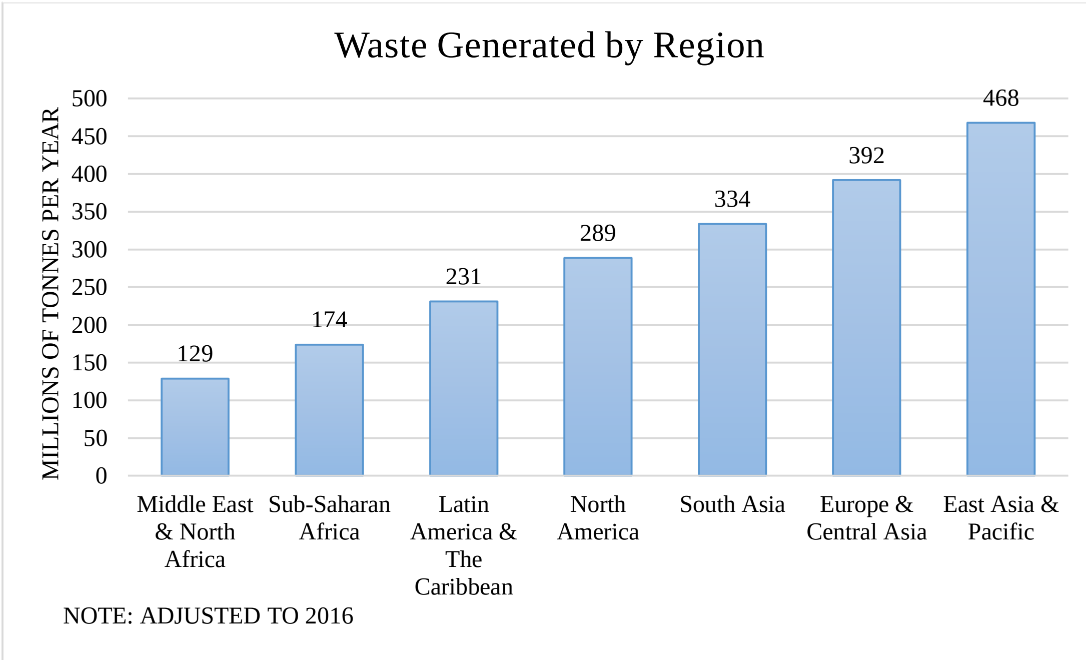

Figure 2. 1: Waste Generated by Region Worldwide

2.3 Bazaar Waste:

Bazaar waste has the potential to serve as an untapped source of renewable energy in our country. Given the high volume of waste generated regularly, much of which comprises fruit and vegetable waste, this waste stream holds significant promise for energy recovery. Anaerobic digestion (AD) of fruit and vegetable waste represents an optimal solution for waste management. By diverting this waste stream away from landfills and instead converting it into biogas, the volume of waste requiring disposal can be significantly reduced. Furthermore, if biogas is used as an internal source of energy, it can generate economic benefits in addition to its value as a renewable fuel (Morales-Polo et al., 2019). Kolkata, the fourth largest city in India in terms of solid waste generation, comprises 36.37% of market waste. Specifically, vegetable market waste is the largest contributor, with an estimated daily generation of 1090 tonnes within the city (Hazra & Goel,2009). Converting vegetable market waste (VMW) into energy briquettes represents a promising opportunity for waste valorization. The calorific values of these briquettes varied between 10.26-16.60 MJ, indicating their potential as a viable energy source (Srivastava et al., 2014). In a country like India, it is estimated that between 25-30% of all fruits and vegetables are wasted or spoiled during handling, transport, and retail marketing (Srivastava et al., 2014).

2.4 Waste Composition

Municipal solid waste (MSW) is typically measured and classified based on its source of generation or the type of material that comprises its physical composition (Shi et al., 2016). The composition and quantity of solid waste vary depending on several factors, including the location where it was generated, the season, people's lifestyles, social factors, economic structure, nutritional habits, and regulations related to waste management and recovery (Ozcan et al., 2016). Weather and seasons are known to have an impact on the composition of waste components (Hla & Roberts, 2015). To accurately estimate its recycling potential and ensure effective management of the entire system, it is necessary to characterize and analyze the composition of the Municipal Solid Waste (MSW) stream (Saidan et al., 2017).

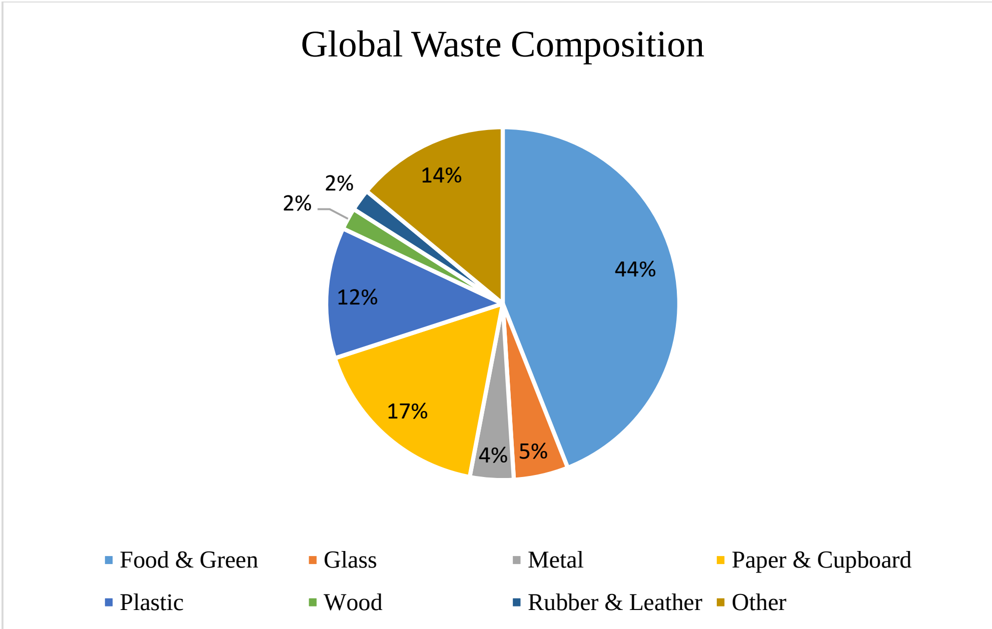

Figure 2. 2: Global Waste Composition by Percentage

2.5 Waste-To-Energy Techniques

1. Incineration: At first, incinerators were mainly used to reduce volume and get rid of dangerous waste to protect the environment and the workers. Energy recovery, however, wasn't the main priority (Brunner and Rechberger, 2015). In industrialized countries, especially, incineration has become a practical waste treatment alternative thanks to the development of air pollution control technologies (Psomopoulos et al., 2009; Ouda et al., 2016; Kumar & Samadder, 2017). Waste with a high calorific value is best burned in an incinerator. It needs a sizable amount of land, ideally inside city limits (Kalyani & Pandey, 2014). The overall conversion efficiency of the incineration process, which has a typical service life of 30 years, is 0.5 MWh per ton of municipal solid waste (MSW). Mixed MSW is accepted as an input by this process. Heat and electricity are hence the final byproducts of this process (Islam, 2016). However, this approach is not appropriate for waste that contains chlorinated compounds, has a high moisture level, or has a low calorific value. Incineration comes with significantly high operating, maintenance, and capital expenditures. Additionally, in order to complete this procedure successfully, trained employees are required (Kalyani & Pandey, 2014).

2. Anaerobic Digestion: Anaerobic digestion is a biological process that involves the microbial degradation of organic, biodegradable matter in the absence of oxygen, resulting in the production of biogas as the end product (Kumar & Samadder,2017). Solid waste materials that have high moisture content, such as food waste, vegetables, and other organic matter, are highly suitable for anaerobic digestion (Habib et al., 2016). To ensure the proper operation of anaerobic digestion, it is crucial to maintain a stable environment for the growth of different microorganisms. This requires careful monitoring and control of key parameters within the correct range throughout the AD process (Morales-Polo et al., 2019), (Hawkes, F.R., 1980). According to reliable estimates, regulated anaerobic digestion of 1 tonne of municipal solid waste (MSW) can produce 2-4 times more methane within a 3-week period compared to the amount produced by 1 tonne of landfill waste over a period of 6-7 years (Ahsan, N., 1999). The efficiency of the anaerobic digestion process depends greatly on the influent substrate's carbon-to-nitrogen (C/N) ratio (Zhang et al., 2014). In order to ensure optimal digestion, it is important to maintain the pH of the system within a proper range. Typically, this falls within the neutral range of 6.5 to 7.6 (Labatut & Pronto, 2018). With an estimated service life of around 20 years, the anaerobic digestion process exhibits an overall conversion efficiency of 0.15 MWh per ton of municipal solid waste (MSW). Sorted MSW is needed for this procedure' input. As a result, this process produces heat, power, and liquefied natural gas (LNG) as its byproducts (Islam, 2016).

3. Pyrolysis: Pyrolysis is a technologically advanced thermal treatment process which takes place between 400-800°C in the absence of oxygen. The amount and quality of the pyrolysis gas, oil, and char that are produced are largely dependent on variables including the heating rate, process temperature, residence duration, waste content, and particle size (Lombardi et al., 2015). The pyrolysis process has an estimated service life of 20 years and an overall conversion efficiency of 0.3 MWh per ton of sorted municipal solid waste (MSW). Sorted MSW materials are the input for this procedure. As a result, liquid, oil, and char are the final byproducts of pyrolysis (Islam, 2016). Notably, the use of pyrolysis in the recycling of used tires has recently attracted a lot of attention because it makes it possible to recover oil, wire, carbon black, and gas (Lombardi et al., 2015). There is still little study on energy recovery from municipal solid waste (MSW) utilizing pyrolysis at a commercial scale, despite the fact that pyrolysis exhibits great performance in treating some waste streams (Kumar & Samadder, 2017).

4. Gasification: Gasification is a specialized thermal conversion technique that involves the carefully regulated conversion of organic molecules into syngas at high temperatures in an oxygen-rich atmosphere. The main byproduct of the gasification process is syngas, which may be burned to provide energy (Kumar & Samadder, 2017). Additionally, it has the potential to function as a priceless feedstock for the manufacture of chemicals and the generation of liquid fuels (Yap and Nixon, 2015). Although the majority of the studies on gasification that have been published have been on homogenous solid fuels like coal and wood as well as particular categories of municipal solid waste (MSW), gasification has historically been employed extensively in the coal sector. It has, however, just lately come to light as an MSW energy recovery solution (Arafat and Jijakli, 2013). With a projected service life of over 20 years, the gasification process boasts an exceptional total conversion efficiency of 0.9 MWh per ton of sorted municipal solid waste (MSW). Sorted MSW is needed for this procedure' input. As a result, the final products of this process are ethanol, methane, hydrogen, and electricity (Islam, 2016).

5. Landfilling: Sanitary landfilling is a controlled waste disposal technique that entails dumping waste on land to reduce any adverse environmental effects and to enable the recovery of biogas and efficient leachate management (Kumar & Samadder, 2017). On the other hand, unhygienic landfilling offers a quicker and less expensive option for getting rid of growing amounts of waste, especially in developing nations. Unfortunately, according to Wang and Geng (2015), this behavior seriously endangers the ecology. Waste disposal occurs in low-lying areas beyond the city limits of many cities in developing nations. Studies (Kumar and Chakrabarti, 2010; Talyan et al., 2008) have noted this. Unsanitary landfilling could be able to temporarily address waste management issues, but it doesn't offer the same environmental protections or long-term sustainability as sanitary landfilling (Kumar & Samadder, 2017). Since highly qualified workers are not always needed, landfilling is a very simple procedure to put into practice. Additionally, landfilling techniques can be used to convert marshy regions into useful spaces. Notably, the breakdown of waste in landfills can result in gas production in a controlled environment. The potential for energy recovery and utilization is increased by the efficient use of this generated gas for direct thermal uses or power generation (Kalyani & Pandey, 2014). With an estimated service life of between 30 and 50 years, the landfill gas recovery process boasts an overall conversion efficiency of 0.23 MWh per ton of municipal solid waste (MSW). This procedure accepts MSW that has been sorted or mixed as input. Consequently, the final products of this process are liquefied natural gas (LNG), heat, and power (Islam, 2016).

2.6 Current Waste-To-Energy Local & Global Scenario:

The goals of waste management are- 1. hygeinisation, 2. Volume reduction, 3. Environmental protection, 4. Mineralization and immobilization of hazardous substances, 5. Resource conservation, 6. Affordable costs and public acceptance (Brunner & Rechberger, 2015). There are currently an estimated 765 energy-from-waste plants worldwide that process municipal solid waste (MSW), with a combined annual capacity of 83 million tonnes. Of these plants, 455 are located in the European Union, while the United States operates 86 facilities (as of 2011-2012) and the People's Republic of China has 150 plants (as of 2014) (Global Waste Management Outlook, UNEP, 2015). Currently, the electricity network covers approximately 33% of the total population, while only 4% is covered under the natural gas network. Interestingly, around 82% of the total electricity generated comes from natural gas as a source (Iqbal et al., 2014). The estimated energy demands for the future are expected to reach 19,000 MW by 2100 and 34,000 MW by 2030 (Mosharraf et al., 2020). The incineration of MSW in Bangladesh can be challenging due to its low calorific value and high water content (Zakir Hossain et al., 2014). Through the landfill gas recovery process, it is possible to generate electricity from MSW in six major cities at a rate of 186,408 kW h/day (Zakir Hossain et al., 2014). After considering various factors such as waste quality and quantity, cost-effectiveness, limited environmental impact, and high potential for energy recovery, stakeholders have identified Anaerobic Digestion (AD) as the best option for waste-to-energy conversion in Chittagong, Bangladesh. The second most preferred technology is Landfill Gas (LFG), which has received 27% of the stakeholder's preference. Gasification and incineration were the third and fourth most favored options, respectively, receiving 21% and 14% of the preference. It is worth noting that LFG will become the most popular solution for waste-to-energy conversion if the economy prioritizes it more than the current preference of 38% (Alam et al., 2022).

2.7 Moisture Content:

The moisture content of municipal solid waste (MSW) varies depending on the type of material (Shi et al.,2016). Generally, the moisture content of solid waste ranges between 15% and 40%. The average moisture content, which can be affected by regional characteristics and socio-economic factors, is reported to be around 20%. However, the moisture content may occasionally reach up to 60% to 70%, depending on the composition of the waste and local climate conditions (Ozcan et al., 2016), (Hui, Y,. 2006), (Tchobanoglous, G., 1993). The presence of a high percentage of organic matter in municipal solid waste (MSW) can be a significant factor contributing to the increased moisture content. As the income level increases, the moisture content of solid waste tends to decrease (Ozcan et al., 2016).

2.8 Calorific Value:

The heating value or calorific value is one of the crucial parameters used to determine the energy content of MSW (Kumar & Samadder,2017).

The energy content of a substance is described using various terms such as HHV, lower calorific value, net heating value, and gross heating value in the literature (Kathiravale et al., 2003). However, inconsistent reporting of these terms creates ambiguity and makes it difficult to compare the reported values. Although these terms are interrelated, the lack of consistency in reporting them can cause significant problems in accurately assessing the energy content of a substance. The literature also exhibits inconsistency in the units used to report the energy content, with various units such as Kj/kg, kcal/kg, Btu/lb, etc. being employed. This inconsistency can make it challenging to compare reported values (Kathiravale et al., 2003). Additionally, some data provide the HHV of individual components as well as a weighted average HHV based on their weight percentages, while others only report the HHV of mixed municipal solid waste (MSW) on a commingled basis. Such variations in reporting can further contribute to the difficulty in accurately assessing the energy content of a substance (Kathiravale et al., 2003). The heating or calorific value of a substance can be measured using a bomb calorimeter or calculated using an empirical model. However, not all MSW management facilities are equipped with bomb calorimeters to determine heating values. Furthermore, experimental measurements of heating values can be cumbersome and require advanced technical skills in handling equipment. The most commonly used method for calculating heating values is the equation developed by Dulong (Kathiravale et al., 2003). However, the Dulong model was originally derived for coal and may not be suitable for estimating the heating value of MSW due to the physical and chemical differences between coal and MSW. Similarly, other advanced models derived for coal or biomass are also not appropriate for estimating heating values in MSW (Kathiravale et al., 2003). Accurate and reliable heating value data are crucial for designing, operating, and maintaining a WTE plant effectively (Shi et al., 2016). According to an extensive study carried out by Tan et al. in 2015 in Malaysia, when considering the production of both electricity and heat, incineration emerged as the most advantageous waste-to-energy alternative based on energy, economic, and environmental assessments. However, anaerobic digestion (AD) was discovered to be a more advantageous process when concentrating only on energy generation. Similar to this, Qazi et al.'s 2018 study in Oman assessed a number of factors and came to the conclusion that anaerobic digestion is the best waste-to-energy technology for the nation. Anaerobic digestion had important advantages in terms of its environmental, economic, and social impact, and was followed by fermentation and incineration. According to Perrot & Subiantoro in 2018, anaerobic digestion became the most appealing waste management option in New Zealand. Its attractiveness was influenced by its cost-effectiveness, environmental friendliness, and compatibility with the nation's current waste management plan. Another investigation by Ouda et al. in Saudi Arabia in 2016 concentrated on the financial benefits of waste-to-energy technologies. They discovered that the most cost-effective choice was anaerobic digestion technology, especially in light of the high moisture content (38.72%) of food waste, which accounts for a sizeable fraction (37%) of the total municipal solid waste

(MSW). Higher efficiency, cheaper capital costs, and lower operating costs were all proved by this technology.

2.9 Resource Recovery

Recycling is the reprocessing of waste either into the same material (closed loop recycling) or a different material (open loop recycling). Another form of recycling is composting. Collected from the biological decomposition process of organic waste into humas, a soil-like material is known as composting (Alamgir & Ahsan., 2007). The USEPA (1996) recommends that recycling be the top priority option used in an integrated solid waste management system. On the other hand, resource recovery involves thorough separation of individual waste components by householders, commercial establishment, and industry of municipal institutions (Pichtel, 2005). It is believed that assessment of waste composition and available recyclable quantities facilitates well-organized and smooth functioning of recycling programs. Ultimately, this reduces the amount of waste generated, thereby reducing total waste management costs. (JP Parfitt, 1997). Studies have shown that, in developing countries, both economic concerns and moral obligations influence recycling and resource recovery outcomes at the household level. (Nyborg et al., 2006). A study result demonstrated that the best scenario is that one including the highest separate collection rate technically and economically feasible to be carried out i.e., 60%, the recourse to anaerobic digestion and biogas production to treat the biowaste separately collected and the maximization of the re-processing of recyclable materials such as PET, HDPE, glass, metals etc. In particular, the Global Warming Potential decrease of 166% and the Eutrophication Potential decrease of 646%, when the alternative scenario, including the recalled features is compared to the usual waste management process (Cremiato et al., 2018). However, the number of materials that can be recovered from the MSW in Bangladesh is about 70% (Alamgir & Ahsan., 2007) The result of the study indicated a high recovery factor for dry recyclables (53.97%) as against food waste (10.03%). (Asare et al., 2020). The potential for waste recovery and reduction based on the waste characteristics are evaluated and it is predicted that 21.64 million US$/year can be earned from recycling and composting of municipal solid waste (Alamgir & Ahsan., 2007). For this resource recovery various techniques are all over the world. Studies have shown that it is better to separate recyclable materials at the source of generation than the separation of mixed waste at a material recovery facility, as cleaner and higher quality materials are produced through sorting at source. (G Nepomuceno, 2002). Hand picking and optical sorting may also be used for more selective separation (Rotter, 2011). Beside those Material recovery facilities can also be installed. Material recovery facilities (MRFs)The most adopted waste management strategy to process municipal solid waste (MSW) (Velis et al., 2010) and refuse from commercial and industrial (C&I) or from construction and demolition (C&D) sources. An important goal of a MRF is to reduce the waste volume and mass before sending it to a landfill. (Vrancken et al., 2017). Material recovery facilities (MRFs) and mechanical-biological treatments (MBTs) are often used by municipalities to process mixed municipal solid waste (MSW), in order to increase resource recovery, as complement or replacement to source-separated collections (Cimpan et al., 2015; Jansen et al., 2013)

2.10 Study Area

Gazipur City Corporation, situated in Gazipur district in central Bangladesh, is a local government body responsible for municipal administration. Gazipur City Corporation is unique among the nation's city corporations in that it was founded recently and is the largest in terms of area. It is divided into 5 zones such as Tongi (zone 1), Gacha & Pubail (zone 2), Gazipur (zone 3), Basan & Koyaltia (zone 4), Konabari & Kashimpur (zone 5). Its vast 329.53 square kilometer area is bordered to the north by Mirzapur Union of Gazipur Sadar Upazila, to the south by Dhaka North City Corporation and Yarpur Union of Savar Upazila, to the east by Bariya Union of Gazipur Sadar Upazila, to the west by Shimulia and Savar Upazila in Damsona Union, and to the east by Nagri Union of Kaliganj Upazila. The Gazipur City Corporation has a population of about 6.5 million people. It is a substantial administrative entity and has 57 wards. Notably, this region, which is home to around 75% of the country's garment manufacturing business, is important to the garment industry.

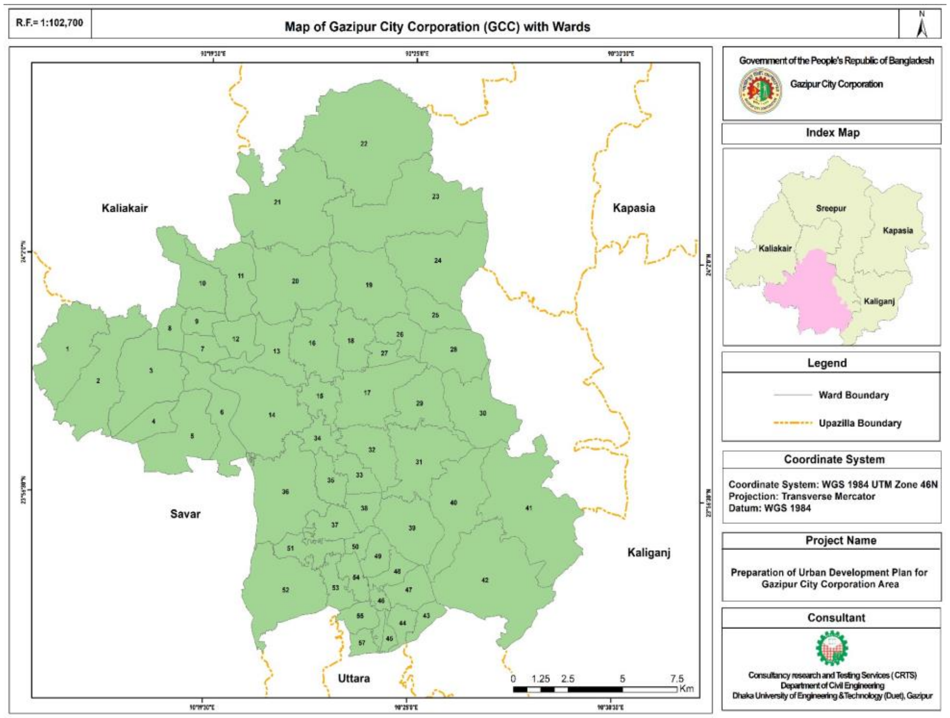

Figure 2. 3: Maps of Gazipur City Corporation (GCC)

2.10.1 Current Conditions of GCC

There are currently 76 ward councilors in GCC who are in charge of administration. A sizable road network, measuring over 1552.83 km in length, is present in the area. A total of 552 culverts are strategically placed throughout the region, and the drainage system has a total length of 670.53 km. The literacy rate of GCC is 64.4% (JICA, 2021). In terms of educational establishments, the GCC is home to 126 madrasas, 52 high schools, 3 government colleges, 3 private colleges, and 5 universities. There are 64 slums, 95 private markets, 23 daily markets, 18 poura marketplaces, and 23 poura markets for commercial activity. In addition, the area has 11 churches, 835 mosques, 835 mandirs, and 55 banks to accommodate people' religious needs. GCC offers access to 26 family planning clinics, 36 private clinics, and 1 government hospital in terms of healthcare amenities. There are nine cinema halls available for entertainment in terms of recreational services. Additionally, a sizable portion of residences in the GCC, namely 11,895 households, have access to water and sanitary facilities (GCC, 2023).

2.10.2 Solid Waste Management of GCC

The GCC's current solid waste management system consists of 92 dustbins that are thoughtfully positioned all across the area. Additionally, the GCC has one medical waste collection van and about 50 slide waste collection vans that are in use. In 2020, the expected daily municipal waste generation rate varies between 3000 and 4000 tons, according to data released by GCC. GCC maintains a daily collection efficiency of 60–70%, managing to collect about 2400–2500 tons of the entire waste produced. Six of the 15 authorized secondary disposal sites (SDSs), which are dispersed throughout different zones and are available permanently, have been established by GCC to help with waste disposal (Field Survey, 2020). According to a field study completed in 2020, there are over 200 non-designated SDSs dispersed throughout the GCC where homeowners and waste collectors dump rubbish. There are two unclean landfills in GCC, one in Kodda (1 ha) and the other in Gacha. The quantity of waste produced in the GCC as a whole, including home, commercial, industrial, and street sweeping debris, is roughly 2500 tons. Day and night shifts are used to collect waste, with each covering half of the collection area. There are 25 transfer stations altogether in the area. Open dumping methods are regrettably still common. Only 4 of the 35 intended members for the GCC's solid waste management section are now actively involved (JICA, 2021). According to the data supplied by JICA in 2021, the GCC also does not currently have a specific team for the handling of medical waste.

Chapter 3: Materials & Methodology

3.1 Sample Collection & Composition Determination:

The whole study area was divided into five zones. Samples were taken randomly from the waste collection vans or trucks from secondary or final dumping sites of each zone. For sampling, 10kg samples were collected from each zone at a time. The samples were collected in a way that they were representative of a large waste pile at the dumping site. A total of 100kg samples were collected and sorted out. Samples were collected in two cycles in dry seasons.

Table 3. 1: Sampling Cycles

Cycle	Zone	Date
1	Zone 1	8 November, 2022
	Zone 2	12 November, 2022
	Zone 3	5 December, 2022
	Zone 4	15 December, 2022
	Zone 5	24 November, 2022
2	Zone 1	3 February, 2023
	Zone 2	13 February, 2023
	Zone 3	25 February, 2023
	Zone 4	8 March, 2023

	Zone 5	13 March, 2023

Questions were asked of the waste collection workers to get an idea from which zone and ward the wastes came. For bringing out waste from the vans or trucks and weighing them, polythenes were used. Hand gloves and face masks were used for safety purposes due to the presence of potentially hazardous materials and foul smells. For getting an accurate composition, the quartering and cone method was used. 10kg samples were spread out on a plastic sheet and mixed to ensure a heterogeneous composition.

Figure 3. 1: Sorting of MSW

Then they were thoroughly mixed, piled into a cone shape, and separated into four portions manually, each consisting of 2.5 kg. Instead of taking one and discarding the rest of the portions, all of them were used for composition purposes. Each quarter consisted of organic waste, plastics, papers, glass, wood, rubber, etc. and they were separated, weighed individually, and noted down. For weighing purposes, two types of weight machines were utilized for accurate results. Human fecal matter and animal waste were excluded from our sample collection work. Samples were sorted on-site in a suitable place near the dumping station.

Table 3. 2: Waste Category in Sampling

Waste Category	**Types**
Organic Waste	Garden/Yard Waste
	Food/Kitchen Waste
Inorganic Waste	Papers
	Plastics/Polythenes
	Rubber
	Leather
	Textiles & Woods
	Glass
	Metals/Tins
Hazardous Waste	Battery
	Aerosol Cans
	Medical Waste

3.2 Moisture Content Determination:

After sampling, one-quarter of the 10kg sample was taken randomly. From there, 0.5kg samples were separated composed of mainly organic waste to put in the oven for moisture content determination. Papers, plastics, wood, etc. were not placed in the oven considering the potential danger. They were dried out in the air for several days for getting the overall moisture content of the municipal solid waste. The standard used to determine the moisture content of the waste sample was ASTM Standard E 871-82 (ASTM,2013). Samples were put in the oven for 24 hours at 103 +- 1-degree Celsius temperature. After 24 hours, they were brought out from the oven and kept at room temperature for 30 mins. They were weighed down again after cooling down to get the moisture content. The formula used in the process is:

Moisture Content = [(A – B)/A] x 100

A = Initial weight of the sample

B = Weight after oven dry

3.3 Calorific Value Determination:

Oven-dried samples of MSW were ground and cut down into smaller pieces and then sieved by a 5-mm sieve for experiment purposes. For determining the higher heating calorific value of the solid waste sample when burnt at constant volume, a bomb calorimeter was used.

Figure 3. 2: Bomb Calorimeter

The standard used to determine the moisture content of the waste sample was ASTM Standard D 56-D1660. 1.9 kg of water was used in this experiment each time and the water equivalent of the calorimeter was 432 gm. Approximately 1-1.5g of oven-dried ground waste samples were put in a crucible which was then placed inside the bomb calorimeter and burnt.

Figure 3. 3: Waste Sample for Combustion

The fuse wire was attached and placed in the crucible in a way that it covered the maximum surface of the sample and didn't touch the wall of the crucible. The bomb was closed and charged at a maximum pressure of 20 atm. The stirrer was started and done continuously. After 3 or 4 mins, the temperature was recorded every minute for 5 mins. Then the firing switch was closed and the temperature was recorded in 30-sec intervals until it reached the maximum temperature. When the temperature became constant and started decreasing after a while, the bomb calorimeter was removed and the unburnt fuse was collected. The higher heating value of the waste samples was determined using this formula:

Heating Value = Heat absorbed by Calorimeter - Heat from fuse wire.

3.4 Potential Power Generated from MSW:

Steam energy was obtained from higher heating calorific value, estimating that 70% of heat energy could convert into steam energy.

$E_S = 0.7 \times E_{H,}$

Where, Es = Steam energy obtained,

Eh = Heat energy.

Then using steam energy electrical power energy was determined which was later used for obtaining station service allowance.

$11395\ E_P = E_{S,}$

Where, E_P = Electrical Power,

$S_A = 0.06 \times E_{P,}$

Where, S_A = Station service allowance,

$U_H = 0.05 \times E_{P,}$

Where, U_H = Unaccounted Heat Loss,

Finally, the net power generation was determined using the following formula.

$E_{NP} = E_P – (S_A + U_H)$

Where, E_{NP} = Net Electrical Power.

3.5 Ash Content Determination:

The ash content of solid waste was determined by using this formula:

% Ash = (Weight of capsule and residue – tare weight of capsule) * 100/ mass of sample; where the units are in gram.

3.6 Resource Recovery from MSW:

To compare the revenue produced by using the 3R approaches with the operation cost per ton of solid waste, an economic study was done. The annual revenue from resource recovery and the annual earnings from fuel cost reductions as a result of volumetric reduction were added together and divided by the annual waste generated in tons to determine the revenue from 3R approaches, measured in BDT per ton. On the other hand, the yearly operation cost, which is likewise expressed in BDT per ton, was calculated by dividing the total of the costs for salaries, fuel, repairs and maintenance, and other expenses by the amount of waste that was produced annually, expressed in tons.

3.7 Solid Waste Generation Projection:

Population projection was done using annual growth and waste generation was projected using this formula:

$$PWG = [\{PBY*(1 + CAGR)^{N}\}*(PCWB+PCWB*WGG)]/1000$$

PWG = Projected waste generation (tons/day)

PBY = Population in baseline year

CAGR = Compound annual growth rate of population

PCWB = Per capita waste generation in baseline year (kg/capita/day)

3.8 Identifying Proper WTE Technology:

Based on the moisture content, calorific value, ash content, waste composition suitable wte technology was proposed in this study.

Chapter 4: Results & Discussions

4.1 General

The study's outcomes and conclusions are presented in this chapter, covering population estimates, waste generation, waste composition, moisture content, higher heating calorific value, and net electrical power of solid waste in the GCC region. Additionally, it thoroughly studies the current waste management situation in the GCC and suggests appropriate waste-to-energy solutions based on various circumstances. The chapter concludes by analyzing each technology's payback period to determine its economic viability.

4.2 Population Estimation & Solid Waste Generation

As the largest city in Bangladesh, GCC has a sizeable population, which leads to enormous waste generation. Waste generation and population number are intimately related. Choosing the best waste-to-energy technologies, and evaluating the possibility of resource recovery all depend on the precise estimation of population distribution throughout various zones. A key indicator of the region's ability to produce electricity is the amount of solid waste that is produced.

Table 4. 1: Population Projection of GCC

Zone	2016	2021	2023	2026	2036
1	650597	805997	867526	959819	1207106
2	448944	556177	598635	662323	832963
3	244528	302935	326061	360750	453693
4	347144	430064	462894	512139	644086
5	326343	404924	435156	481450	605490
Total	2017556	2499468	2690273	2976481	3743338

In our study, the projected population of GCC for the year 2023 is determined to be 2,690,273, which closely aligns with the value of 2,674,697 obtained from the housing and census data of 2022 for GCC. Subsequent population increases are expected, as the housing and census survey of 2022 was conducted in the past.

Table 4. 2: Waste generation projection of household waste of GCC (tons/day)

Zone	2016	2021	2023	2026	2036
1	218	281	311	353	469
2	175.5	229	250	288	382
3	91.5	122	131	153	203
4	115	150	163	188	250
5	117.5	154	167	193	257
Total	717.5	935	1022	1175	1561

In our study, the projected household waste generation of GCC for the year 2023 is determined to be 1022 tons/day, whereas the entire waste generation of GCC which includes household, industrial, commercial, and street sweeping waste was found to be 2500 tons/day.

4.3 Composition of Solid Waste

A range of factors, including the climate, socioeconomic conditions, and others, have a considerable impact on the composition of solid waste in different regions and cities. Designing adequate collection trucks and choosing proper waste treatment techniques require a thorough understanding of the composition of the solid waste in a given area. In our study, organic waste—which mainly consists of food and yard waste—was found to be the prevailing type of waste in the GCC. Additionally, all zones regularly contained combustible waste types such as paper, plastics, and textiles. Across all zones, it was common to find small quantities of non-combustible materials like glass, metal, wood, rubber, leather, and medical waste.

4.3.1 Composition of Solid Waste from Household

Table 4. 3: Waste generation projection of household waste of GCC (tons/day)

	Composition (% by weight)								
Cycle	**Food & Yard Waste**	**Paper**	**Plastics/ Polythene**	**Glass**	**Metal**	**Textiles & Wood**	**Rubber & Leather**	**Others**	**Total**
Average in Dry Season									
Cycle 1 (November-December)	77.03	5.65	8.21	0.96	0.86	4.51	0.40	2.35	100.00
Cycle 2 (February-March)	75.58	5.82	8.70	2.06	0.60	5.05	0.65	1.55	100.00
Average	76.31	5.73	8.46	1.51	0.73	4.79	0.53	1.95	100.00

The two cycles of our study were cycle 1, which was conducted in the colder months, and cycle 2, which was conducted as summer was about to arrive. The percentage of organic waste was found to have marginally decreased during cycle 2, which may have been caused by moisture evaporating as a result of the increased temperatures. In contrast, cycle 2 saw a significant increase in the proportion of glass components, which is probably related to summer's higher use of glass materials. Additionally, cycle 1 had a higher percentage of medical waste, which suggests that cold-related illnesses were more common at that time.

Table 4. 4: Zone wise waste composition of MSW of GCC

	Composition (% by weight)								
Zone	**Food & Yard Waste**	**Paper**	**Plastics/ Polythene**	**Glass**	**Metal**	**Textiles & Wood**	**Rubber & Leather**	**Others**	**Total**
Average in Dry Season (From 2 Cycles)									
1	77.93	4.42	7.88	1.13	0.41	5.11	1.59	1.54	100.00
2	74.39	7.01	7.82	1.16	0.83	6.30	-	2.49	100.00
3	76.04	5.15	9.32	2.73	1.60	3.38	-	1.78	100.00
4	77.97	5.65	8.61	1.38	0.19	4.34	0.59	1.29	100.00
5	75.20	6.44	8.65	1.14	0.64	4.81	0.46	2.66	100.00
Average	76.31	5.73	8.46	1.51	0.73	4.79	0.53	1.95	100.00
Variance	2.59	1.05	0.39	0.48	0.29	1.61	0.42	0.36	-
Standard Deviation	1.61	1.03	0.62	0.69	0.54	1.50	0.65	0.60	-

In our study, it was observed that food and yard waste, paper waste, and plastic waste, which together account for almost 90% of all waste kinds, make up a substantial component of the GCC's waste stream. Following these major waste categories, textile waste makes up a sizable portion of total waste. In our study, medical waste is included in the category of "other types of waste," and it was found that it is frequently disposed of without taking appropriate precautions in all zones.

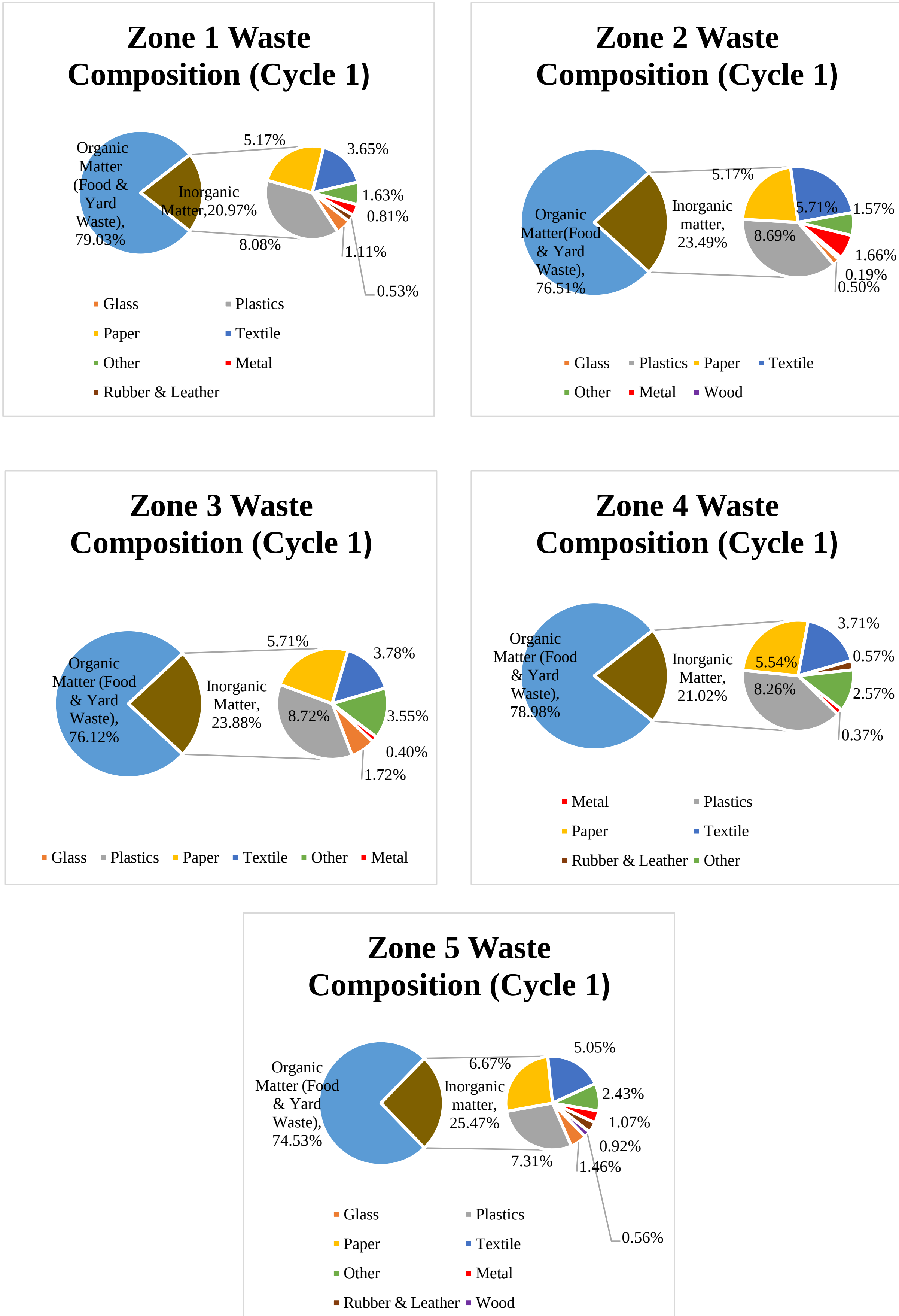

Figure 4. 1: Waste composition of different zones of GCC (Cycle 1)

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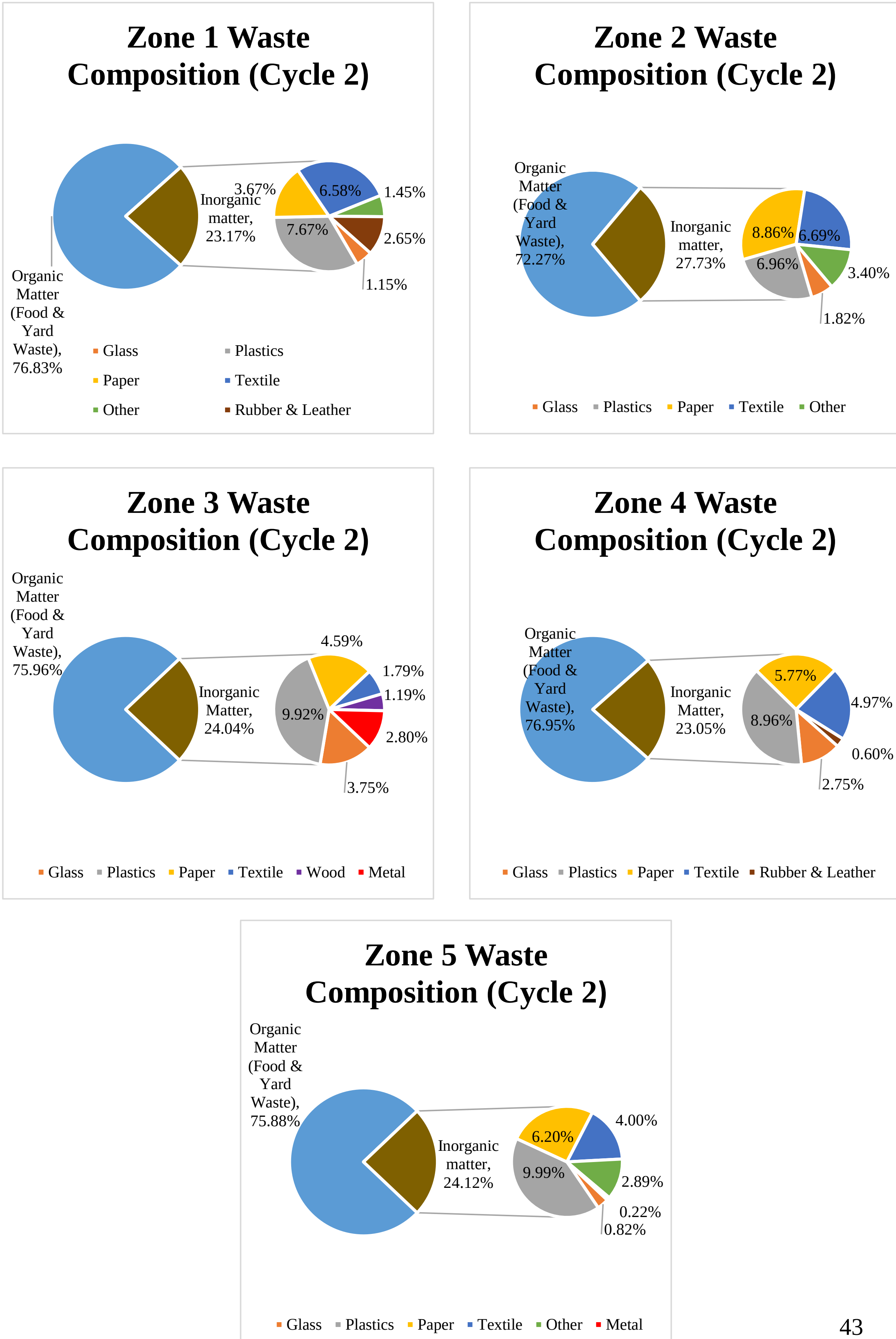


Figure 4. 2: Waste composition of different zones of GCC (Cycle 2)

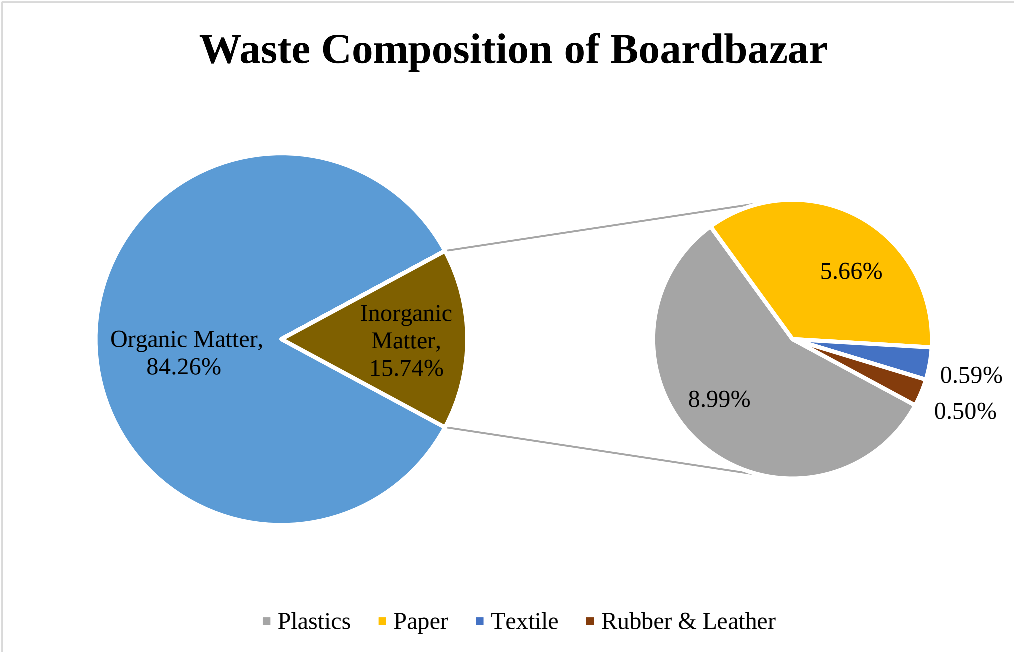
4.3.2 Composition of Solid Waste from Local Bazaar

In local bazaar, everyday tones of vegetable waste is generated. Some portion of them are collected and dumped in final landfills whereas some portion of them are dumped nearby lowlying areas. The prevailing type of waste in local baazar is organic waste consists of vegetable, and discarded portion of fish and meat waste. Also for buying and selling purpose in these types of local bazaar, polythenes are used in large number and they are also being discarded here and there. Paper is also used in some shops and they produce a significant percentage of waste also.

Table 4. 5: Composition of bazaar waste in GCC

	Composition (% by weight)								
Bazaar	**Food & Yard Waste**	**Paper**	**Plastics/ Polythene**	**Glass**	**Metal**	**Textiles & Wood**	**Rubber & Leather**	**Others**	**Total**
Average in Dry Season									
Boardbazar	84.26	5.66	8.99	-	-	0.59	0.50	-	100.00
Shalna	85.14	5.37	9.04	-	0.45	-	-	-	100.00
Average	84.70	5.51	9.02	-	0.23	0.29	0.25	-	100.00

In our study, it was found that almost 85% of all wastes generated in local bazaar are organic waste- mainly vegetable and fish market waste. The wastes generated in meat shops are used as a source of food for fish cultivation in local ponds. Also, a higher percentage of plastic wastes mainly polythenes were found in the stream where local bazaar waste was dumped. Uses of single use plastic plays the negative role in this case. Furthermore, paper waste mainly portion of old newspaper used as a cover for different type of products while buying and selling in local bazaar was found here.



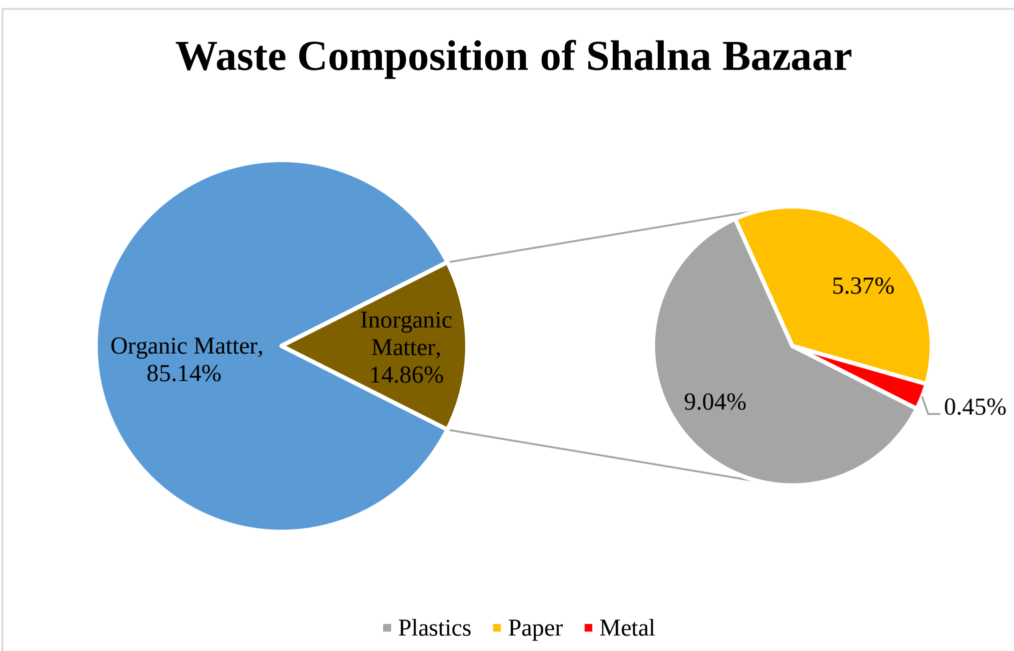


Figure 4. 3: Waste Composition of Local Bazaar of GCC

4.3.3 Comparison with Previous Studies

Table 4. 6: Comparison of composition of MSW of different city corporations

Waste Category	Solid Waste Composition (%)								
	GCC[1]		DCC[2]	CCC[2]	KCC[2]	RCC[3]	BCC[2]	SCC[2]	MCC[4]
	Household	Bazaar							
Organic Matter	76.31	84.70	68.30	73.61	78.85	72.29	80.77	73.49	83.00
Paper	5.73	5.51	10.69	9.89	9.42	5.79	6.92	8.37	9.00
Plastics	8.46	9.02	4.31	2.81	3.08	4.74	3.85	3.72	6.00
Textile & Wood	4.78	0.29	2.21	2.13	1.35	4.25	1.54	2.33	-
Rubber & Leather	0.53	0.25	1.40	0.99	0.58	0.82	0.77	0.47	-
Metal	0.73	0.23	2.00	2.21	1.15	1.24	1.54	0.93	1.00
Glass	1.51	-	0.69	0.99	0.58	0.48	0.77	0.93	1.00
Other	1.95	-	10.39	7.38	5.00	10.39	3.85	9.77	-
Total	100	100	100	100	100	100	100	100	100

[1]This study, [2]Alamgir & Ahsan 2007, [1]This study, [1]This study,

Compared to previous studies, the percentage of organic portion (food & yard waste) of GCC is quite similar with other city corporations. The real difference was found in the percentage of plastic waste percentage. Compared to other city corporations, where the study was conducted a long time ago, the percentage of plastic waste found in our study is much higher. Recent studies suggest a spike in the percentage of plastic waste. From the pandemic, the use of single use plastics increased in an alarming rate.

Table 4. 7: Comparison of composition of MSW of GCC

Waste Category	Solid Waste Composition (%)			
	GCC[1]		GCC[2]	
	Household	SDS	Household	Bazaar
Organic Matter	83.50	77.04	76.31	84.70
Paper	5.70	6.75	5.73	5.51
Plastics	6.34	6.66	8.46	9.02
Textile & Wood	1.32	1.52[*]	4.78	0.29
Rubber & Leather	0.66	0.59	0.53	0.25
Metal	0.62	1.37	0.73	0.23
Glass	0.91	2.81	1.51	-
Other	0.95	3.27	1.95	-
Total	100	100	100	100

[1]This study, [2]Chowdhury et al. (2021)

Comparing our study's findings to those of Chowdhury et al., who performed research within the GCC, a significant drop in the percentage of organic waste in households was found. The various waste collecting techniques used can be the cause of this difference. Unlike the previous study, which collected rubbish directly from residences, our study gathered waste utilizing waste pickup vans. The study by Chowdhury et al. also showed a decline in the percentage of organic waste at the secondary dumping location. A large increase in the percentage of plastic waste was also found in our study, suggesting that after the COVID-19 epidemic, more people are using plastic products. This discovery emphasizes the pandemic's potential effects on waste composition and consumption habits.

4.4 Moisture Content

Municipal solid waste (MSW) management depends heavily on moisture content, which can also have a variety of consequences on the processes involved in waste disposal as a whole. It affects the volume, density, stability and compaction of MSW, thereby impacting the entire waste management system. Moreover, moisture content is essential for the effective breakdown of organic waste and the creation of biogas in anaerobic digestion systems. As a result, managing and keeping optimal moisture levels is a key part of successful MSW management and sustainable waste disposal practices. It is significant to remember that depending on the particular type of waste, the moisture content of MSW can change. In this regard, the percentage of organic waste has a significant impact on the amounts of moisture content found.

Table 4. 8: Moisture Content of MSW of different zones of GCC

Zone	Moisture Content	Average Moisture Content of GCC
1	56.23	55.00
2	53.59	
3	53.60	
4	57.41	
5	54.15	

The average moisture content of municipal solid waste (MSW) in the GCC region, according to our study, was found to be 55%. Similar to this, Habib et al. (2021) conducted study and found that the household components (RCC) of MSW had an average moisture content of 48.28%. Furthermore, Hossain et al. (2014) indicated that the moisture content of MSW ranged from 45% to 50% in a prior study. Given the increased proportion of organic waste in our investigation compared to Habib et al.'s findings (2021), it is obvious that the average moisture content in our sample was also higher.

4.5 Higher Heating Calorific Value

Municipal solid waste (MSW) has a greater heating calorific value (HHCV), which measures how much heat energy is released per unit mass of waste upon complete combustion under regulated circumstances. It serves as a gauge for the waste's energy content and shows how much heat can be produced during burning. For energy recovery, power generation, waste management planning, emission control, and resource optimization, the HHCV of MSW is essential.

Table 4. 9: HHV of MSW of different zones of GCC

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Crucible + MSW pellet (g)	14.5473	15.0263	14.8083	14.6663	14.8113
Mass of crucible (g)	13.5403	13.5403	13.5403	13.5403	13.5403
Mass of MSW pellet (g)	1.007	1.486	1.268	1.126	1.271
Final Temperature in K	28.131	31.243	29.818	29.955	28.275
Initial Temperature in K	26.669	28.953	27.843	28.242	26.328
Uncorrected Temperature Rise (K)	1.462	2.29	1.975	1.713	1.947
HHV	14.09	14.98	15.1	14.78	14.9

The average HHV of GCC was found to be 14.76 MJ/kg in our study. Compared to that, the average HHV of RCC was found to be 14.9 MJ/kg in the study done by Habib at el. in 2021.

4.6 Net Electrical Power

Average heat energy = 14.76 MJ/kg

Steam energy= 0.7 * 14.76 = 10.33 MJ/kg

The steam energy of MSW of Rajshahi City Corporation (RCC) was found to be 10.43 MJ/kg in study done by Habib at el. (2021) which is close to our value.

For determination of net electrical power,

$11395E_P = E_s$

$E_P = 10.33*10^3/11395$

Electric Power Generation, $E_P = 0.9065$ kWh/kg

Station Service Allowance, $S_A = 0.06 * 0.9065$

$S_A = 0.0544$

Unaccounted Heat Loss, $U_H = 0.05 * 0.9065$

$U_H = 0.045325$

Net Electrical Power, $E_{NP} = E_P – S_A = 0.9065 - 0.0544 - 0.045325 = 0.807$ kWh/kg

The net electrical power of MSW of Rajshahi City Corporation (RCC) was found to be 0.8604 kWh/kg without considering the unaccounted heat loss in study done by Habib at el. in 2021.

Table 4. 10: Determination of net electrical power of MSW of GCC

Heat Energy (MJ/kg)	Steam Energy (MJ/kg)	Electrical Power, E_P (kWh/kg)	Station Service Allowance, S_A (kWh/kg)	Unaccounted Heat Loss, U_H (kWh/kg)	Net Electrical Power, E_{NP} (kWh/kg)

14.76	10.33	0.9065	0.0544	0.045325	0.807

Daily waste generation = 1022 ton/day (Only household)

Moisture content = 55%

Amount of dry waste = 1022*0.55 = 562.1 ton/day whereas the amount of dry waste in RCC was only 185.26 ton/day.

Energy Potential from MSW in GCC = 0.807*1000*562.1

= 453614.7 kWh/day

= 453.615 mWh/day

The above generated electricity is for one day and one day 24 hours, so using this net electric power is calculated for per hour basis.

Net electric power generated = 453.615/24 = 18.9 MW

The energy potential of RCC was calculated to be 6.64 MW from household in the study done by Habib et al. in 2021. Compared to that, GCC has way more potential to generate significant amount of electricity from household portion of MSW due to its immense waste generation every day. And if the waste generated from industrial, commercial, street sweeping part can be added, the energy potential of GCC increases more than double.

4.7 Ash Content

The inorganic residue left over after burning or incineration and made up of non-combustible materials like minerals and metals is known as the ash content of municipal solid waste (MSW). Based on the type of waste, recyclables, and the effectiveness of the treatment, it varies. The ash content might vary further based on individual waste characteristics and treatment techniques, often falling between 10% and 40%. The effectiveness of waste treatment, residue disposal, resource recovery, and environmental effects all depend on the ash concentration of MSW. It aids in the evaluation of treatment procedures, chooses the best disposal techniques, makes resource recovery possible, and resolves environmental issues.

Table 4. 11: Ash Content of MSW of different zones of GCC

Zone	Ash Content (%)	Average Ash Content of GCC (%)
1	11.68	11.48
2	10.68	
3	10.18	
4	11.96	
5	12.88	

The average ash content of GCC was found to be 11.48% in our study which is well in the range between 10-40% showing how much ash content can be generated in this region if incineration is implemented in GCC.

4.8 Bazaar Waste Generation

Waste produced in local bazaars, or bazaar waste, often comprises of a range of waste forms. Depending on the types of businesses and activities taking place, several waste types may be present in bazaars. Food waste, such as spoiled or expired food, peels, packaging waste, paper waste (receipts, fliers), plastic waste (bags, cutlery), glass waste (bottles, shattered glass), and other waste (textiles, e-waste, non-recyclables) are all included in bazaar waste. To address these waste kinds and enhance sustainability in bazaars, proper waste management is essential.

Table 4. 12: Waste Generation from Local Bazaar of GCC

Shop Type	Size	Total Waste (kg/day)
Vegetable Shop	Small	17.68
Vegetable Shop	Small	14.30
Vegetable Shop	Large	31.20
Vegetable Shop	Small	15.91

Vegetable Shop	Large	26.02
Fish Shop	-	5.29
Fish Shop	-	4.65
Vegetable Shop	Large	35.14
Vegetable Shop	Small	10.73
Vegetable Shop	Large	29.97
	Total	190.88

Average waste generation per shop = 190.88/10 = 19.09 kg

There are around 80 shops.

So total waste generation per day = 80*19.09 = 1592 kg/day

There are around 23 same types of baazar in GCC.

Total waste generation from Bazaar = 23*1592 = 36.62 ton/day

4.9 Biogas Generation from Household and Bazaar Waste

Table 4. 13: Biogas Generation from MSW and local bazaar of GCC

	MSW	**Bazaar**
Total MSW generation	1022 tons/day	36.62 tons/day
Food and Vegetables	779.89 tons/day	16.7706 tons/day
Total Biogas Generation*	116983.23 m^3	2515.59 m^3
Compost Fertilizer**	255.5 tons/day	9.155 tons/day

*From 1 ton of MSW, anaerobic digestion can produce 150 m^3 biogas (Rana, 2016).

**From 1000 ton of MSW, anaerobic digestion can produce 250 tons compost (Rana, 2016).

According to our study, the GCC's household waste has the capacity to produce about 116,983.23 m^3 of biogas. Similar to bazaar waste, bazaar waste has the capacity to produce 2,515.59 m^3 of biogas. Additionally, digestate, a product of anaerobic digestion, can be used as compost fertilizer. In particular, 9.155 tons of compost from bazaar and 255.5 tons of compost from household waste can be produced. These results emphasize the considerable biogas generation potential as well as the valuable digestate resource that can be produced from GCC waste streams for agricultural use.

4.10 Techno-Economical Analysis of the Proposed AD plant in GCC

Anaerobic digestion stands out as the best waste-to-energy method for the GCC due to the high moisture content of solid waste, as well as the high capital costs and environmental damage associated with incineration. It's crucial to remember that this method cannot be implemented effectively without pre-treatment. Below is a techno-economic study of an anaerobic digestion (AD) plant that takes into account a number of presumptions. An key consideration in the analysis is the expected cost of the compost made at the AD plant, which is 6 taka per kg. For treatment of organic waste, this AD plant can be used. Resource recovery is a valuable solution for plastic, paper and metal wastes.

Table 4. 14: Techno-economic analysis of AD plant in GCC

Input Parameters	Values
Beginning design year	2023
Construction duration	3 years
Year of the beginning of operation	2026
Lifetime	25 years
Year of the end of operation	2051
Electricity generation from 1 tom of organic waste	0.992 MWh

Operating days in a year	365
Operating hours in a year	7446
Waste capacity per year	779.89*365 or 284700 tons
Plant capacity factor	85%
Facility annual throughout per year	284700*85% or 241995 mWh
Electricity generation efficiency	36%
Electricity production per year	241995*36%*0.992 or 86421.25 mWh
Plant capacity	86421.25/7446 or 11.61 mWh
Capital expenditure per MW	USD 4339000 or BDT 466.43 million
Capital Expenditure (CAPEX)	466.43*11.61 or 5415.25 million
Fixed Operating Cost (% of CAPEX/Year)	3
Fixed Operating Cost	5415.25*3% or 162.46 million
Variable Operating Cost (USD 4.4*mWh)	4.4*86421.25 or USD 380253.5 or BDT 40.87 million
Revenue from compost per day	BDT 1.53 million
Revenue from compost per year	BDT 558 million
Cost of electricity (Assumed)	BDT 7.82 taka
Annual revenue from electricity	7.82*1000*86421.25 or BDT 675.81 million
Annual net cash inflow	(675.81 + 558 – 162.46 – 40.87) ot BDT 1030.48 million
Payback period (CAPEX/ annual net cash inflow)	5415.25/1030.48 or 5.26 years

4.11 Resource Recovery Potential of GCC

This study aimed to This study aimed to According to our study's characterization data, organic waste makes up the majority of the GCC's municipal solid waste (MSW). Besides, various waste categories, including paper, plastic, glass, textile, wood, metal, and other waste types were also identified. Because some of these waste kinds are incombustible or nonbiodegradable, they cannot all be used in waste-to-energy systems. Additionally, there are a limited number of these waste products available. Given these elements, resource recovery stands out as the most successful strategy since it provides both economic and social advantages while protecting natural resources. Resource recovery techniques including recycling, reuse, and others bring economic and social benefits.

4.11.1 Potential of Resource Recovery

Our characterization data make it clear that a sizable portion of recyclable or reusable waste is not being recovered on a daily basis. These salvageable waste materials have the potential to develop into significant assets for GCC, bringing in money and cutting back on waste disposal expenses. The expected recoverable waste quantities for the five zones of the GCC in the table that is provided are outlined:

Table 4. 15: Weight of recoverable materials in GCC

Wt. of Recoverable Material in Dry Season														
Zone	Total Waste Generated	Paper	Plastic	Metal	Leather & Rubber	Glass	Wood & Textile	Paper	Plastic	Metal	Leather & Rubber	Glass	Wood & Textile	Total
	Ton/Day	Dry Season (%)						Dry Season (Ton/Day)						Ton/Day
1	281	4.42	7.88	0.41	1.59	1.13	5.13	12.420	22.142	1.152	4.4679	3.1753	14.415	57.7736
2	229	7.01	7.82	0.83	0	1.16	3.15	16.05	17.907	1.900	0	2.6564	7.2135	45.7313
3	122	5.15	9.32	1.6	0	2.73	1.68	6.28	11.370	1.952	0	3.3306	2.0496	24.9856
4	150	5.65	8.61	0.19	0.59	1.38	4.34	8.47	12.915	0.285	0.885	2.07	6.51	31.14
5	154	6.44	8.65	0.64	0.46	1.14	2.4	9.912	13.321	0.985	0.7084	1.7556	3.696	30.3842
Total	935							53.148	77.657	6.276	6.0613	12.987	33.884	190.0147

A total of 190.014 tons of waste may be retrieved per day from these zones, per the statistics. This comprises a variety of recyclable goods like glass, paper, metal, and recyclable forms of wood and leather. Notably, with a daily potential recovery of 77.65 tons, plastic makes up the greatest proportion of recoverable waste. This significant buildup of plastic waste points to a worrying rise in plastic consumption.

4.11.2 Revenue from Resource Recovery

The authorities can make money from the recovered materials from the five GCC zones because of their high worth. The opportunity to lower net spending on solid waste collection and handling is made possible by this greater income. The potential annual revenue from resource recovery is shown in Table 4.16 taking into account both a 100% and a 70% recovery rate for the total recoverable waste.

Table 4. 16: Recyclable items in GCC

Recyclable Item	Unit Prize* (BDT/Ton)	With 100% Recovery		With 70% Recovery	
		Weight (Ton/Day)	Market Value (BDT/Day)	Weight (Ton/Day)	Market Value (BDT/Day)
Paper	5000	53.1487	265743.5	37.20409	186020.45
Plastic	5000	77.657	388285	54.3599	271799.5
Metal	7000	6.2754	43927.8	4.39278	30749.46
Leather & Rubber	6000	6.0613	36367.8	4.24291	25457.46
Glass	3000	12.9879	38963.7	9.09153	27274.59
Wood & Textile	1000	33.8844	33884.4	23.71908	23719.08

Total		190.0147	807172.2	133.01029	565020.54
Annual Revenue (Million BDT)		294.617853		206.2324971	

*Price obtained from local recyclers who collect waste from SDSs / informal sectors.

The data indicates that the annual income generated would be 294.617 million BDT if a 100% recovery rate is assumed. However, it might not be practical in practice to achieve a 100% recovery rate. According to Alamgir & Ahsan (2007), Bangladesh's real recovery rate for commodities from MSW is around 70%. Table 4.16 demonstrates that we can generate 206.2324 million BDT yearly from resource recovery initiatives when taking this 70% recovery rate into account.

The potential yearly revenue from resource recovery in the GCC is estimated to be 154.34 million BDT with a 100% recovery rate and 108.04 million BDT taking a 70% recovery rate into account, according to a recent study conducted by Chowdhury (2021). Our annual revenue from resource recovery has increased by 90% as the total amount of waste produced and the unit cost of recoverable waste have gone up due to inflation. Resource recovery is not currently practiced in the GCC. However, some people make a living by removing different products from landfills in an unofficial manner. Due to this, GCC not only loses out on possible resource recovery money but also leaves a sizable volume of recoverable materials uncollected. Segregating recoverable waste at the household level is essential to promoting waste recovery. This can be accomplished by providing separate containers in various colors for organic, plastic, and other debris. These procedures can be used in businesses and educational institutions.

Table 4. 17: Revenue through resource recovery in GCC

Revenue Through Resource Recovery at SDS			
Recyclable Item	Unit Prize* (BDT/Ton)	Weight (Ton/Day)	Market Value (BDT/Day)

Paper	5000	53.1487	265743.5
Plastic	5000	77.657	388285
Metal	7000	6.2754	43927.8
Leather & Rubber	6000	6.0613	36367.8
Glass	3000	12.9879	38963.7
Wood & Textile	1000	33.8844	33884.4
Total		190.0147	807172.2
Total Revenue (Million BDT/Day)			0.8071722
Annual Revenue (BDT/Day) with 100% revenue at MRF			294.617853
Associated Cost for Low-Tech MRF at SDS			
	Daily	Annual	Total
Total Generated Waste (ton)	935	341275	—
Capital Cost [1](Million BDT@85000BDT/Ton)	—	—	794.75
Operations & Maintenance Cost [1](Million BDT@1700 BDT/Ton)	2.03	580.1675	—

The recovery procedure can also be improved by establishing a material recovery facility (MRF) at secondary dumping stations and final disposal locations. However, it should be understood that the expense of putting an MRF into place is rather considerable. Given that the GCC produces waste at a rate of 935 tons per day and 341,275 tons annually, a low-tech MRF unit's operation and maintenance (O&M) expenses would be roughly 2.03 million BDT, assuming a dollar exchange rate of 1$=109 BDT. As indicated in Table 4.3, this expense is more than twice as much as the potential revenue generated through resource recovery. It's vital to note that the year does not account for the time worth of money. Therefore, the GCC cannot economically install an MRF at this time. However, if 100% waste collection can be secured in the future and the percentage of recoverable goods can be raised by a factor of 2.5, implementing an MRF might become financially viable. Given the budgetary considerations, it is not currently the best option for the GCC.

4.11.3 Reduction of Waste Through Resource Recovery

Table 4. 18: Reduction of waste through resource recovery in GCC

	Zone	Paper	Plastic	Metal	Leather & Rubber	Glass	Wood & Textile	Total
Avg. Weight Reduction Potential (ton/day)	1	12.420	22.142	1.152	4.4679	3.1753	14.415	57.7736
	2	16.05	17.907	1.900	0	2.6564	7.2135	45.7313
	3	6.28	11.370	1.952	0	3.3306	2.0496	24.9856
	4	8.47	12.915	0.285	0.885	2.07	6.51	31.14
	5	9.912	13.321	0.985	0.7084	1.7556	3.696	30.3842
Total(ton/day)		53.148	77.657	6.276	6.0613	12.987	33.884	190.0147

Utilizing resource recovery techniques can significantly reduce the quantity of waste that needs to be managed, which will save money. The weight of waste that can be decreased by resource recovery is shown in Table 4.4. This decrease lessens the amount of waste that must be transported from secondary disposal sites (SDS) to landfills and lessens the load on those facilities. Less land will therefore be needed for landfill purposes. A total of 190.01 tons of waste are thought to be recoverable through resource recovery operations.

Chapter 5: Conclusion and Recommendations

5.1: Conclusion and Recommendations

This study aimed to find appropriate waste-to-energy technologies for use in the GCC region as well as examine the composition, moisture content, calorific value, and ash content of solid waste. The study produced the following significant results and recommendations:

1. In terms of household composition, organic waste, which makes up about 76.31% of the total, is the most prevalent type observed. Following after, with 8.46% of the waste composition, are plastics. Paper comes in third with 5.73% of the total. Additionally, the following waste categories collectively account for 4.79%, 1.51%, 0.73%, 0.53%, and 1.95% of the waste: textiles and wood, glass, metal, rubber and leather, and other types of waste.
2. When the content of bazaar waste was examined, it was discovered that organic waste predominates, accounting for about 84.70%—significantly more than the percentage seen in household waste. Following behind, plastics make up 9.02% of all waste types. A percentage of 5.51% places paper in third place. Moreover, just a small portion of the total waste composition is made up of materials like textiles, wood, metal, rubber, and leather.
3. The GCC region produces a significant amount of waste each day—up to an astounding 1022 tons from household. With the exception of DSCC and DNCC, this sum is noticeably more than that of other city corporations. The GCC generates 36.62 tons of waste from local bazaar each day, the majority of which is organic waste The real number can be much higher from local bazaars. To reduce the environmental and health risks associated with such high levels of waste generation, it is critical to address this enormous waste output and develop efficient waste management systems.
4. The moisture percentage of municipal solid waste in the GCC region has been determined to be 55%. The waste stream's substantial amount of organic material is the leading cause of this high moisture content. The presence of

moisture in solid waste must be considered when choosing the best waste management strategy, especially for combustion-based systems. The moisture content can be reduced by using appropriate drying processes or pre-treatment procedures.

5. The GCC region's municipal solid waste (MSW) has a considerable heat energy value of 14.76 MJ/kg. This suggests the possibility of using the right waste-to-energy technologies to extract valuable energy from the waste. Notably, a net electric power generating potential of 18.9 MW was discovered using only domestic waste. The establishment of a waste treatment facility with a 20 MW capacity is advised given the significant volume of waste produced in the GCC. Such a facility would make it possible to effectively process and manage the enormous amounts of waste generated in the area. The power generation capacity can be extended beyond the initial 18.9 MW by using cutting-edge waste-to-energy technology and combining waste from other industries. This highlights the huge potential for utilizing the energy component of the waste stream in the GCC to produce sustainable electricity.
6. Given the high moisture content of the waste, our study indicated that anaerobic digestion (AD) can be used in the GCC to turn organic waste into electricity. AD is capable of producing 2,515.59 m^3 of biogas from bazaar waste and 116,983.23 m^3 from household waste. Additionally, it can create 9.155 tons of compost per day from bazaar waste and 255.5 tons per day from domestic waste. The techno-economic analysis showed that the AD plant have a payback period of 5.26 years.
7. Municipal solid waste (MSW) in the GCC region has an ash percentage that was measured at 11.48% in our study. The ash content of MSW typically ranges between 10% and 40%, therefore this is within the expected range. Waste management authorities can gain a better understanding of the waste composition and make educated judgments about waste treatment and disposal options by examining the ash content of GCC's MSW.
8. From our analysis about resource recovery, we have found that we can recover 133.01 ton of waste per day which includes 37.20 ton of paper, 54.35 ton of plastic, 4.39 ton of metal, 4.24 ton of leather & rubber, 9.09 ton of glass, 23.71

ton of wood & textile. This waste can produce 206.232 million BDT revenue. As separation from household level is the best way for resource recovery, we have to work to change public behavior and make them aware about separation of waste. Different types od dustbin have to be supplied by the city corporation in order to prevent mixing of various kind of wastes. A MRF plant can be installed in final disposal site and the operation and maintenance cost will bear by the GCC until it becomes a profitable one.

5.2: Future Scopes

Further study is necessary to develop waste-to-energy deployment and ensure appropriate solid waste management in the GCC. Investigations are advised in the following areas:

1. In addition to concentrating on household waste, additional research can be done to examine the generation and waste characteristics of commercial, industrial, institutional, and street-sweeping waste in the GCC region, giving a thorough picture of overall waste generation.
2. Given that the scope of this study was restricted to the dry season, it is advised to carry out comparable research during the wet season in order to discover seasonal variations and evaluate the potential for energy generation from municipal solid waste (MSW) under wet conditions. Investigating the moisture content during the wet season would also be beneficial.
3. Since pH and the C/N ratio were not examined in our study, future research can test these variables in MSW samples from the GCC region.
4. An upcoming study might compute the amount of methane gas produced by unsanitary landfills in the GCC region and assess the possible decrease in greenhouse gas emissions brought about by waste-to-energy initiatives.
5. It is advisable to carry out a future study to count the number of transfer stations and sanitary disposal sites (SDS) used for waste dumping in the GCC region in order to acquire a thorough understanding.

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APPENDIX I: Zone Wise Data Collected for Waste Composition

Table A1. 1: Zone 1, Cycle 1 Data Collected for Waste Composition Determination

Zone 1 (Cycle 1)									
Waste Type	1st Portion (~2.5Kg)		2nd Portion (~2.5Kg)		3rd Portion (~2.5Kg)		4th Portion (~2.5Kg)		Average
	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	
Organic Matter	2.061	82.42	1.872	74.89	1.948	77.92	2.022	80.876	79.03
Paper	0.110	4.38	0.074	2.95	0.156	6.22	0.178	7.113	5.17
Plastics	0.182	7.29	0.132	5.29	0.193	7.74	0.300	12.010	8.08
Glass	-	-	0.111	4.42	-	-	-	-	1.11
Textile	0.148	5.91	0.095	3.82	0.122	4.88	-	-	3.65
Wood	-	-	-	-	-	-	-	-	0.00
Metal	-	-	-	-	0.081	3.24	-	-	0.81
Rubber & Leather	-	-	0.053	2.12	-	-	-	-	0.53
Other	-	-	0.163	6.50	-	-	-	-	1.63
Total	2.500	100.00	2.500	100.00	2.500	100.00	2.500	100.000	100.00

Table A1. 2: Zone 1, Cycle 2 Data Collected for Waste Composition Determination

Zone 1 (Cycle 2)									
Waste Type	1st Portion (~2.5Kg)		2nd Portion (~2.5Kg)		3rd Portion (~2.5Kg)		4th Portion (~2.5Kg)		Average
	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	
Organic Matter	1.822	76.23	1.788	71.84	1.633	75.60	2.008	83.667	76.83
Paper	0.048	2.01	0.056	2.25	0.153	7.08	0.080	3.333	3.67
Plastics	0.178	7.45	0.225	9.04	0.176	8.15	0.145	6.042	7.67
Glass	0.110	4.60	-	-	-	-	-	-	1.15
Textile	0.232	9.71	0.156	6.27	0.073	3.38	0.167	6.958	6.58
Wood	-	-	-	-	-	-	-	-	0.00
Metal	-	-	-	-	-	-	-	-	0.00
Rubber & Leather	-	-	0.264	10.61	-	-	-	-	2.65
Other	-	-	-	-	0.125	5.79	-	-	1.45
Total	2.390	100.00	2.489	100.00	2.160	100.00	2.400	100.000	100.00

Table A1. 3: Zone 2, Cycle 1 Data Collected for Waste Composition Determination

Zone 2 (Cycle 1)									
Waste Type	1st Portion (~2.5Kg)		2nd Portion (~2.5Kg)		3rd Portion (~2.5Kg)		4th Portion (~2.5Kg)		Average
	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	
Organic Matter	1.865	74.61	1.931	77.23	2.003	80.11	1.852	74.090	76.51
Paper	0.000	0.00	0.133	5.32	0.158	6.31	0.226	9.034	5.17
Plastics	0.325	13.00	0.187	7.47	0.165	6.59	0.193	7.703	8.69
Glass	0.050	2.00	0.000	0.00	0.000	0.00	0.000	0.000	0.50
Textile	0.228	9.13	0.136	5.45	0.072	2.89	0.135	5.392	5.71
Wood	0.019	0.76	0.000	0.00	0.000	0.00	0.000	0.000	0.19
Metal	0.000	0.00	0.113	4.54	0.052	2.09	0.000	0.000	1.66
Rubber & Leather	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.000	0.00
Other	0.013	0.51	0.000	0.00	0.050	2.01	0.095	3.782	1.57
Total	2.500	100.00	2.500	100.00	2.500	100.00	2.500	100.000	100.00

Table A1. 4: Zone 2, Cycle 2 Data Collected for Waste Composition Determination

Zone 2 (Cycle 2)									
Waste Type	1st Portion (~2.5Kg)		2nd Portion (~2.5Kg)		3rd Portion (~2.5Kg)		4th Portion (~2.5Kg)		Average
	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	
Organic Matter	1.707	68.28	1.874	74.96	2.113	84.53	1.533	61.327	72.27
Paper	0.215	8.60	0.194	7.78	0.180	7.20	0.296	11.841	8.86
Plastics	0.108	4.32	0.178	7.12	0.207	8.27	0.203	8.126	6.96
Glass	0.182	7.28	0.000	0.00	-	-	-	-	1.82
Textile	0.288	11.52	0.253	10.14	-	-	0.128	5.108	6.69
Wood	-	-	-	-	-	-	-	-	0.00
Metal	-	-	-	-	-	-	-	-	0.00
Rubber & Leather	-	-	-	-	-	-	-	-	0.00
Other	-	-	-	-	-	-	0.340	13.599	3.40
Total	2.500	100.00	2.500	100.00	2.500	100.00	2.500	100.000	100.00

Table A1. 5: Zone 3, Cycle 1 Data Collected for Waste Composition Determination

Zone 3 (Cycle 1)									
Waste Type	1st Portion (~2.5Kg)		2nd Portion (~2.5Kg)		3rd Portion (~2.5Kg)		4th Portion (~2.5Kg)		Average
	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	
Organic Matter	1.622	64.88	1.82	72.80	2.13	85.20	2.04	81.60	76.12
Paper	0.213	8.52	0.118	4.72	0.08	3.20	0.16	6.40	5.71
Plastics	0.227	9.08	0.205	8.20	0.14	5.60	0.3	12.00	8.72
Glass	-	-	0.172	6.88	-	-	-	-	1.72
Textile	0.268	10.72	-	-	0.11	4.40	-	-	3.78
Wood	-	-	-	-	-	-	-	-	0.00
Metal	-	-	-	-	0.04	1.60	-	-	0.40
Rubber & Leather	-	-	-	-	-	-	-	-	0.00
Other	0.17	6.80	0.185	7.40	-	-	-	-	3.55
Total	2.5	100	2.5	100	2.5	100	2.5	100	100.00

Table A1. 6: Zone 3, Cycle 2 Data Collected for Waste Composition Determination

Zone 3 (Cycle 2)									
Waste Type	1st Portion (~2.5Kg)		2nd Portion (~2.5Kg)		3rd Portion (~2.5Kg)		4th Portion (~2.5Kg)		Average
	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	
Organic Matter	1.842	75.28	1.89	75.06	1.92	75.50	1.97	78.02	75.96
Paper	0.132	5.39	0.093	3.69	0.11	4.33	0.125	4.95	4.59
Plastics	0.237	9.69	0.255	10.13	0.213	8.38	0.29	11.49	9.92
Glass	0.136	5.56			0.24	9.44	-	-	3.75
Textile	0.03	1.23	0.07	2.78	0.06	2.36	0.02	0.79	1.79
Wood	-	-	-	-	-	-	0.12	4.75	1.19
Metal	0.07	2.86	0.21	8.34	-	-	-	-	2.80
Rubber & Leather	-	-	-	-	-	-	-	-	0.00
Other	-	-	-	-	-	-	-	-	0.00
Total	2.447	100	2.518	100	2.543	100	2.525	100	100.00

Table A1. 7: Zone 4, Cycle 1 Data Collected for Waste Composition Determination

Zone 4 (Cycle 1)									
Waste Type	1st Portion (~2.5Kg)		2nd Portion (~2.5Kg)		3rd Portion (~2.5Kg)		4th Portion (~2.5Kg)		Average
	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	
Organic Matter	1.995	79.79	2.025	81.00	1.932	77.30	1.945	77.820	78.98
Paper	0.141	5.66	0.145	5.80	0.068	2.72	0.199	7.948	5.53
Plastics	0.193	7.70	0.195	7.78	0.144	5.75	0.295	11.815	8.26
Glass	-	-	-	-	-	-	-	-	0.00
Textile	0.114	4.56	0.098	3.91	0.159	6.38	-	-	3.71
Wood	-	-	-	-	-	-	-	-	0.00
Metal	-	-	0.038	1.50	-	-	-	-	0.38
Rubber & Leather	0.057	2.28	-	-	-	-	-	-	0.57
Other	-	-	-	-	0.196	7.85	0.060	2.417	2.57
Total	2.500	100.00	2.500	100.00	2.500	100.00	2.500	100.000	100.00

Table A1. 8: Zone 4, Cycle 2 Data Collected for Waste Composition Determination

Zone 4 (Cycle 2)									
Waste Type	1st Portion (~2.5Kg)		2nd Portion (~2.5Kg)		3rd Portion (~2.5Kg)		4th Portion (~2.5Kg)		Average
	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	
Organic Matter	1.996	79.84	1.789	71.56	1.938	77.52	1.972	78.88	76.95
Paper	0.185	7.40	0.072	2.88	0.184	7.36	0.136	5.44	5.77
Plastics	0.234	9.36	0.259	10.36	0.166	6.64	0.237	9.48	8.96
Glass	-	-	0.275	11.00	-	-	-	-	2.75
Textile	0.085	3.40	0.105	4.20	0.212	8.48	0.095	3.80	4.97
Wood	-	-	-	-	-	-	-	-	0.00
Metal	-	-	-	-	-	-	-	-	0.00
Rubber & Leather	-	-	-	-	-	-	0.060	2.40	0.60
Other	-	-	-	-	-	-	-	-	0.00
Total	2.500	100	2.500	100	2.500	100	2.500	100	100.00

Table A1. 9: Zone 5, Cycle 1 Data Collected for Waste Composition Determination

Zone 5 (Cycle 1)									
Waste Type	1st Portion (~~.5Kg)		2nd Portion (~2.5Kg)		3rd Portion (~2.5Kg)		4th Portion (~2.5Kg)		Average
	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	
Organic Matter	1.884	75.35	1.813	72.50	1.870	74.80	1.887	75.462	74.53
Paper	0.082	3.27	0.164	6.55	0.180	7.18	0.243	9.707	6.67
Plastics	0.153	6.10	0.137	5.46	0.206	8.25	0.236	9.438	7.31
Glass	0.146	5.83	-	-	-	-	-	-	1.46
Textile	0.144	5.75	0.225	8.99	0.074	2.94	0.063	2.504	5.05
Wood	-	-	0.056	2.25	-	-	-	-	0.56
Metal	-	-	0.107	4.26	-	-	-	-	1.07
Rubber & Leather	0.092	3.69	-	-	-	-	-	-	0.92
Other	-	-	-	-	0.171	6.82	0.072	2.889	2.43
Total	2.500	100.00	2.500	100.00	2.500	100.00	2.500	100.000	100.00

Table A1. 10: Zone 5, Cycle 2 Data Collected for Waste Composition Determination

Zone 5 (Cycle 2)									
Waste Type	1st Portion (~2.5Kg)		2nd Portion (~2.5Kg)		3rd Portion (~2.5Kg)		4th Portion (~2.5Kg)		Average
	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	
Organic Matter	1.88	78.99	1.79	77.89	1.74	71.52	1.75	75.11	75.88
Paper	0.184	7.73	0.124	5.40	0.114	4.69	0.163	7.00	6.20
Plastics	0.21	8.82	0.244	10.62	0.28	11.51	0.21	9.01	9.99
Glass	-	-	-	-	0.08	3.29	-	-	0.82
Textile	0.086	3.61	0.14	6.09	0.045	1.85	0.104	4.46	4.00
Wood	-	-	-	-	-	-	-	-	0.00
Metal	0.02	0.84	-	-	-	-	-	-	0.21
Rubber & Leather	-	-	-	-	-	-	-	-	0.00
Other	-	-	-	-	0.174	7.15	0.103	4.42	2.89
Total	2..38	100	2.298	100	2.433	100	2.33	100	100.00

Table A1. 11: Zone 2, Local Bazaar Data Collected for Waste Composition Determination

Zone 2 Local Bazar (Boardbazar)									
Waste Type	1st Portion (2.5Kg)		2nd Portion (2.5Kg)		3rd Portion (2.5Kg)		4th Portion (2.5Kg)		Average
	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	
Organic Matter	2.081	83.24	2.170	86.80	2.025	81.00	2.150	86.00	84.26
Paper	0.165	6.60	0.104	4.16	0.191	7.64	0.106	4.24	5.66
Plastics	0.230	9.20	0.226	9.04	0.284	11.36	0.159	6.36	8.99
Glass	-	-	-	-	-	-	-	-	-
Textile	0.024	0.96	-	-	-	-	0.035	1.40	0.59
Wood	-	-	-	-	-	-	-	-	-
Metal	-	-	-	-	-	-	-	-	-
Rubber & Leather	-	-	-	-	-	-	0.050	2.00	0.50
Other	-	-	-	-	-	-	-	-	-
Total	2.500	100	2.500	100	2.500	100	2.500	100	100.00

Table A1. 12: Zone 4, Local Bazaar Data Collected for Waste Composition Determination

Zone 4 Local Bazaar (Shalna Bazar)									
Waste Type	1st Portion (2.5Kg)		2nd Portion (2.5Kg)		3rd Portion (2.5Kg)		4th Portion (2.5Kg)		Average
	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	Weight (Kg)	Percentage (%)	
Organic Matter	2.024	80.96	2.144	85.76	2.213	88.52	2.133	85.32	85.14
Paper	0.198	7.92	0.113	4.52	0.106	4.24	0.120	4.80	5.37
Plastics	0.278	11.12	0.243	9.72	0.181	7.24	0.202	8.08	9.04
Glass	-	-	-	-	-	-	-	-	-
Textile	-	-	-	-	-	-	-	-	-
Wood	-	-	-	-	-	-	-	-	-
Metal	-	-	-	-	-	-	0.045	1.80	0.45
Rubber & Leather	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-
Total	2.500	100	2.500	100	2.500	100	2.500	100	100.00

APPENDIX 2: Zone Wise Data Collected for Moisture Content Determination

Table A2. 1: Zone 1 Data Collected for Moisture Content Determination

Zone 1				
Waste Type	**Initial Weight**	**Final Weight**	**Moisture Content**	**Total Moisture Content**
Organic	0.607	0.117	80.774	56.23
Paper	0.082	0.077	6.098	
Plastics	0.129	0.127	1.550	
Textiles	0.077	0.071	7.792	

Table A2. 2: Zone 2 Data Collected for Moisture Content Determination

Zone 2				
Waste Type	**Initial Weight**	**Final Weight**	**Moisture Content**	**Total Moisture Content**
Organic	0.558	0.124	77.78	53.59
Paper	0.078	0.074	5.13	
Plastics	0.104	0.102	1.92	
Textiles	0.096	0.088	8.33	

Table A2. 3: Zone 3 Data Collected for Moisture Content Determination

Zone 3				
Waste Type	**Initial Weight**	**Final Weight**	**Moisture Content**	**Total Moisture Content**
Organic	0.566	0.119	78.98	53.60
Paper	0.08	0.076	5.00	

Plastics	0.125	0.123	1.60	
Textiles	0.089	0.081	8.99	

Table A2. 4: Zone 4 Data Collected for Moisture Content Determination

Zone 4				
Waste Type	**Initial Weight**	**Final Weight**	**Moisture Content**	**Total Moisture Content**
Organic	0.633	0.119	81.20	57.41
Paper	0.074	0.069	6.76	
Plastics	0.12	0.118	1.67	
Textiles	0.091	0.085	6.59	

Table A2. 5: Zone 5 Data Collected for Moisture Content Determination

Zone 5				
Waste Type	**Initial Weight**	**Final Weight**	**Moisture Content**	**Total Moisture Content**
Organic	0.547	0.119	78.208	54.15
Paper	0.073	0.069	5.890	
Plastics	0.114	0.102	10.526	
Textiles	0.101	0.093	8.020	

APPENDIX 3: Data Collection Sheet for Calorific Value Determination

Weight of coal fuel example:

Length of fuse wire:

Length of fuse wire not burnt:

Weight of calorimeter water: 1900 gm

Water equivalent of calorimeter: 432 gm

Time		Temperature (Celcius)	Time		Temperature (Celcius)
Min	Sec		Min	Sec	
0	0		8	45	
1	0		9	0	
2	0		9	15	
3	0		9	30	
4	0		9	45	
5	0		10	0	
6	0		13	0	
7	0		15	0	
7	15		17	0	
7	30		19	0	
7	45		20	0	
8	0		21	0	
8	15		22	0	
8	30		23	0	

APPENDIX 4: Zone Wise Sample Data for Ash Content Determination

Table A4. 1: Zone Wise Sample Data Collected for Ash Content Determination

Weight of capsule and residue	Tare weight of Capsule	Mass of sample
13.658	13.5403	1.0075
13.699	13.5403	1.486
13.6694	13.5403	1.268
13.675	13.5403	1.126
13.704	13.5403	1.271