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Life Cycle Assessment and Multi-Criteria Decision Analysis for Improvement of Sustainable Waste Management System in Ulaanbaatar, Mongolia

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ADB	Asian Development Bank
BC	Black carbon
CBA	Cost-Benefit Analysis
CERA	Comparative Environmental Risk Assessment
DEMATEL	Decision making trial and evaluation laboratory
DMS	Data management system
DP	Dynamic Programming
DPSIR	Driving–forces-pressures-state-impact-responses
DSS	Decision Support Systems
DST	Decision support tool
EIA	Environmental Impact Assessment
EMS	Environmental Management systems
EIA	Environmental Impact Assessment
ES	Expert System
EMS	Environmental Management systems
EPR	Extended Producer Responsibility
ERA	Environmental Risk Assessment
EQT	Emission Quantification Tool
FM	Forecasting Models
GHG	Greenhouse gas
GWP	Global warming potential
GIS	Geographic Information System
IMS	Integrated Modeling System
IOA	Input-Output Analysis
IP	Integer programming
IPPC	Integrated pollution prevention control
ISWM.	Integrated Solid Waste Management
IVF	Interval-valued fuzzy
IWM	Integrated Waste Management
IGES	Institute for Global Environmental Strategies
IOA	Input-Output Analysis
IMS	Integrated Modeling System
IOA	Input-Output Analysis
IP	Integer programming
IPPC	Integrated pollution prevention control
IWM	Integrated Waste Management
IPCC	Intergovernmental Panel on Climate Change
ISWM	Integrated Solid Waste Management
IWM	Integrated Waste Management
KOICA	Korean International Cooperation Agency

LATS	Landfill Allowance Trading System
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCCA	Life Cycle Cost Analysis
MBT	Materials Recovery Facility
MBT	Mechanical Biological Treatment,
MAUT	Multiple attribute utility theory
MBMS	Model base management system
MCDM	Multicriteria decision making
MSW	Municipal solid waste
MCEA	Modified cost-effectiveness analysis
MFA	Material Flow Analysis
MIS	Management Information System
MOP	Multi-objective programming
JICA	Japan International Cooperation Agency
OM	Optimization Models
RDF	Refuse derived fuels
SA	Sustainability Assessment
SD	Scenario Development
SM	Simulation Models
SoEA	Socio-economic assessment
SWIM	Solid Waste Integrated Model
SLCP	Short-lived climate pollutants
SWM	Solid Waste Management
TOPSIS.	Technique for order preference by similarity to an ideal solution
WASTED	Waste Analysis Software Tool for Environmental Decisions

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SUMMARY

Since the 1990s, citizens increase and moved from the countryside to the Ulaanbaatar city, and civilization has occurred which resulted in a big change in increasing many factories, lack of public transportation, environmental pollution, and expanding Traditional tent (Ger) area. In the case of Ulaanbaatar, the landfill method is currently in use and has a significant impact on the environment, causing soil, water, and air pollution at the same time.

Waste management is one of the areas that needs close attention in pursuit of sustainable development. The present study intends to development of sustainable waste management system for Ulaanbaatar, Mongolia. The waste management model developed intended to promote sustainable decision making, covering the four columns: technical, environmental, economic, and social aspects. This research analyzed for each of the waste disposal methods, to develop and select the waste management best option. For it, the System Dynamics to design a mathematical model based on the waste disposal data from 2011up to 2018, and scenario analysis to forecast the future evolution of the municipal solid waste until 2030 under a different waste management plan.

The first, based on the municipal waste disposal budget data; comprises systems engineering models including cost-benefit analysis, forecasting analysis of each scenario explores opportunities to increase waste revenues and reduce annual costs from waste transportation, collection services and waste treatment whereas the second introduces system assessment tools including scenario development, material flow analysis, life cycle assessment (LCA), and Life Cycle Cost Analysis (LCCA) Life Cycle Impact Assessment, Socio-economic assessment.

IPCC-2006 software was used to calculate economic efficiency and environmental risk for each waste treatment option. The analysis includes a Life Cycle Assessment (LCA) where in direct and indirect GHG emissions during landfilling, waste incineration, mechanical biological treatment processing, composting, recycling, and the overall energy consumption from municipal solid waste (MSW) treatment system were considered for city.

The literature performed have indicated that sustainable assessment models have been one of the most applied into solid waste management, being methods like LCA and optimization modeling (including

multicriteria decision making (MCDM)) also important systems analysis methods. These were the methods (LCA and MCDM) applied to compose the system analysis model for solid waste.

Multi-criteria decision-making analysis can be used in solid waste management as well, as it is used to assess environmental risks and economic benefits and to weigh them to develop policy and planning. Multicriteria decision making have included several data from life cycle assessment to construct environmental, social, and technical attributes, plus economic criteria obtained from collected data from stakeholders involved in the study.

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method has been widely used to inform decision making.

The research has conducted an online questionnaire survey, MCDM the technique helped to capture the knowledge of the local experts, and using the TOPSIS, and ranked various waste disposal methods.

As the result, the possibility of changing the management system that incurs losses each year to cover the costs of waste transportation, waste sorting, and recycling can be offset by waste management activities rather than the state budget. Current management not only pollute soil, water, and air but also fail to conserve natural resources. RDF has not been advantageous considering all criteria.

The results have shown that waste incineration is the most cost-effective option in Ulaanbaatar city in terms of saving coal resources and reducing coal production.

The inclusion of these results into multicriteria decision making was successful to reach the one best solution.

Further research regarding the Management Information System (MIS) would be essential to manage information flows from different sources, support large- scale systems analyze in search of some adaptive solid management strategies, and assess not only technology-based options but also market-based instruments.

Keywords: Ulaanbaatar city, Waste management, Waste treatment, Multi-Criteria Decision Making (MCDM), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method, Cost-revenue analysis, Life Cycle Assessment

CHAPTER I

1. INTRODUCTION

1.1 Background

Mongolia, located in Central Asia, has a vast area with a population of 3 million and a landlocked country situated in East Asia, bordered by China and Russia. Modern urban planning began in the1950s, with most of the old ger (Traditional tent) districts replaced by Soviet-style flats.

In 1990, Mongolia's transition to democracy and a market economy, and an influx of migrants from the rest of the country has led to an explosive growth in its population, a major portion of whom live in ger districts, resulting in changes in citizens lifestyles, this has increased waste production with a rising population, and the environment of Ulaanbaatar city is thus under novel threat. The residential area, i.e., the ger districts have expanded due to population flowing in from rural areas towards the capital, leading to a rise in mismanaged areas where garbage has accumulated.

Major characteristics of city. The city characterized by ger area and apartment areas, and citizens of 40 % are live in apartment area and connected to central pure water and heat dispatch systems. A ger district is a form of residential district in Mongolian settlements (Fig.1.1).

They usually consist of parcels with one or more detached houses or gers (hence the name), surrounded by two-meter-high wooden fences. In other countries, gers are known as Yurts. Most ger districts are not connected to water supplies, so people get their drinking water from public wells. For a warm

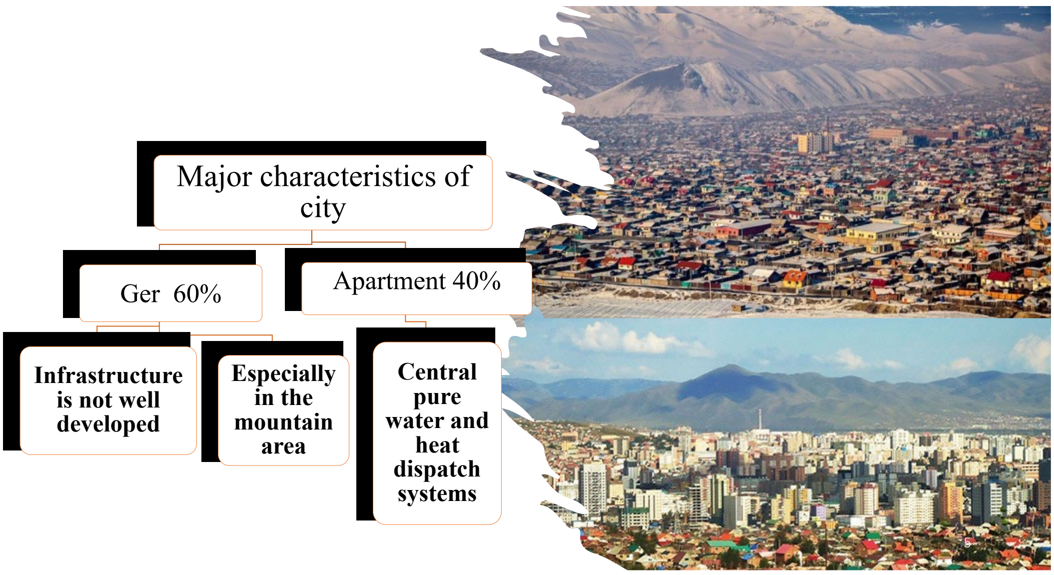

Fig. 1.1 Major characteristics of city

shower or a bath, there are bathhouses. Since there is no sewer system, ger district parcels usually have a pit toilet. Even in capital Ulaanbaatar, around 60% of the population live in ger area, especially in the mountain area where infrastructure is not well developed. As a result, the population of the city is increasing, and the area of Ulaanbaatar is expanding year by year. Depending on the lifestyle both in the apartment and ger district, the amount and types of waste are different between summer and winter. Because, city has changeable climate, and there are big temperature differences between the summer and winter seasons. Especially in the winter, since the outside is extremely cold, the citizens in "ger" need to burn coal in their homes to heat in winter. An oft-cited problem of ger districts in Ulaanbaatar and several other larger Mongolian cities is the air pollution and ash waste (especially in winter) caused using simple iron stoves for cooking and heating (Enkhchimeg., B, Takehiko.M.2021)

It is resulted, there are many illegal dumpsites huge amount of coal ash in the ger districts and one of the reasons for environmental pollution in the city.

Climate. Owing to its high elevation, its relatively high latitude, its location hundreds of kilometers from any coast, and the effects of the Siberian anticyclone, Ulaanbaatar is the coldest national capital in the world.

According to the Ulaanbaatar city, meteorological and environmental analysis department (2022), an average high-temperature of 24.5°C (76.1°F) and an average low-temperature of 12.9°C

Ulaanbaatar is the coldest national capital in the world

- Warmest month – July
- Summer reaches +27
- Average humidity - 60%

- Roads and streets are covered by ice and snow.

Fig.1.2 Changeable climate country

(55.2°F), July is the warmest month, and the average relative humidity is 60% in Ulaanbaatar, Mongolia. Winter starts in December and ends in February, the ger households burn coal in their oven during this long winter. Because in winter it reaches -30 degrees of centigrade and in this season most roads and streets are covered by ice and snow. It is very difficult to remove all ice and snow from the land surface during cold weather and it demands a very high cost. In this connection, the roads are slippery with ice in the mountain area, therefore it is hard to get waste trucks to the remote areas. Also, burning coal results in producing huge ash waste generation in the ger district. In the Fig.1.2, shows that there is a big temperature gap between summer and winter in the city.

Socio-Economic situation. The Mongolian economy is relatively diversified. Agriculture accounts for about 33% of gross domestic product (GDP), industry and construction for 27.5%, and services for about 40% (Statistical Yearbook, 2018).

Mining ventures, mainly in copper, provide an estimated 37% of the economy's export earnings (2018). Mongolia possesses more than 70 million head of livestock (by end of 2020), as well as sizeable reserves of copper, gold, coal, and other minerals.

According to World bank report (2022), over the past 30 years, Mongolia has transformed into a vibrant democracy, tripling its GDP per capita since 1991. With vast agricultural, livestock and mineral resources, and an educated population, Mongolia's development prospects look promising in the long-term assuming the continuation of structural reforms. Mongolia's economic growth is projected to rise slightly but remain modest at 2.4% in 2022, with the rise mainly driven by the removal of COVID-19 related restrictions and a strong rebound in the agriculture sector. Rising private and public investments and household consumption are expected to support domestic demand. Mongolia's national poverty headcount rate in 2020 was 27.8%, 0.6% points lower than in 2018. While estimates show that poverty in 2020 was slightly lower than it was in 2018, the COVID-19 pandemic has sharply slowed down the pace of poverty reduction. Simulations indicate that had the COVID-19 pandemic not occurred, the poverty rate may have declined to 24.3% in 2020, suggesting that the pandemic may have contributed to an increase in poverty by about 3.5% points in 2020. The wide array of COVID-19 relief packages, including top-ups on existing social assistance programs, played a crucial role in preventing a rise in poverty between 2018 and 2020. Total budget expenditure remained high, driven by higher social

Population growth :

2.2% per year

- GDP:

2015 -6.7%

2020 -3.7%

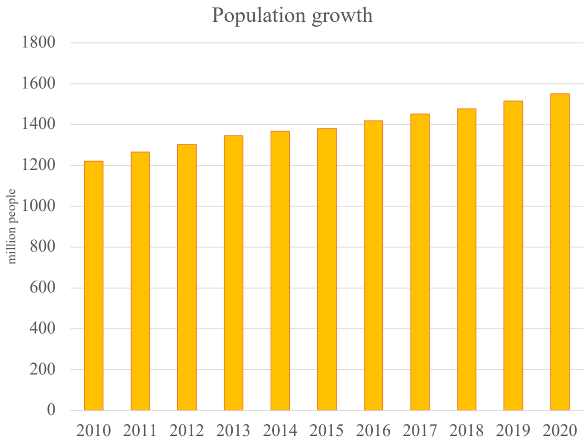

Fig.1.3 Socio-Economic situation and Population growth

welfare spending. The consolidated budget expenditure increased by 12% in 2021 to reach 32% of GDP, mainly due to higher spending on social protection and welfare. Social welfare spending reached 7% of GDP in 2021, up from 2.4% on average during 2017 to 2019, reflecting generous but poorly targeted government income support measures. Moreover, health expenditure increased to 5.3% of GDP in 2021 from 3.7% in 2020, following the surge in domestic COVID cases in 2021. While recurrent spending increased to 29% of GDP in 2021, capital expenditure dropped to 6.9% of GDP in 2021 from 8% in 2020 but remained above its average during pre-COVID years.

Population density and growth. According to the Ministry of Labor and Social Protection introduced, Ulaanbaatar has experienced steady growth in its population since the 1920s, mostly because of migration, primarily from the rural areas around the city. The city has grown nearly 1,000 times over the last 88 years to reach its current population. Population density or the number of people per sq. km in Mongolia has increased by 0.4 to 2.1 sq. km and the city covers over 1,800 square miles and has a population density of 704 people per square mile. 46% of Mongolia's population resides in capital city of Ulaanbaatar, 19% living in the Khangai region, 16% in the central region, 13% in western areas and 7% in eastern aimags. In terms of population age structure, the share of children aged 0-14 comprised 31.5% of the total population, people in the 15-64 age bracket make 64.4% while people aged over 65 are 4.1% of the population.

During the transition period between 1990 and 2002, there was, in essence, no regulation in terms of urban planning and, as a result, many “illegal” buildings were built; ger districts in UB grew by 58% during this time (Bolorchimeg.B,. Mamoru.I, 2017).

Ulaanbaatar is the most populated administrative area in Mongolia. More than half of the 1.3 million residents of Mongolia’s capital, Ulaanbaatar. According to the 2020 census, the population of Ulaanbaatar city is 1,499,140 and the number of households is 414,292. Based on these statistics, since the 2010 national census, Ulaanbaatar’s population is expected to continue to grow, and the residents of Ulaanbaatar city has grown by an average of 2.2% per year (Fig.1.3). Also, in 2019 a revised population projection of Mongolia, which expects the population will increase to four million by 2030 and to five million by 2045.

Environment. Mongolia’s natural ecosystems are relatively fragile, given that they are highly susceptible to degradation by both natural and human impacts, and slow to recover. Furthermore, Mongolia's endowment of renewable natural resources is limited. In urban areas, environmental and natural resource issues, such as air quality, water supply, waste disposal, and land degradation, have reached a critical stage. Beyond the cities, other pressing environmental issues include locally severe environmental degradation from mining and petroleum extraction, natural disasters, and damage to natural heritage (including biodiversity). Meanwhile, a significant portion of the land resources in Mongolia are threatened by overgrazing, deforestation, erosion and desertification.

1.2 Current situation of waste management in city

The city has no waste sorting system and large amounts of waste are transported to landfills without sorting. Besides, due to waste transportation fees are not very high, this created a waste management system with high cost and low income. Also, the reason of the increasing illegal waste, the waste collection date and point has been not fixed. Especially, waste collection is very hard in the ger areas. Because, road conditions are poor, population density is low, and households and neighborhoods are haphazardly organized, making garbage collection inefficient. Illegal dumpsites for household, commercial, and industrial waste have proliferated in public spaces, partly due to the lack of dependable garbage collection service, and partly because many ger residents are new to the urban setting and are accustomed to disposing of their waste informally.

According to the responses in interviews that we conducted on visits to the Narangiin Enger landfill site, and Scavengers collect recyclable waste products, including bottles, cans, plastic bottles, metal, and old electronic devices in severely toxic conditions. These scavengers sell the collected items to waste transfer centers. From there, all those recyclable waste products go to very limited, low power recycling plants, and the remaining items are exported to China.

Waste management policy in the city. According to Office of the Mayor of Ulaanbaatar city, department the law on “Environmental Protection” and Government National Plan on “Waste reduction management” were enacted by the Mongolian Parliament in 1995 and 1999 respectively. Several national policies have been developed and approved by the Government such as National Policy on Ecology in 2000. In spring 2012, the Parliament of Mongolia adopted a “New Law on Waste” combining the Law on Household and Industrial Waste and Law on Hazardous and Toxic Chemicals. The new Law has introduced 3R principles. In addition, a Waste Reduction Action Plan was approved by the Government. Mongolia faces number of challenges in waste management. There is a lack of national coordination on waste management policies. The technical and human resources for the solid waste management in the country are inconsistent. Currently insufficient budget is allocated to the waste management at national as well as local level and poor public involvement, particularly private sectors, and civil groups.

According to the waste management structure, the local governments are responsible for overall management of industrial and domestic solid waste in Mongolia, although most local governing authorities have limited human resources or have neither sufficient financial resources nor the machinery or technology to properly manage waste. The implementation of the Government policy has been delayed, however, in all but areas around the capital city, due to sparse population and insufficient finances, as well as lack of knowledge and technology in relation to the management of waste. However, there are many requirements can be named under this issue; the major decisive challenges can be divided into 3 levels including three parts’ participation. First of all, in national level government has to upgrade its legal system as well as reform methods of controlling and implementing them with high consideration of future changes, Secondly, in local administrative level the city authorities has to research possibility to recycle and reuse by constructing related infrastructures, as well as reform waste payment and punishment system while improving public education on managing waste. Thirdly, in communal level public organizations and NGO's participation is needed to improve people's contribution in the society by providing them proper knowledge and information to build the social habit to manage waste properly.

Waste treatment facility in the city. Currently, there are no waste-to-energy facilities in UB. However, a refuse derived fuel (RDF) facility was constructed with the assistance of the KOICA.

The state inspection agency's results state that the facility was not constructed according to the specifications and the laws of Mongolia. The facility could not operate due to 3 main reasons.

- Occurrence of blocking condition from not installing the crusher of RDF production facility,
- Absence of RDF consumers, to due inclusion of harmful substances in the RDF ingredient,
- Inadequacy of ventilation and heating facilities.

1.2.1 The waste amount and distinctive feature

According to report from the Ulaanbaatar Waste Management Department (2010 to 2020), 2,697.3 tons/day in winter (from December to February), and 3,445.5 t/day in the summer (from June to August) of waste is transported and buried to the landfill site in the city, as seen in Fig.1.4. Based on the investigation of average waste composition data of MSW in the city region wide, the waste stream has 22% to 24% mixed waste, 18% to 20% organic waste (livestock bone), 24% to 25% recyclable waste (such as metal, glasses, paper, plastics, and livestock leader), other waste 22% of the total waste in winter and summer. Metals, glass, paper, and organic waste are separated for recycling. Residual paper, plastic such as contaminated with other waste and mixed wastes can be used in waste incineration plant and mechanical biological treatment. In winter, 14% ash from Ger areas, and 9% construction waste from will be removed by landfill method

Recyclables. In the Ulaanbaatar city no legal regulation to sort waste. Due to the lack of was sorting, a few private recycling plants are not able to operate on a regular basis. Recycling materials delivered through waste pickers and recycling agents are expensive due to transportation cost and other expenditures. Currently, 23 small and medium-sized recycling plants are in operation where metals, paper, glass, and plastic waste products are processed.

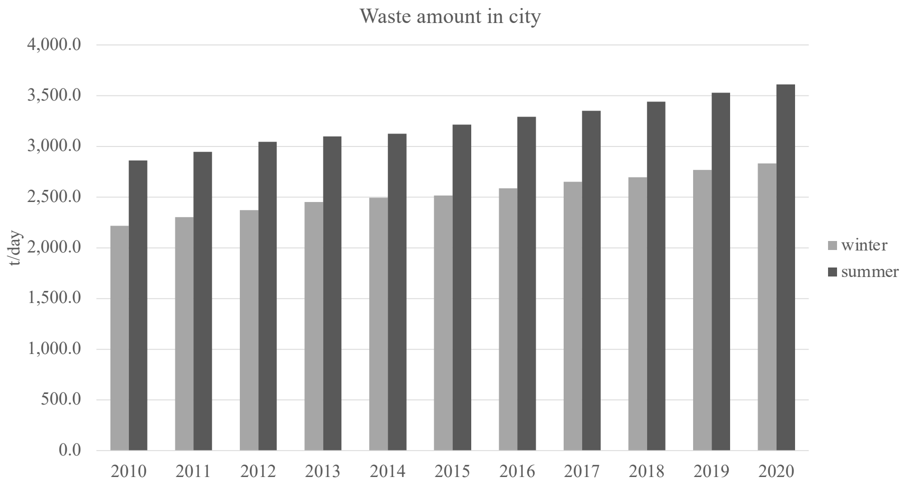

Fig.1.4 Waste generation volumes in city from 2010 to 2020

Mongolia is a livestock country and generated huge amount of animal product waste. However, it has not been studied in detail. Animal product waste connection with the Mongolian lifestyle, livestock bone and leather (18%) are occupying large amount in food garbage and recyclables waste.

According to the previous study, the yearly meat consumption per person is 96 kg in Mongolia and 30% is bone.

Ash. In winter, ash (14%) from ger areas will be removed by the landfill method. According to the information from the "Air quality division" of the Ulaanbaatar city governor's office, 62% of all households live in ger and 3-5 tons of coals are used for each ger household. 127,596 ger households use 504,500-600,500 tons of coal is burnt in small ovens per day for their heating. It can be seen from this estimation that 35 tons of coal is burnt every day and generate ashes. The Ulaanbaatar city governor's office must research possibility to recycle and reuse the ashes from house-regions actively. Also, the office can search possibilities, to make construction materials in light concrete industries by using material industries. Some research for reusing ashes, which are from power stations, are made any research for appropriate versions of reprocessing, especially for house-regions. The most important problem for making construction materials by using ashes is there are under-burnt coals in ashes. Ashes consisted of many kind substances and mixed with other solid wastes.

Illegal waste. Is shown in the result of the survey, the illegal wastes are relatively huge compared to the daily waste products. Particularly, depending on the lifestyle of ger households, the coal ash is generated much more in winter season and in some case thrown illegally. Because of Mongolia windy weather in spring season, the illegally thrown wastes are flapping and being spread in the large land.

1.2.2 Waste collection and transportation

According to Ulaanbaatar city, Waste Management Department report (2018), municipal waste of households and enterprises of Ulaanbaatar city is transported to three landfill sites by 289 trucks that belong to 18 waste transportation companies. Waste trucks in city, of which only 70%-85% are used daily. Because waste trucks break down during the transportation, due to damage caused by the transportation of heavy goods on mountainous, non-asphalt roads.

Before the 1990s, Mongolia had a centralized economic system, and the transportation of waste belonged to the state organization. The capacity of the waste state-owned entity was limited and had a limited number of trucks operated every day. Since that time, as transferred to a market-oriented economy, socio-economic life, as well as living style, has completely changed. In connection with this transfer, consumption of household raised, and household waste was also increased. Although a waste management system was developed compared to the previous society, unfortunately, there is still a lack of proper waste management system and capacity. Due to slippery roads in winter, the amount of garbage transport is less than in summer. Information on waste transportation routes and fuel consumption is unclear in some districts, making it difficult to analyze waste costs. Overall, a lack of information is one of the main obstacles to improving waste management systems. Recycling it are important for decreasing the amount of waste, which transported and to be eliminated in centralized dust-points. The ash can be used for construction materials. However, no sorting system, amount of generation waste is directly transported landfills. Besides in, the few private recycling plants in Ulaanbaatar are not able to operate on a regular basis. Recyclables delivered through waste pickers and recyclables are expensive, due to high transportation cost and other associated expenditures. Also, half the waste disposal budget is spent on waste transportation services alone.

1.2.3 Payment of waste transportation

According to the Ulaanbaatar city, Waste Management Department report (2018), 95% of apartment households, 40% of ger households and 60% of enterprises have paid their waste fee, every month. This fee is not sufficient for transporting all wastes to the landfills, its connection, city governor needs to allocate additional waste transportation budget to the whole city budget every year.

Monthly waste transportation fee for a household is 2000-3000 Mongolian tugrug (appr.1.2-1.7 USD) and that is fixed for each month on the other hand the fee is not depending on waste size and dimension. Although, there are differences between the wastes produced by the apartment and the ger households in winter season, unfortunately there are almost no differences for waste fees between them. It can be concluded from the above mentioned that the payment system of waste in Ulaanbaatar city is not balanced. Although, there are significant improvements in solid waste management in Ulaanbaatar, there remain some major problems. Municipal solid waste management still lacks capacity and effective methods of regulation. Governmental subsidy is insufficient, making the Municipal Solid Waste Management system solely dependent on waste collection fees from citizens.

1.3 Problem statement in city

The current situation of Ulaanbaatar city and problems with waste management is like other developing countries. To create a new model of waste collection, transportation, and treatment system and to enhance waste management, first, it is better to determine the amount of waste and distinctive features of generated waste (Shigefumi Okumura, 2017)

Lack of financial planning and management capabilities is common in many developing countries. Furthermore, a developed recycling industry is a prerequisite for the recycling process, and recycling factories are required for overseas waste disposal or for waste disposal in remote areas, where transportation costs are high, and an adequate recycling business cannot be established. (Batkhuyag,.et al, 2016)

These values show that the current system of waste management is still underdeveloped and is in dire need of immediate attention and improvement, especially in Ulaanbaatar city (Bolorchimeg.B,.et al, 2017).

Extensive environmental education is essential for collaboration with the community. In addition, the problems of unemployment and poverty are inextricably linked to the existence of waste pickers, and social consideration in waste management is required (U. Bilguun., et al, 2017)

Due to rapid urbanization especially in developing countries, the amount of solid waste and household hazardous waste has been increasing; however, municipal waste management and treatment capacity are not able to handle the waste. The municipal revenue from taxpayers is not enough (Temuulen.M, 2015).

Ulaanbaatar has three landfill sites in the mountains outside of the city. These landfills have no facilities for treatment or to prevent trash scattering or leakage. Burning waste is normally in the open landfill, allowing smoke and fly ash to settle over the city and “ger” area. The open burnt waste of many kinds of wastes gives the rise to concerns about the de novo synthesis of dioxins, and the contamination of soil, crops, and livestock by these and other hazardous substances (Temuulen Murun (2015)).

The soil erosion and contamination spread all over Ulaanbaatar due to expanding Ger district, and illegal land applications. There are almost no soil-reclamation activities, such as covering the soil with green plants or trees in Ulaanbaatar (Batkhishig., et al, 2013)

Illegal dumpsites are common in the ger areas and are the result of various factors including infrequent household collection, lack of central collection points to dispose of waste, and poor sensitization of residents. Due to those unpredicted citizens increase and movement from countryside to the city, civilization has occurred which resulted in big change in increasing many factories, luck of public transportation, and environment pollution and expanding ger area. These problems have dramatically increased to solve. Besides that, as the lifestyle and socio-economic situation of the citizens are changing, amount of the municipal waste are also increasing, in this regards type of generated waste are also increasing. In addition, it is the worst management because it is not possible to generate revenue via waste landfill disposal. Therefore, it is necessary to consider methods such as burning waste to waste incineration plant renewable energy source. Additional options also include processing fertilizers or separating recyclable materials by Mechanical Biological Treatment (MBT).

CHAPTER II.

2. LITERATURE REVIEW AND SOLID WASTE MANAGEMENT IN THE ULAANBAATAR CITY

2.1. Global waste management situation

Waste amount. According to the World bank report (2022), The world generates 2.01 billion tons of municipal solid waste annually, with at least 33% of that—extremely conservatively—not managed in an environmentally safe manner. Worldwide, waste generated per person per day averages 0.74 kilogram but ranges widely, from 0.11 to 4.54 kilograms. Though they only account for 16% of the world's population, high-income countries generate about 34%, or 683 million tons, of the world's waste. When looking forward, global waste is expected to grow to 3.40 billion tons by 2050, more than double population growth over the same period. Overall, there is a positive correlation between waste generation and income level. Daily per capita waste generation in high-income countries is projected to increase by 19% by 2050, compared to low- and middle-income countries where it is expected to increase by approximately 40% or more. Waste generation initially decreases at the lowest income levels and then increases at a faster rate for incremental income changes at low-income levels than at high income levels.

The total quantity of waste generated in low-income countries is expected to increase by more than three times by 2050. The East Asia and Pacific region is generating most of the world's waste, at 23%, and the Middle East and North Africa region is producing the least in absolute terms, at 6%. However, the fastest growing regions are Sub-Saharan Africa, South Asia, and the Middle East and North Africa, where, by 2050, total waste generation is expected to more than triple, double, and double respectively. In these regions, more than half of waste is currently openly dumped, and the trajectories of waste growth will have vast implications for the environment, health, and prosperity, thus requiring urgent action. High-income countries generate relatively less food and green waste, at 32% of total waste, and generate more dry waste that could be recycled, including plastic, paper, cardboard, metal, and glass, which account for 51% of waste. Middle- and low-income countries generate 53% and 57% food and green waste, respectively, with the fraction of organic waste increasing as economic development levels decrease. In low-income countries, materials that could be recycled account for only 20% of the waste stream. Across regions, there is not much variety within waste streams beyond those aligned with income. All regions generate about 50% or more organic waste, on average, except for Europe and Central Asia and North America, which generate higher portions of dry waste.

2.1.1 Waste treatment in the world

Waste collection is a critical step in managing waste, yet rates vary largely by income levels, with upper-middle- and high-income countries providing nearly universal waste collection. Low-income countries collect about 48% of waste in cities, but this proportion drops drastically to 26% outside of urban areas. Across regions, Sub-Saharan Africa collects about 44% of waste while Europe and Central Asia and North America collect at least 90% of waste. It is a frequent misconception that technology is the solution to the problem of unmanaged and increasing waste. Technology is not a panacea and is usually only one factor to consider when managing solid waste.

Countries that advance from open dumping and other rudimentary waste management methods are more likely to succeed when they select locally appropriate solutions. Globally, most waste is currently dumped or disposed of in some form of a landfill. Some 37% of waste is disposed of in some form of a landfill, 8% of which is disposed of in sanitary landfills with landfill gas collection systems. Open dumping accounts for about 31% of waste, 19% is recovered through recycling and composting, and 11% is incinerated for final disposal. Adequate waste disposal or treatment, such as controlled landfills or more stringently operated facilities, is almost exclusively the domain of high- and upper-middle-income countries. Lower-income countries generally rely on open dumping; 93% of waste is dumped in low-income countries and only 2% in high-income countries. Three regions openly dump more than half of their waste—the Middle East and North Africa, Sub-Saharan Africa, and South Asia. Upper-middle-income countries have the highest percentage of waste in landfills, at 54%. This rate decreases in high-income countries to 39%, with diversion of 36% of waste to recycling and composting and 22% to incineration. Incineration is used primarily in high-capacity, high-income, and land-constrained countries. Based on the volume of waste generated, its composition, and how it is managed, it is estimated that 1.6 billion tons of carbon dioxide (CO2) equivalent greenhouse gas emissions were generated from solid waste treatment and disposal in 2016, or 5% of global emissions. This is driven primarily by disposing of waste in open dumps and landfills without landfill gas collection systems. Food waste accounts for nearly 50% of emissions. Solid waste–related emissions are anticipated to increase to 2.38 billion tons of CO2-equivalent per year by 2050 if no improvements are made in the sector. In most countries, solid waste management operations are typically a local responsibility, and nearly 70% of countries have established institutions with responsibility for policy development and regulatory oversight in the waste sector. About two-thirds of countries have created targeted legislation and regulations for solid waste management, though enforcement varies drastically. Direct central government involvement in waste service provision, other than regulatory oversight or fiscal transfers, is uncommon, with about 70% of waste services being overseen directly by local public entities. At least half of services, from primary waste collection through treatment and disposal, are operated by public entities and about one-third involve a public-private partnership. However, successful partnerships with the private sector for financing and operations tend to succeed only under certain conditions with appropriate incentive structures and enforcement mechanisms, and therefore they are not always the ideal solution. Financing solid waste management systems is a significant challenge, even more so for ongoing operational costs than for capital investments, and operational costs need to be considered upfront. In high-income countries, operating costs for integrated waste management, including collection, transport, treatment, and disposal, generally exceed $100 per ton. Lower-income countries spend less on waste operations in absolute terms, with costs of about $35 per ton and sometimes higher, but these countries experience much more difficulty in recovering costs. Waste management is labor intensive, and costs of transportation alone are in the range of $20–$50 per ton. Cost recovery for waste services differs drastically across income levels. User fees range from an average of $35 per year in low-income countries to $170 per year in high-income countries, with full or nearly full cost recovery being largely limited to high-income countries. User fee models may be fixed, or variable based on the type of user being billed. Typically, local governments cover about 50% of investment costs for waste systems, and the remainder comes mainly from national government subsidies and the private sector

2.2 Global system analysis for solid waste management

To further elucidate the essence and uniqueness of systems analysis, it would be very insightful if those systems engineering models for SWM may be reviewed and discussed individually in greater detail. From a technical point of view, four modeling techniques can be classified as: 1) CBA, 2) FM, 3) SM, and 4) OM, and 5) IMD. These form the basis of the review of different types of analytical tools for system assessment in the next section.

2.2.1 System Engineering Models

Complexity in SWM system arises from siting facilities, selecting technologies, and comparing management options. To tackle the synergistic interfaces, systems engineering models can be helpful for promoting analysis based on cost-benefit analysis (CBA), optimization models (OM), simulation models (SM), forecasting models (SM) and integrated modeling systems (IMS).

Cost-Benefit Analysis (CBA). Cost-benefit analysis is a modeling technique for decision-makers to assess the positive and negative economic effects of a project or policy in which all relevant impacts are measured in both physical and monetary values. The theoretical foundation of CBA is economic welfare theory expressed through the linkages of the willingness-to-pay for a benefit and the willingness to accept for a cost. Within such a context, benefits are defined as increases in human well-being (utility), and costs are defined as reductions in human well-being. In many applications of SWM, it is necessary to estimate the monetary value of environmental and ecological impacts (i.e., indirect benefits and costs) which do not have a direct price estimable via the market mechanism so that the non-market value of natural resources can be considered in decision analysis for SWM (Boardman et al., 2001).

Those goods with no market value are often referred to as public goods ‘. However, the value of these public goods must be derived in some unique ways, such as through observed behavior, surveys, or estimated shadow prices (Boardman et al., 2001).

The idea of decision making behind CBA is that a project should be carried out if the sum of direct and indirect benefits exceeds sum of the direct and indirect costs (EEA, 2003).

Economic impacts in this regard were assessed through the quantification of costs (capital, operational and expansion from different waste unit operations, tax/fees) and revenues (energy production, materials like recyclables and compost). Oftentimes, the value of all costs and benefits involved may be expressed as an assessment metrics in a case-based scenario of SWM for justification as a pure CBA or as an integral part of the FM, SM and OM. For this reason, as one of the objective functions, CBA is always deemed an integral part of systems engineering models. However, this should not prohibit CBA to be deemed as an independent system assessment tool. From policy standpoint, this metrics with having all CBA, FM, SM, and OM components cohesively integrated can be used in the ex-ante evaluation for the selection of an investment project (EEA, 2007a. 2007b).

Yet, this metrics can also be used in the ex-post evaluation to measure the economic impact of an intervention when its effects may go beyond the simple financial effects for both the private and public investors in major infrastructure projects, especially in the transportation and environmental sectors (EEA, 2007a).

Some countries have developed guidelines such as the Nordic guideline for CBA in solid waste management specifically for waste management (Nordic Council, 2007).

The methodology can be generally described by the following five steps: 1) objective definition and scope, 2) inventory, 3) monetary valuation, 4) discounting and 5) evaluation. Objective definition and scope is needed to precisely identify the problem to analyze which alternatives are to be assessed, functional units, system boundaries, and time horizon. Inventory is the step to be used for listing economic effects, effects from treatment of waste (Reuse to final disposal of waste), time consumption and space in households, and environmental effects. Monetary valuation should be carried out to estimate direct and indirect economic costs and benefits in a project properly discounted to the present value based on the choice of a discount rate. Evaluation is the last step, resulting in the result of the assessment in terms of net present value. The applications of CBA to aid in decision making of SWM systems may be deemed essential regardless of whether other types of models, such as forecasting, simulation, and optimization models, need to be applied.

Forecasting Models. Both planning and design of SWM systems require accurate prediction of solid waste generation (Dyson and Chang, 2005).

Obtaining data related to solid waste generation is a difficult quest. At the onset of a SWM system, it is necessary to characterize the waste streams quantitatively and qualitatively and construct a management information system to accumulate the information flows over time. Even so, data from historic records normally is not available and data is often highly uncertain mainly because of its vague nature and disparate records in measurements. To capture the trend in waste generation, forecasting models have been developing since the 2010s for solid waste management, based on methods like system dynamics, regression analysis, multiple regression analysis, correlation analysis, grey fuzzy dynamic modeling, time series analysis and material flow analysis methods. Decision and policy makers in SWM systems or governmental institutions often prefer to apply forecasting models to avoid missing links in long-term ISWM planning. Single and multiple regression analyses are the most common forecasting methods for estimating solid waste generation. These models are designed to describe and evaluate the relationships between a given variable (e.g., waste generation) and one or more relevant variables for making good predictions of the future trend of waste generation. When applied, they predict the outcome of a given factor (dependent or explained variable) based on the interactions with other related drivers (independent or explanatory variables). Factors that influence solid waste generation are normally related to population (Grossman et al., 1974, Saeed et al., 2009, Jiang et al., 2009), income level (Grossman et al., 1974; Beigl et al., 2005), dwelling unit size (Grossman et al., 1974), total consumer expenditure and gross domestic product (Daskalopoulos et al., 1998b), production measures, household size, structure, and per capita retail and tipping fees for waste disposal (Hockett et al., 1995).

These modes therefore help understand which variables are best related to solid waste generation. Factors identified as relevant often include household size, tenure, and type of accommodation, home heating arrangements, employment status, social class, education level attained by head of a household, and age profile of residents (Abu- Qdais et al., 1997; Dennison et al., 1996a, b; Benítez et al., 2008).

Recently, Beigl et al. (2008) presented a review concerning forecasting models applied to support SWM systems. Thøgersen (1996) used single regression analysis to assess relations between MSW production and consumption styles and Gay et al. (1993) have applied input-output analysis to estimate county and city- level solid waste composition and generation.

Simulation Models. Simulation modeling is defined as the use of digital computers to trace lengthy chains of continuous or discrete events based on the cause-and-effect relations describing the operations in complex systems and helping investigate the dynamic behavior of the system (Wang et al., 1996).

When applied to handle SWM issues, the interactions between selected variables, each of which can affect and be simultaneously affected by the others, can hardly be amenable to purely mental evaluation or ordinary mathematical treatment (Wang et al., 1996). Making an analogy to Driving Forces-Pressures-State-Impacts-Responses (DPSIR) framework terms, simulation models predict the state and sometimes the impact of determined pressure (Wang et al., 1996).

Such efforts may help to predict the consequences of some sources of environmental impacts with or without involving the time domain. In SWM systems, it is possible to use the same perspective for investigating the behavioral patterns of the system of systems with changing inputs when choosing parameters to understand how the object that is being simulated, behaves (state). The purpose of such simulation models in this field can be logistic simulation, single and multi-machine processes, simulation of the environmental fate and transport of waste constituents, and simulation of costs and schedules for waste management project or program (Miller et al., 2003).

Such simulation models can test the SWM systems at low cost. With such a tool at hand, it is possible to allow the exploration of complex systems in many ways (Wang et al., 1996).

The more variables (e.g., locations of facilities, size and type of collection trucks, type of recyclable materials to be collected) that users can specify, the more dimensions the model can investigate when simulating a complex system. These computer-based models can then simulate the dynamic evolution of a real or proposed system and could be formulated via a spreadsheet based, discrete-event, transaction-based approach to modeling specific changes to the system in the context of system dynamics studies (Miller et al., 2003).

Within this context, spreadsheet-based models are the most used, Microsoft Excel being the predominant software package. These models typically use columns in the spreadsheet to represent the system ‘s state variable at a point in time. They consist of entities (units of traffic), resources (elements that service entities) and control elements (elements that determine the states of the entities and resources). Therefore, the applications of such models can make SWM systems process waste streams more easily understandable (i.e., in other words, how the waste life cycle works) and can show, through trying different changes in simulation, whether there is a need for improving the SWM systems. In the context of system assessment, the applications of simulation tools for decision making can be further classified into two different types of models.

One type encompasses the environmental assessment models, like LCA and MFA models, and the other type assesses only the functionality of SWM systems. The LCA and MFA models will be discussed independently in separate subsections below as part of the assessment tools.

Optimization Models. Optimization models are the core of the systems engineering modeling approach. Single objective programming (SOP) models aim to search for the optimal solution associated with a well-defined SWM problem in which there is a single objective and several technical and managerial constraints in the context of MCDM (Edwards-Jones et al., 2000).

These models were often applied to help solve cost minimization issues and were normally formulated by deterministic methods, including linear programming, non-linear programming, dynamic programming, and mixed-integer programming models. Along these lines, these optimization models can optimize economic issues like the minimization of total costs or to maximize the total benefits to help the vehicle routing (Liebman et al., 1975), to decide what type of SWM system should be designed and the location of landfill facilities, incinerators, transfer stations (Anderson and Nigam, 1967; Anderson, 1968; Esmaili, 1972; Helms and Clark, 1974; Marks and Liebman, 1970, 1971; Gottinger, 1986, 1988; Kirka and Erkip, 1988).

Approaches applied to improve results might concern uncertainty associated with either datum or the waste management decision making itself. The methods that were applied for addressing the uncertainty impacts mainly consist of fuzzy set theory, grey system theory, and probabilistic theory. Some of these techniques are used alone or in combination with others. Stochastic programming requires large data sets for the identification of the probabilistic distributions, and its application is helpful to effectively reflect the probability distributions of a single right-hand side value in a constraint of optimization models (Huang et al., 2001; Li et al., 2006c).

A subjective continuous membership function is usually used for the description of this kind of vague information (Chang et al., 1997a). It enables one to deal with uncertainties connected with vagu linguistic expressions in decision making when probabilistic data are not available. Grey systems theory applied to support optimization analysis in SWM systems is capable of dealing with several uncertain parameter values while at the same time addressing the vagueness of its intrinsic characteristics in the information during parameter estimation (Chang et al., 1997a).

Such parameters are most likely expressed as interval numbers linked with the environmental or economic factors in objective functions and constraints. It was applied to handle a variety of uncertainty concerns associated along with costs minimization in different SWM systems with respect to construction and expansion planning of waste management facility and waste flow allocation planning (Huang et al., 1992, 1994, 1995a, b). Huang et al. (1993) first conducted cost minimization using a grey fuzzy integer programming model. Huang et al. (2001) pointed out that integrated methods with various combinations of the three uncertainty theories above can produce answers concerning types, times, and sites for SWM practices with improvements in uncertainty, data availability and computational requirements. Such integration enables us to handle uncertainty of different sources at the same time (Zou et al., 2000).

With such a philosophy, the interval- parameter fuzzy-robust programming model was developed and applied to a SWM system to minimize the total system cost through optimal waste flow allocation (Nie et al., 2007).

Facing the need to include multiple objectives, such as the need for minimization of total cost and maximization of recycling efforts at the same time, multi-objective programming (MOP) models were often formulated and applied. These deterministic MOP solution procedures may search for the compromised or satisfactory solution via a variety of methods. They include, but are not limited to the AHP, TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution), ELECTRE (Elimination and Choice Translating Algorithm), PROMETHÉE (Preference Ranking Organization Method for Enrichment Evaluation), and NAIADE (Novel Approach to Imprecise Assessment and Decision Environments), to aid in SWM decision making (Caruso et al., 1993; Hokkanen and Salminen, 1997; Chang and Lu, 1997; Chang et al., 2009).

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Table.2.1 System Engineering Models

Types of systems engineering models	Description
Cost-benefit analysis	To assess positive and negative economic and physical effects independently or support simulation and optimization models for systems analysis
Optimization model	To reach the best solution among numerous alternatives, considering one or several objectives.
Simulation model	To trace the lengthy chains of continuous or discrete events based on cause-and-effect relations describing the operations in complex systems and helping investigate the dynamic behavior of the system
Forecasting model	To characterize waste streams quantitatively and qualitatively and construct a management information system to accumulate information over time. To predict waste generation, time-series regression analysis
Integrated modeling systems	To improve synergistic connections among different models, concatenating their total functionalities.

during parameter estimation (Chang et al., 1997a).

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Integrated Modeling System. The Integrated modeling system class consists of different types of models which, by their nature, present different features, scales, and complexity. From an environmental point of view, they may significantly help address the forcing of human-induced impacts, identify the responses in the environmental systems, and assess consequences due to such disturbances in our society (Huang and Chang, 2003).

From the perspective of MSW management, the use of IMS can be helpful to understand the driving forces that are responsible for the SWM system behavior and the consequences of that outside the systems. Models used in the context of IMS therefore may cover the integration or coupling of simulation, forecasting, and optimization analyses. This is, however with a higher uncertainty, most of the time, since data from SWM systems are often of low quality, the methods that were employed to address various types of uncertainties by themselves, exhibit a higher variation over time in the context of integrated modeling analysis.

2.2.2 Analytic tools for system assessment

The classification of analytical tools for system assessment includes: 1) SD, 2) MFA, 3) LCA, 4) RA, 5) EIA, 6) SoEA, 7) SA. They are complementary in many real-world applications. A summary of all the contemporary assessment tools for various process assessments would be very helpful for model synthesis and integration when dealing with a variety of SWM systems in different countries.

Material Flow Analysis. Material Flow Analysis According to Brunner and Rechberger (2003), material flow analysis (or accounting) is a systematic assessment of the flows and stocks of materials within a system defined in a space and time. It connects the sources, the pathways, and the intermediate and final sinks of a material management (Brunner and Rechberger, 2003).

Because of the law of the conservation of matter, the results of a MFA can be controlled by a simple material balance comparing all inputs, stocks, and outputs of a process management (Brunner and Rechberger, 2003).

MFA have somewhat left the traditional SWM boundary, focusing on product consumption patterns, waste generation, recycling, recovery, and reuse. It is this distinct characteristic of MFA that makes the method attractive as a decision-support tool in resource - waste -, and environmental management (Brunner and Rechberger, 2003).

MFA can also be designed to understand the material flow that occurs during different phases of the product life relating it to temporal aspects so as to predict when it will become waste and in which phase of its waste life it will be standing. There exist three methods to make MFA practical (Brunner and Rechberger, 2003).

The first method is directly designed for addressing waste composition (sampling and waste characterization, including chemical analysis. The second one focuses on market product analysis, which requires information related to goods production and destination during their consumption. The third method is related to indirect analysis linking waste treatment with waste composition. The advantage of the third method is that the outputs of the process are less heterogeneous than waste inputs. In general, process- based MFA is primarily used to analyze specific questions of resources and waste management and industry-based MFA focusses more on the environmental impact of economic development by analyzing total material throughput in a system (Porter et al., 2005).

In the case study developed by Liu et al. (2006), on the other hand, the data considered were waste possession, obsolete ratio, population, sales, and number of households linking anthropogenic metabolism, meaning that it works based on economic principles, in the nexus of industrial ecology, economic planning, and waste management. These types of practices lay down the foundations of life-cycle assessments, eco-balancing, environmental impact statements, and waste management collectively.

Life-cycle Assessment. LCA is a framework to quantify (CO2, etc.) the environmental impacts of a product or service across all stages of its life cycle. Also, an LCA uses inputs on the amount of chemicals, water, energy, and raw materials used in each stage of production, such as resource extraction & processing, transportation, manufacturing, distribution, usage, and disposal. It then quantifies the environmental impacts in terms of various categories, such as a wastewater, solid waste. LCA includes the "Cradle to Grave", and it is the full Life Cycle Assessment from resource extraction (cradle) to use phase and disposal phase (grave). Also, LCA includes the "Well to Wheel", and it used for transport fuels and vehicles. The first stage (upstream) factors the feedstock or fuel production and processing and fuel delivery. The downstream stage deals with vehicle operation itself (i.e., tailpipe emissions). Some example uses of LCAs includes understanding the embodied carbon and broader environmental impact of an entire building. Comparing embodied carbon of different structural materials in a building (e.g., steel vs. concrete to choose the one with the lowest carbon footprint).

Life Cycle Cost Analysis. LCCA is the process for evaluating the total financial cost of an asset or investment over its service life. Life Cycle Cost Analysis goes beyond 'first cost thinking' – instead factoring in the total cost of ownership of design decisions. LCCA includes the initial cost (capital expenditure) plus the future costs of the asset like operational costs (e.g., utilities), maintenance costs, repair, and replacement. LCCA is useful because just focusing on the first cost can create long-term financial risk. For example, a 'cheaper', more unreliable & inefficient system can end up being more expensive over 20 years, as well as cause broader business resilience issues. Because LCCA just focuses on the pure financial impacts of an asset, and the output is in currency. It is very good for comparing decisions. Typical outputs of an LCCA are the total cost of the investment is currency, and return on investment as %, payback period as years to recoup the investment. Some example uses of LCCAs includes the quantifying the total cost of a building over its intended lifespan. Deciding between three different HVAC retrofit alternatives — each with different upfront costs, energy implications, and useful lives based on total cost of ownership (FEMP, 2011).

Life Cycle Impact Assessment. LCIA is a step for evaluating the potential environmental impacts by converting the LCI results into specific impact indicators. Conducting LCIA must follow several sub steps: First is to select impact categories for analysis. The major impact categories are divided into three general groups in terms of impacting subjects. Second is to assign the LCI results to different impact categories (classification). Third, the potential impact indicators are calculated (characterization. (Dongyan Mu, Chunhua Xin, Wenguang Zhou, 2020)

Socio-economic Assessment. Social impacts include non-technical indicators and criteria such as employment, public health, willingness to pay, odors, noise, traffic vehicles, and public participation. Socio- economic assessments are practices that apply integrated market-based and/or policy/regulation requirements for SWM such as Waste-to-Energy (WTE) taxation. The way that such system engineering models and assessment tools, like LCA, IMS, MFA, and SD, can perform largely fits in this mission. In the case of optimization analysis in the context of a full-cost accounting approach, the inclusion of these socio-economic factors into the models can be done through the use of financial objectives and/or constraints. For example, such applications include but are not limited to CBA-based linear programming (Chang et al., 1997a; Chang et al., 1996),

CBA-based integer programming (Chang et al., 2005), CBA- based fuzzy goal programming (Chang and Wang, 1997a), fuzzy contingent valuation method for fair fund distribution (Chang et al., 2009), GIP-based game theory for landfill space pricing (Davila et al., 2005), optimal control of landfill space consumption (Chang and Schuler, 1991), and CBA-based MCDM (Karagiannidis and Moussiopoulos, 1997; Rousis et al., 2008). They can also be linked with regulations in a wealth of SWM issues that expand the nature of these assessments such as DSS (Fiorucci et al., 2003; Costi et al., 2004), multiobjective programming (Minciardi et al., 2008), as well as the quality assurance requirements system products, like RDF. Table 2.1 summarizes the recent trend in this regard.

Sustainable Assessment. Sustainable assessment refers to the integration of different methodologies in such a way that is geared toward obtaining an analysis, an evaluation or a planning that approaches several management aspects in which the sustainability implications may be emphasized and illuminated. Such models are different to an IMS or others in terms of the sustainability concerns. For example, the development of such a SA scheme may be motivated by taking the energy production and material recycling into account when modeling the SWM systems allowing the system planning/evaluating/analysis to become more sustainable. In particular, the UK‘s Waste and Resources Action Programmed works with local authorities, business and households to prevent waste, increase recycling and develop markets for recycled and sustainable products that is a big database in support of SD (WRAP, 2009).

LCA combined with other types of system assessment methods, like a MFA, allows the assessment of systems to consider new perspectives, such as sustainability implications. For example, MFA and substance flow analysis (SFA) were used together in the ORWARE model, helping to understand where substances are being concentrated. It is important when necessary to control output

Table.2.2 Analytic tools for system assessment

Systems assessment tools	Description
Management information system, decision support system and expert systems	Consists of different methods applied to exchange and manage information; used to help in decision making.
Scenario development	To create hypothetical sequences of events constructed for the purpose of focusing attention on causal processes and decision points.
Material flow analysis	Consists of a systematic assessment of the flows and stocks of materials within a system defined in space and time.
Life cycle impact assessment	LCIA is a step for evaluating the potential environmental impacts by converting the LCI results into specific impact indicators. Conducting LCIA must follow several sub steps: First is to select impact categories for analysis. The major impact categories are divided into three general groups in terms of impacting subjects. Second is to assign the LCI results to different impact categories (classification). Third, the potential impact indicators are calculated (characterization).
Life cycle cost analysis	LCCA is the process for evaluating the total financial cost of an asset or investment over its service life. LC CA goes beyond 'first cost thinking' – instead factoring in the total cost of ownership of design decisions. LCCA includes the initial cost (capital expenditure) plus the future costs of the asset like operational costs (e.g., utilities), maintenance costs, repair, and replacement.A procedure that aims to ensure that the decision-making process concerning activities that may have a significant influence on the environment takes into account the environmental aspects related to the decision.
Socio-economic assessment	Consists of computer-based practices that apply integrated market-based and/or policy/regulation requirements for SWM.
Sustainable assessment	Refers to the integration of different methodologies in such a way that obtaining an analysis, an evaluation or a planning that approaches several management aspects in which sustainability implications may be emphasized and illuminated.

quality more than the assessment of environmental impacts since SFA can bring the flow of concentration or dissolution of harmful substances to a LCA when they leave the system.

Proper arrangement of a LCA with MFA and energy analysis methods was made possible by Cherubini et al. (2008), where an SWM system was analyzed with a new perspective, (zero landfill emissions), making environmental impact and energy balance much easier to understand and where and how the material and energy are being wasted. Other types of integrated models applicable in this regime are MCDM and policy impact potential analysis (PIPA) method, which is designed to include the policy aspect in addition to the common aspects of technical, economic, environmental, and social ones being brought through MCDM (Su et al., 2007).

Note that a SEA is a procedure method, which needs quantifiable arguments to be used in the assessment of plans, programs, and policies. LCA was used to assess environmental impacts as an integral part of SEA alternatives. The combination of SEA and LCA related to the models that are more focused on environmental assessment has different orientations. Besides, using this type of integration it was found difficult to get the public and non-expert elements of a SEA process connected to the LCA results.

Bringing environmental and economic assessment together for SWM was also performed by a LCA with both aspects optimized (Solano et al., 2002a, b; Harrison et al., 2001) and assessed with 67 respects to environmentally economic options (Viotti et al., 2005).

Under the umbrella of MCDM, a LCA brings different aspects besides economic, technical, social, and environmental concerns, such as global warming potential and public health impact. Forecasting models were also combined with a LCA for making a best bet of waste to be generated. An LCA-ISWM model accounting for temporal effect falls into this category (den Boer et al., 2007).

In addition, an MFA can be combined with a CBA, for the optimization analysis of SWM systems (like Markal and MIMES/Waste for Sweden models). GIS combined with a LCI, an EIA, and an optimization model can represent a typical ramification in systems analysis. One salient example is landfill siting issues considering social, economic, and technical aspects simultaneously with such integration described above (Chang et al., 2008; 2009).

Table 2.2 summarizes all the latest developments on this front. The MCDM model allows us to identify a more holistic solution to waste management and provides insight into preferable municipal waste management alternatives. Modeling frameworks enable us to address each aspect of a complex problem in a systematic manner.

2.3 Literature survey in Ulaanbaatar city

According to the World bank report (2022), Compared to those in developed nations, residents in developing countries, especially the urban poor, are more severely impacted by unsustainably managed waste. In low-income countries, over 90% of waste is often disposed in unregulated dumps or openly burned. These practices create serious health, safety, and environmental consequences. Poorly managed waste serves as a breeding ground for disease vectors, contributes to global climate change through methane generation, and can even promote urban violence.

2.3.1 Implement project in city

Mongolia has been seeking partners who have developed economy to overcome the difficulties of transaction from centralized to market-oriented economy since 1990.

The Ulaanbaatar city office has been trying to implement some projects in cooperation with developed countries to develop capacity building and to train employees since 2003. Within the framework of some certain cooperation with developed societies such as Japan, they are working on classifying the wastes, re-using the wastes, transporting wastes to the landfill based on eco-friendly method and train citizens how to classify the wastes.

JICA project. In Ulaanbaatar city, issues related to solid waste management have become severe due to population increase and change of lifestyle. Therefore, JICA conducted a Study "The Study on Solid waste management plan for Ulaanbaatar city in Mongolia" from 2004 to 2007 and a Master plan up to 2020 for Ulaanbaatar city was formulated. Based on the outcome of the projects, the technical cooperation project started in 2009 to develop human resource for solid waste management in Ulaanbaatar city. JICA volunteers are dispatched to support better waste management and environmental education for young generation to reuse/reduce/recycle/waste. Through Technical Assistance project, more than 60 human resources' skills and knowledge are improved (JICA 2007).

RDF described in the SWMP is made of paper and plastic so that it is similar to refuse paper and plastic fuel. Therefore, we assumed that the drying process, which would require large amounts of energy for RDF production, would not be necessary. For when RDF is used as a substitute fuel in a coal fired power station, we used a thermal efficiency of 34%, the thermal efficiency of the number 4 coal fired power station that provides about 70% of electricity supplies to Ulaanbaatar (JETO, 2007).

Medical waste management project. Within the framework of the project for developing Health sector in Mongolia from 2012 to 2018, The government of Mongolia is implementing the project titled "Development of management of medical waste" in cooperation with the Government of Japan and The Asian Development Bank (ADB, 2018).

KOICA project. The project for establishing sorting and RDF plant in some landfill areas such as "Narangiin enger", "Morin davaa" and "Tsagaan davaa" is being implemented in cooperation with the Korean International Cooperation Agency (KOICA). Under the grant aid of 3.5 mill. USD of this project, the classifying and solid fuel plants were established in the land fill area:" Narangiin enger" in

2014. In the plant wastes are classified and 2 tons of solid fuel can be produced every day (KOICA 2014).

The Asia foundation projects. Since December 2012, The Asia Foundation and the Ulaanbaatar City Municipality have been working together to devise comprehensive ways of addressing the garbage problem. In a joint project, Urban Services for the Ger Districts of Ulaanbaatar, funded by Australia's Department of Foreign Affairs and Trade, the Foundation has partnered with the Ulaanbaatar City

Municipality to tackle the persistent problems of delivering city services in the ger districts, particularly solid waste management. The project has focused on the development and implementation of six model "khoroos," or sub-districts, where the interconnected problems of solid waste management can be addressed holistically. The model-khoroo approach has allowed possible solutions to be explored, using a testing and demonstration logic in which lessons learned at the micro level led to improved practices that can have a transformative effect on solid waste management policy at a larger scale. The six model khoroos were created with the active support of khoroo, district, and city officials, waste transportation companies, and, most importantly, khoroo residents themselves, thereby involving all stakeholders in various initiatives such as the development of solid waste collection schedules and community landscaping projects to convert illegal dumpsites into comfortable public spaces. The new solid waste schedules increased collection frequency, setting twice-a-month service as a minimum standard, and raised public awareness of waste collection schedules. The new regulation, developed jointly by the mayor's office and the Foundation, sets minimum service standards, creates stronger monitoring and evaluation systems, and requires new contracts with all solid waste companies based on rigorous performance reviews. The new standards and incentives are expected to result in reduced illegal dumping, cleaner communities, and more effective and dependable solid waste service for ger area households, including those in areas that are inaccessible by truck (AFP, 2012)

2.4 Material and Method

Production has the disadvantage of increasing greenhouse gas emissions, but it also has many advantages, such as reducing environmental pollution, selling the energy and fertilizers produced, making a profit, recycling, and saving natural resources. For this objective, different techniques can be used Environmental life cycle assessment (LCA) is a systems analysis tool (Diaz R Warith M,2006).

The used of LCA had started in the 1960s to evaluate the limitations of raw material and energy use in the USA, focusing primarily on energy and resource requirements of waste (Wenzel et al. 1997). All waste treatment methods emit a considerable amount of direct GHGs/SLCPs from waste transportation, operational activities, and during waste treatment. Life cycle assessments (LCA) are both analytical tools used to support decision-making in environmental management (Su et al., 2007).

To ensure a correct implementation in regard to the avoided burden through successful MSW recycling and reuse, the co-products in the expanded system boundary should have the same function as the raw products. (Tillman et al. 1994; Guinée et al. 2002; Thomassen et al. 2008; Finnvedden et al. 2009).

LCA is a methodical approach for quantifying GHGs emissions with consideration of all the phases of the life cycle such as transportation, operation (pre-processing, treatment), and disposal.
MCDM estimation can be used in waste management as it is used to assess environmental risks and economic benefits, and to weigh them against one another to develop policy and planning. MCDA is a tool that incorporates value judgments of individual decision-makers or multiple stakeholders to reach optimal decisions. MCDA tools utilize different optimization methods to rank alternatives, select a single optimal alternative or differentiate between acceptable and unacceptable ones. Alternative options are compared for their consequences (including environmental) and ranked based on a set of preselected criteria (B.G. Hermanna, C.Kroezea ,2007)

TOPSIS is one of the multiple criteria decision-making methods that was first introduced by Yoon and Hwang and uses the principle of the determining relative proximity of the alternative to the optimal solution using Euclidean distance. This is based on the principle that the selected variants are the shortest distance from the geometric point to the positive ideal solution and the farthest from the negative ideal solution (Young-Jou Lai, Ting-Yun Liu, Ching-Lai Hwang,1994).

2.5 Goals and Scope of Study

The main goal of the thesis was the improvement to sustainable solid waste management system in Ulaanbaatar, Mongolia.

To fulfill the goal, several sub-objectives were defined:

To estimates economic efficiency Life Cycle Cost Analysis methods based on the municipal waste disposal budget data; used tool a Cost-benefit Analysis (CBA)of each scenario explores opportunities to increase waste revenues and reduce annual costs.

Also analyzes Life Cycle Impact Assessment (LCIA) for each waste treatment option and includes a Life Cycle Assessment (LCA) that considers direct and indirect GHG emissions during landfilling, waste incineration, composting, recycling, or energy consumption from waste treatment in Ulaanbaatar city.

This research was conducted based on the multi-criterion decision-making (MCDM) method for evaluating the performance of each scenario considered hereafter as well as interviews with experts. These interviews were used to identify key ideas related to waste management.

These issues have been considered using Technique For Order Preference by Similarity to Ideal Solution （TOPSIS） analysis to determine the potential impacts of environmental, economic, technical, and social factors, which were analyzed for each waste disposal method to develop and select the best option.

2.5.1 General structure of the thesis

The present thesis is divided in six chapters and in two annexes.

In Chapter I is provided the introduction to the work developed and presented in the thesis and following the purposes of the thesis.

In Chapter II is conducted a literature review with the purpose of answering to know what waste management systems analysis are, their methods, how have been applied in waste management systems and which are the benefits and drawbacks in this specific field. The result of those chapters has been the prevalence of LCA, LCCA and MCDM methods has the most adequate to be applied in Ulaanbaatar city.

Both methods are presented and explained in Chapters III and IV, respectively. All the data

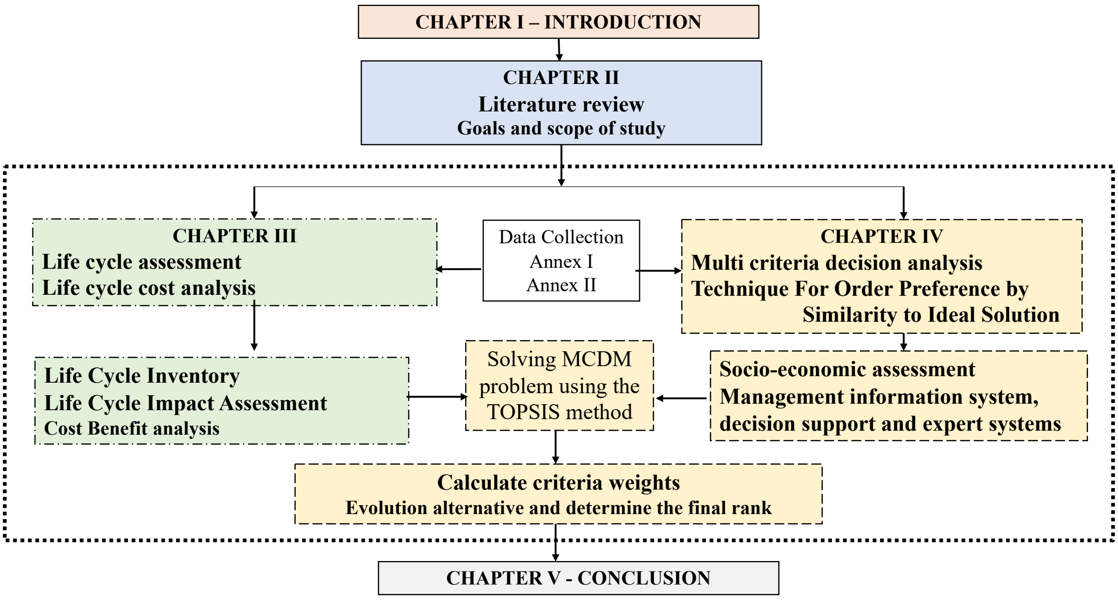


Fig.2.1 General Structure of the Thesis

used to conduct LCA, LCCA and MCDM is presented in Annexes I and II. Finally, in Chapter V are presented the conclusions of the thesis.

In Chapter I, an introduction has been elaborated focusing in Ulaanbaatar characterizes, Municipal Solid Waste management and environmental pollution. Besides the scarce information, the relevant information was obtained from scientific articles.

In Chapter II a deep literature review concerning systems analysis methods was made, focusing on 9 methods: 1) cost-benefit analysis, 2) forecasting analysis, 3) simulation analysis, 4) optimization analysis, 5) scenario development, 6) material flow analysis, 7) life cycle assessment, 8) life cycle impact assessment, 9) socio-economic assessment and management information system, decision support and expert system. Scientific articles have been the basic information used to perform the literature review.

Concerning systems analysis methods, the LCA, LCCA study is presented in Chapter III. LCA, LCCA was performed using IPCC 2006 package. The data used are mentioned in Annex I.

In Chapter IV is showed the MCDM development for the case study. The MCDM method applied is TOPSIS for weight criteria. In Annex II, the information used in both methodologies is referred, in Fig.2.1 General Structure of the Thesis.

CHAPTER III

3. Life Cycle Assessment and Life Cycle Cost Analysis of Municipal Solid Waste Management in Ulaanbaatar City

3.1. Description of the study area

According to World Bank report, managing waste properly is essential for building sustainable and livable cities, but it remains a challenge for many developing countries and cities. Effective waste management is expensive, often comprising 20%–50% of municipal budgets. Operating this essential municipal service requires integrated systems that are efficient, sustainable, and socially supported.

Environmental problems facing Mongolia include desertification, inadequate water supply, and air and water pollution. The presence of the Gobi Desert in the southeastern part of the country and mountains in the northwest provide natural limits to the amount of agricultural land.

Environmental and social conditions of Ulaanbaatar city. Ulaanbaatar is the capital of Mongolia located in the central part of the country. The average altitude is about 1,300 m. The population of Ulaanbaatar city is continuously increasing through the years. The city is facing environmental and infrastructure difficulties because of over population. Ulaanbaatar city is planned to be city of 800 thousand people in 1980s. Unfortunately, due to economy and political situation the city is hardly managed over population. The Fig.3.1 in above is showing the household growth of the city. Most of this waste is dumped in three disposal grounds, only one of which is categorized as a sanitary landfill.

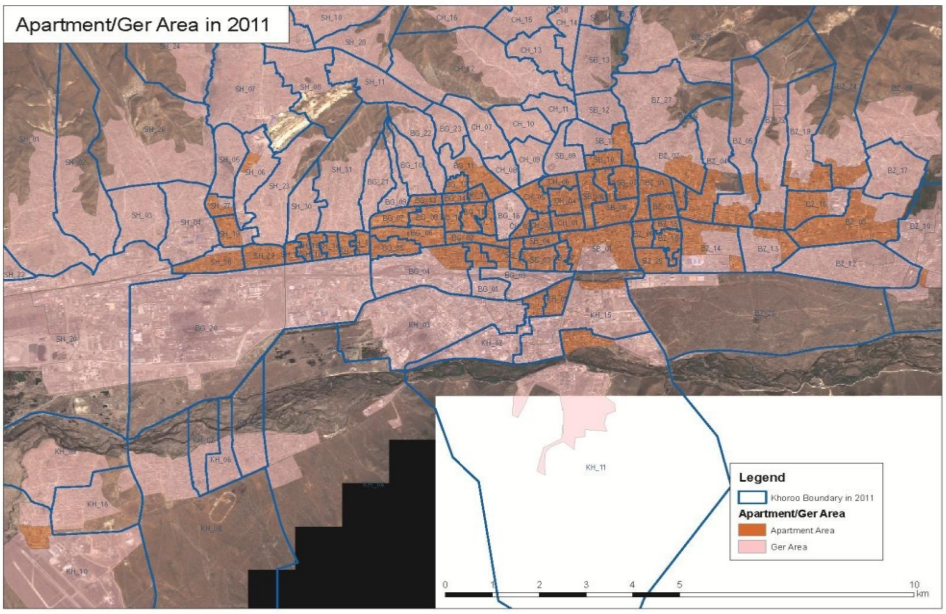


Fig.3.1 Apartment and ger area in the city

Waste segregation, collection, transportation, material recycling and energy recovery are all gaps in the city's waste management value chain. Improper handling of waste is, therefore, challenging the environment and public health of the city.

The study target area. The city includes six central districts—Bayangol (BGD), Bayanzurkh (BZD), Songinokhairkhan (SKhD), Sukhbaatar (SBD), Khan-Uul (KhUD) and Chingeltei (ChD), totalling 3256.6 km2.

According to the National Statistics Office, housing census 2020 conducted earlier this year, the total number of households has increased by 25.7% since 2010, of which urban households increased by 26.4% and rural households by 24.3%. The latest census counted the current population of Mongolia at 3,296,866 and the number of households at 897,427. The previous national population and housing census in 2010 counted 2,756,685 people. Since the 2010 population census, the average annual population growth rate has been at 2.2 $%. Average household size or the average number of persons per household is 3.6 memebers.

At the national level, 897.4 thousand households were registered, of which 59.7% were one-family household, 22.7% were multiple-family household, 15.4% were non-family, and 2.2% were mixed. At the national level, the average number of household members was 3.6 people, which is the same as the 2010 national average. However, the proportion of households with 1-2 members has changed significantly. Specifically, households with 1-2 members increased by 4.5 points in urban areas and by 5.1 points in rural areas from the previous census.

Greenhouse Gases (GHG) emissions in city. According to Minister for Nature and the Environment of Mongolia, Mongolia GHG emissions per capita was at level of 7.69 tons of GHG per capita in 2021, up from 7.64 tons of GHG per capita previous year, this is a change of 0.54%. Fossil fuel combustion is the largest source of GHG emissions in Mongolia, accounting for about 60% of all emissions. The second largest source is from the conversion of grasslands for cultivation (20-27%). Emissions from industrial processes account for less than 1% of all emissions. The single largest source of CH_4 is livestock herding. Methane emission from this sector accounts for about 90-93% of Mongolia's total emission. However, the total methane emission from Mongolian livestock is very low compared to other countries. The Energy sector produces around 60% of the country's GHG and 6-7%

of methane emissions. The conversion of grasslands to cultivated land produced the second largest emission source of GHG and represents 20.6-27.85% of total emission.

In Ulaanbaatar city, ger households are using coal as a heating and cooking which is primer need of the people in extreme cold weather. Coal is the major source of black carbon. Black carbon consists of pure carbon in several linked forms. It is formed through the incomplete combustion of fossil fuels, biofuel, and biomass, and is emitted in both anthropogenic and naturally occurring soot.

Carbon black (subtypes are acetylene black, channel black, furnace black, lamp black and thermal black) is a material produced by the incomplete combustion of coal and coal tar, vegetable matter, or petroleum products, including fuel oil, fluid catalytic cracking tar, and ethylene cracking in a limited supply of air. Carbon black is a form of procrystalline carbon that has a high surface-area-to-volume ratio, albeit lower than that of activated carbon. Organic carbon aerosol from fossil fuel sources is invariably internally and externally mixed to some degree with other combustion products such as sulphate and black carbon (Novakov,1997; Ramanathan, 2001).

The current International Agency for Research on Cancer (IARC) evaluation is that, "Carbon black is possibly carcinogenic to humans (Kuempel, Eileen D.Sorahan, Tom, 2010)

Short-term exposure to high concentrations of carbon black dust may produce discomfort to the upper respiratory tract through mechanical irritation.

Predicted values for waste generation volumes in city. Managing MSW efficiently depends largely on the waste composition produced by the population. Waste composition is influenced by socioeconomic status, the size of the household, and even by seasons. Due to the dynamic nature of waste composition and quantity, it is challenging to manage the handling and disposal of waste in an economically and environmentally feasible manner. To conduct a successful decision-making process leading to feasible and sustainable waste disposal strategies, it is advisable to start with a clear statement of the problem. One of the first critical steps in the process of developing a reliable waste management plan requires the performance of a waste characterization analysis (LT Vasconcelos, 2022)

Using Mongolian statistics, the future growth rate of waste production was determined by increasing the amount of waste produced by the urban population growth rate from 2010 to 2020. Based on the socio-economic situation and population growth, (Fig.1.3).

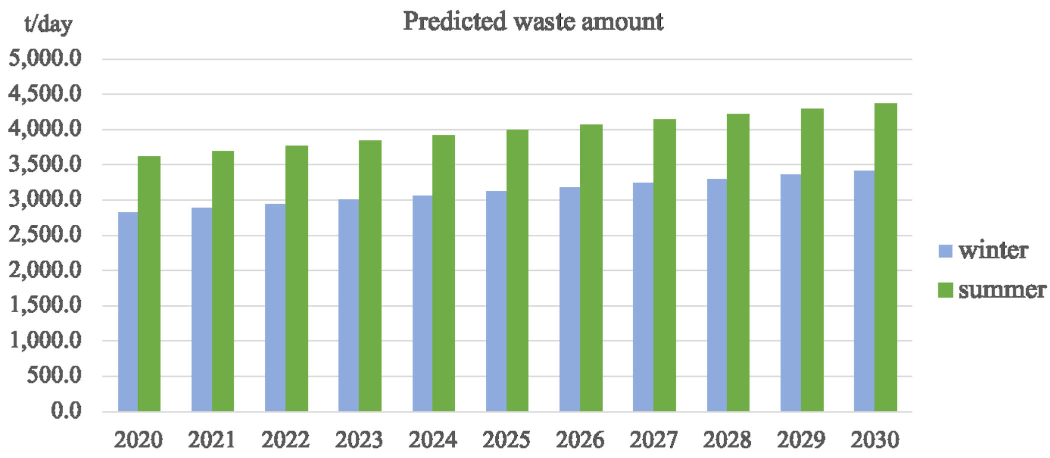


Fig. 3.2 Predicted values for waste generation volumes in the city.

With rapid population growth and urbanization, annual waste generation is expected to increase. The creation of Fig.3.2 is based on waste generation volumes in city from 2010 to 2020 (Fig.1.4.). Due to rapid population growth and urbanization, the city population growth by 2.3%, every year, calculated following Eq.3.1.

$$r = \frac{Year_x - Year_y}{Year_y} \qquad \text{Eq. 3.1}$$

r -population growth, *x*-last year, *y*-next year. Waste generation volumes in Ulaanbaatar from 2020 to 2030 were predicted. When looking forward, city annual solid waste generation is expected to increase by 26% from 2020 levels, grow to 3,423.4 - 4,366.8 tons/day in 2030.

3.2 Methodology

Life Cycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA) are both useful frameworks to (1) help understand the impact of investments, and (2) to compare investments. An LCA quantifies the environmental impact of a decision, but nothing of the financial implication, whereas an LCCA does the opposite. However, decision-making can be improved if the two ideas are combined – i.e., that of using (1) a financial lens, and (2) quantifying the broader lifetime social & environmental impacts of an investment. This is where Cost-Benefit Analysis is a great tool. CBA is a sustainability business case framework to quantify in dollar terms the financial, social, and environmental impacts resulting from an investment. CBA expands LCCA by looking at the environmental & social costs and benefits of a decision, as well as pure financial impacts.

3.2.1 Research method

This research customized LCA and LCCA methodology was developed and applied to conduct a comparison of waste management alternatives for the Ulaanbaatar city Solid Waste Management system. In Goal and Scope definition three major stages, that LCA consist of two step: life cycle inventory, life cycle impact analysis, and LCCA of two step: life cycle cost analysis and cost benefit analysis interpretation of the results. From a scientific point of view, the outcomes expected from the study are: Bring more scientific knowledge concerning the combined use of LCA, LCCA and MCDM methods based on TOPSIS.

The overall LCIA (net GHG/SLCP emissions) from technologies (Composting, Recycling, Mechanical Biological Treatment (MBT) and Incineration) is estimated as shown Fig.3.3.

The schematic of the SWM to be analyzed is shown in Fig.3.3, which generally covers all stages of SWM involved from raw waste pick-up to the delivery to bins, to some intermediate processing units, and to the final disposal at landfills. Both main waste treatment lines are represented as two separate processes with MBT and Waste incineration. Also, the Fig.3.3 shows the input in the system (energy, raw material, and waste source) of solid waste and outputs (GHG emission from transportation and waste treatment, and solid emissions,) after treatment (MBT, composting, incineration, and landfilling) of solid waste. IPCC 2006 package was used to support the LCA and Emission Quantification Tool

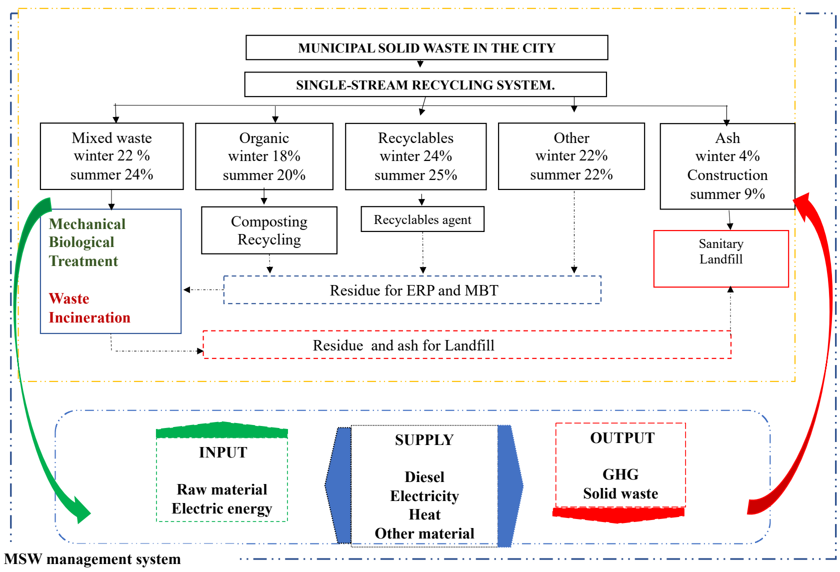


Fig.3.3 The schematic of SWM system at Ulaanbaatar.

(EQT). Developed by the Institute for Global Environmental Strategies (IGES) on behalf of the Climate and Clean Air Coalition's Municipal Solid Waste Initiative (CCAC-MSWI), which has been designed to support a rapid assessment of greenhouse gases (GHGs) and short-lived climate pollutants (SLCPs) (i.e., black carbon) associated with solid waste. This is the version II of the EQT, which follows a life cycle assessment (LCA) approach to account for both actual and projected waste related emissions.

Single-stream recycling system. Therefore, this research proposed a Single-stream recycling system in Ulaanbaatar city. Single-stream recycling is a system in which recyclables of all kinds (including plastics, paper, metal, and glass) are placed in a single curbside bin by consumers. The recyclables are then collected and transported to a Materials Recovery Facility (MRF) where they are sorted and processed.

3.2.2 Life Cycle Impact Assessment

In this study, the emissions considered were CO2, CH4, and N2O. The emission factors used in this study for CO2, CH4, and N2O were obtained from the Intergovernmental Panel on Climate Change (IPCC). The results of the collected and estimated inventory data were categorized.

This chapter describes the calculation of GHG emissions and avoided GHG from different waste management technologies and sections The technologies and sections include waste transportation, operational activities, incineration, open-burning, landfilling, composting, recycling. Also, air pollutant, GHG emissions avoidance from energy recovery and compost production is explained.

- GHG emissions from the transport of solid waste to the technologies due to combustion of diesel fuel.
- GHG emissions from Scenarios operational activities
- GHG emissions from waste management process
- Air pollutants released from landfilled disposal site
- Avoided GHG emissions from MBT technologies (fertilizer production in compost and RDF).
- Avoided GHG emissions from reduced production of original materials when the original materials replaced by recycling and composting.
- Avoided GHG emissions from Waste incineration (electricity and/or heat production (energy

recovery)).

This study was to estimate the amount of recovery of raw materials and the GHG emissions for four different waste management options. The first scenario is the existing situation in Ulaanbaatar, i.e., landfilling. S2 and S4 is waste incineration and MBT method. S3 is a policy scenario to support recycling and composting to conserve natural resources. GHG emissions from certain technologies like composting, recycling, MBT, and waste incineration are estimated as shown in the equation below. For S2, S3 and S4, which are recycled, incinerated, and removed using the MBT method; GHG emitted from this production process and transportation during the disposal process are also calculated. The overall climate impacts (net GHG/SLCP emissions) from technologies (Composting, Recycling, Mechanical Biological Treatment (MBT) and Incineration) is estimated by following Eq (3.2):

$$GHG\ Emission_{WT} = \frac{Fuel_{(L/day)} \times NCV_{(MJ/L)} \times EF_{(kg/MJ)} + EC_{(kWh/day)} \times EE_{diesel}}{AOW_{(t/day)}} \quad \text{Eq (3.2)}$$

Fuel $_{(L/day)}$-the total amount of diesel consumption, NCV_{FF}-net calorific value of fossil fuel consumed**,** *EF*-CO_2, CH_4, N_2O emission factor of old truck diesel, *EC* $_{(kWh/day)}$-electricity consumption for operation activities and $AOW_{(t/day)}$ -amount of waste used for (Mechanical Biological Treatment (MBT), Composting, Recycling, and Waste incineration.

Waste treatment operational old truck diesel and electricity consumption is used as a default data for calculation of GHG emission of electricity supply for operational activities, as seen Table 3.1.

The emissions factor of different energy sources is showed in Table 3.2 GHGs and SLCP emissions factor. In the calculation of GHG emission used to IPCC default factor, the emissions factor of different energy sources that waste treatment operational diesel and electricity consumption. In some process such as landfilling, composting and pre-treatment processes such as mechanical biological treatment consume electricity and heat for operation of machineries. As the combustion of fossil fuels is considered as a source for providing heat, the tool considers only CO2 as GHG emission gas and the

Table 3.1 GHGs and SLCP emission factors

Type of fuel	Energy content of fuel (MJ/L)	IPCC default emission factors (kg/MJ) (IPCC Tier I approach)			Density of fuel	BC emissions (g/MJ) (Ref:EMEP/EEA Guidebook 2016)
		CO_2	CH_4	N_2O	kg/L	
Diesel-Transportation	43	0.0741	0.0000039	0.0000039	0.84	0.0234
Diesel -Waste treatment	43	0.0741	0.000003	0.0000006	0.84	0.0234

Table 3.2 Electricity and fuel consumption for waste treatment operational activities.

Emidance	Operational requirements	Auxiliary materials (per ton waste input in the operation)	Reference:
MBT-RDF (25MJ/t)	Crude oil: 600L/t of mixed waste	Electricity:208kWh/t of RDF Diesel: 0.65 L/t of RDF (Pilling, aeration, screening)	Arena, U., Mastellone, M.L., Perugini, F. (2003)
MBT-Compost like material	200 kg/ t of mixed waste	Electricity:0.2kWh/t of waste Diesel: 3.5 L/t of waste	Cherubini, F., bargigli, S. Ulgiati, S. (2008)
Incineration	Electrical efficiency 20%.	Electricity: 66.8kWh/t Diesel: 157L/t	Cherubini, F., bargigli, S. Ulgiati, S. 2008.
Recycling	Material recovery 80-90%.		
Composting	200-300kg/t of organic waste	Diesel:2.0L/t of organic waste.	IPCC 2006
Landfill		Electricity:0.1 kWh/t Diesel:0.8L/t (Bulldozers, backhoes)	Mendes, M. R., Toshiya Aramaki, T., Hanaki, K. 2004.
Transportation		Diesel:0.125 L/t Electricity: 2.5 kWh/t	Diaz and . Warith, 2006

CH_4 and N_2O emissions assumed to be negligible for fossil fuel combustion.

3.2.2.1 Life Cycle Inventory

The Life Cycle Inventory (LCI) is the second phase of the LCA. It is an inventory of input/output data related to the SWM system that is being studied. It involves the collection of the data which is necessary to meet the goals of the defined study (ISO 2006b). In accordance with the scope of the study, an LCI was prepared for the waste management activities specified.

3.2.2.2 Scenario Development

Scenarios are hypothetical sequences of events constructed for the purpose of focusing attention on causal processes and decision points (Kahn and Wiener, 1967).

A more recent definition of scenario refers it as archetypal descriptions of alternative images of the future, created from mental maps or models that reflect different perspectives on past, present, and future developments (EEA, 2000).

Such definitions emphasize the future image concept and associated events, expected and unexpected ones, but also bring out the notion that scenarios are not predictions or projections.

Scenario development therein is thus a system analysis tool to make visions of future SWM conditions to assess some prescribed problems that might happen in the future. Such a methodology can show how alternative policy decisions may reach specific goal and purpose given the resources availability and limitations. Scenario development (or scenario building) can be divided in two steps:

the scenario design step, where driving forces, events and trends are established to construct the scenario; and scenario calculation, where models are used to finish the scenario, bringing more information to characterize it.

Scenario 1 (S1), 100% Landfill approach.

Landfill. JICA conducted a Study "Study on Solid waste management plan for Ulaanbaatar city, to assist in the implementation of the Master plan, the Japanese Government implemented the Grant Aid in 2008 for the construction of the "Narangiin enger Disposal Site" and donated machines and equipment such as waste collection vehicles and heavy machines.

Landfilling/open dumping is among the more common waste disposal practices in most cities of the developing world. There are numerous environmental issues generated by landfills (A Siddiqua, 2022)

Landfills and open dumps are differentiated by the Institute for Global Environmental Strategies (IGES) into categories including landfills without gas recovery, sanitary landfills with gas recovery, managed-semi-aerobic landfills, open dumping-deep (>5 m waste) landfills, open dumping-shallow (<5 m waste) landfills, and uncategorized landfills.

Unmanaged SWDS cause serious local environmental and health problems, such as fire and explosion accidents, pollution of surrounding air and waters, and outbreaks of pests and infections. However, the IPCC Guidelines and this report on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (Good Practice Report) are intended to address greenhouse gas aspects only. Managed SWDS must have controlled placement of waste (i.e., waste directed to specific deposition areas, a degree of control of scavenging and a degree of control of fires) and will include some of the following: cover material, mechanical compacting, or levelling of waste.

Ulaanbaatar's current waste treatment method is 100 % landfill method. Therefore, to dispose of waste, large volumes of waste are transported daily without classification. Ulaanbaatar has a sanitary landfill without gas recovery (Narangiin enger) and two uncategorized landfill sites (Tsagaan davaa and Moringiin davaa). The two uncategorized landfills do not have facilities for treatment or to prevent trash scattering or leakage and are at full capacity of which two are already full. Ulaanbaatar is surrounded by big mountains, and there may not be sufficient building land new landfill sites in the city.

S1, the current management uses a 100% landfill method, and of the total volume of waste, 46.8% is buried in sanitary landfill (without gas recovery) sites and 53.2% is disposed in uncategorized landfill sites. The future scenarios considered, the total of waste, 40%–45% (S2), 75%–80% (S3), and 30%–35% (S4) will being bury in sanitary landfill (without gas recovery) sites.

Usually, no operational activities at dumpsites and therefore additional energy not required. Calculated to average diesel and electricity consumption for operation activities at the Narangiin Enger landfill site and diesel was 0.8L/ton of landfilled waste for operation of machineries, such as bulldozers, backhoes etc. Also, calculated to grid electricity was 0.1 kWh per ton of landfilled waste for activity of landfill site.

Scenario (S2), MBT and recycling method.

Mechanical biological treatment. Japan International Cooperation Agency (JICA), a study of separating paper and plastic from waste, using them as raw materials for producing refuse-derived fuel (RDF), and using the RDF as a coal substitute fuel in a coal-fired power station is proposed. The goals of this plan include recovering energy from waste in Ulaanbaatar's MSW and reducing landfill volumes.

The MBT process involves breaking down the organic components using naturally occurring aerobic microorganisms, which break down waste into carbon dioxide and compost. In fact, total mass loss during the MBT process may be as high as 50% (K Bernat, 2014).

The MBT system enables the recovery of materials from within mixed waste and facilitates the stabilization of biodegradable components of the material. MBT can also process the waste to produce a high calorific fuel, called refuse-derived fuel (RDF). RDF can be used in cement kilns or thermal combustion power plants and is generally produced from plastics and biodegradable organic waste.

A key advantage of the MBT process is that its high temperature essentially kills all pathogens and weed seeds that might be found in waste. As far as other GHG emissions from composting process are concerned, these emissions may also occur due to fossil fuel and grid electricity consumption for operational activities (CO2, CH4, N2O), as well as during the degradation of organic waste (CH4, N2O).

Generally, MBT is an aerobic process, and therefore, a large fraction of the degradable organic carbon in the waste material is converted into GHG emission. GHG emissions have a biogenic origin and would not be considered for GHG calculations (M Sánchez-García, et.2015).

Mechanical biological treatment**,** developer suggests selecting the option 'Utilization of compost-like product as a fertilizer to reduce chemical fertilizer application' only if the product meet the quality standard of compost. The MBT is composed of mechanical sorting to remove recyclables and combustible fraction for RDF production, allowing the remaining fractions to be sent to the anaerobic digestion unit. Normally, the mechanical sorting process includes flail mills, trammels, magnetic separator, eddy currents separator, and ballistic separator. Sometimes manual sorting is included too to separate materials for recycling and RDF. After being sorted, the remaining fractions of waste with mechanical and biological recovery potential may be treated by the thermophilic, dry anaerobic digestion resulting in a digestate with several decomposed substances. The residual parts may be decomposed further using an aerobic treatment process. It may lead to the production of fresh compost. After this process, fresh compost is still not mature, and it must be deposited in piles for eleven more weeks, to produce mature compost. The biogas produced as an integral product of the MBT process may be used to generate electricity.

Compost like material, technology is not designed to produce compost from the treated organic material, because organic matter in mixed waste would yield contaminated compost in most of the cases. Composition of waste which is dispose at the landfills and open dumps has been derived considering the separated organic waste fraction and recyclables from collected waste for composting and recycling respectively.

RDF, production of energy using RDF or crude oil would not greatly contribute as a climate friendly solution since this energy production has a fossil-fuel-based origin (waste plastic originated as a product of virgin crude oil). In other words, emissions from combustion of crude oil produced (from the plastic) and RDF (plastic fraction) would be equivalent to the emissions of virgin fossil fuel (crude oil) combustion to obtain an equivalent amount of energy. Therefore, GHG avoidance due to combustion of produced RDF or crude oil has not been accounted for in this simulation. It was assumed that the produced crude oil can be used to replace the conventional crude oil and the produced RDF can be used in Cement kiln to replace the consumption of coal (the usual scenario). Thus, GHG emissions related to virgin oil and coal extraction, transportation and processing are included since utilization of RDF/crude oil may indirectly influence avoidance in the virgin fossil fuel production chain. Plastic waste uses for RDF/crude oil production (energy consumption). 600L of crude oil is produced per ton of mixed plastic waste.

S2 is focusing on MBT and the recycling process. The terms mechanical biological treatment or mechanical biological pre-treatment relate to a group of solid waste treatment systems. Biological can also refer to a composting stage. Here the organic component is broken down by naturally occurring aerobic microorganisms. They break down the waste into carbon dioxide and compost. There is no green energy produced by systems employing only composting treatment for the biodegradable waste. MBT plant will be established, selling only bottles and landfills in the winter to separate the ash. In this scenario, materials such as metal, glass, and paper are assumed to be sold as recyclable waste. During the production of paper and plastic, RDF fuel will be processed to produce compost from mixed waste and food waste, which will then be put into economic circulation.

The treatment of organic waste with fertilizers and methods, such as MBT, will extend the life of landfills and reduce transportation costs and waste amount. In this scenario, recyclables, such as metal, glass, plastic, and paper, are separated for recycling. As shown in Fig.3.3, All the recyclables are 24% to 25% in the winter and summer seasons, respectively. In this scenario, materials including metal, glass, and paper are assumed to be sold as recyclable waste. Ash waste to landfill, in the winter season. The city's amount of mixed waste occupied 40% in winter and 45% in summer out of all waste types which is higher in the waste. Food waste and other types of waste can be recycled using the MBT method. During the production of paper and plastic, RDF fuel will be processed to produce compost from mixed, food, and other wastes, which will be put into economic circulation.

MBT plant operational activities refer to filling, aeration, screening, etc. According to literature, RDF production uses energy consumption, diesel is 0.65 L, and electricity is 208 kWh per ton of RDF (Arena et al, 2003)

Also, shredding of organic waste, turning compost using wheel loaders or compost turners, diesel fuel consumption for operation is 3,5 L/ton of organic waste. The electricity requirement for operational activities at the plant for the weighing machine is 0.2 kWh/t of waste. Generally, 200–300 kg of natural compost per ton of organic waste can be expected to be produced (IPCC).

For S2, CO2 and SLCP emission estimated by the equation Eq (1) and used "Default emission factor" in Table 3.1 and Electricity and fuel consumption for waste treatment operational activities in Table 3.2 Electricity and fuel consumption for waste treatment operational activities.

The compost which is produced through aerobic degradation of organic waste in composting facility can be used as fertilizer or soil amendment in agriculture. Therefore, by replacing the fertilizer by compost, the GHG emissions which are yielded through fertilizer production can be avoided.

The avoided GHG emissions from fertilizer replacement calculated by using the GWP as follows (Eq 3.3):

$$GHG\ Emission\left(\frac{kg\ CO_{2e}}{Year}\right) = M_C\left(\frac{Ton\ Compost}{Year}\right) \times [EF_{CO_2}\left(\frac{kg\ CO_2}{Ton\ Compost}\right) + EF_{CH_4}\left(\frac{kg\ CH_4}{Ton\ Compost}\right) \times GWP_{CH_4}\left(\frac{kg\ CO_2}{kgCH_4}\right) + EF_{N_2O}\left(\frac{kg\ N_2O}{Ton\ Compost}\right) \times GWP_{N_2O}\left(\frac{kg\ CO_2}{kg\ N_2O}\right)] \quad \text{Eq (3.3)}$$

where M_C is the amount of compost production.

Scenario (S3), Recycling and Composting.

Recycling and Composting. One of the key environmental benefits of recycling is its significant contribution to GHG mitigation. Thus, incorporating recycling into integrated waste management would be the most valuable action to drive the entire system towards sustainability. A positive effect of recycling is seen in all relevant scenarios, especially in the acidification category, where the net effect is an ecological benefit. The most likely explanation is that the production of materials from virgin material resources requires considerable amounts of energy based on 'dirty' fuels such as coal and crude oil (Miliute et al. 2010).

Incorporating Recycling and Composting into integrated waste management would be the most valuable action to drive the entire system towards sustainability. Composting is a microbial (Bacteria, fungi, and actinomycetes) based aerobic process that is now considered an environmentally sound way to reduce organic waste and produce organic fertilizer or soil conditioner (Gautam et al. 2010).

Compost and recycling are considered equivalent to the corresponding fuel consumption for transportation of virgin materials, and therefore ignore emissions from long-distance transportation of recyclables. Incorporating recycling and composting in integrated waste management is the most valuable action to drive the entire system towards sustainability. A key advantage of the composting process is that its high temperature kills all pathogens that might be found in the waste. Recycling is the recovery of useful materials, such as paper, glass, plastic, and metals, from trash to make new products, thus reducing the amount of virgin raw materials needed. One of the key environmental benefits of recycling is its significant contribution to GHG mitigation.

Recycling is the recovery of useful materials, such as paper, glass, plastic, and metals, from trash to make new products, thus reducing the amount of virgin raw materials needed. One of the key environmental benefits of recycling is its significant contribution to GHG mitigation. Thus, incorporating recycling into integrated waste management would be the most valuable action to drive the city towards sustainable waste management.

Composing. Composting is a specific waste management process by which organic waste is aerobically converted to a stabilized solid product called compost, which can then be used as fertilizer or soil amendment. There are three common methods of composting: windrow composting, aerated static pile composting and in-vessel composting. As a small fraction of carbon in the waste may be converted to CH4 in anaerobic sections within composting piles, most of the generated CH4 is oxidized in the aerobic sections of the compost. Therefore, most of the carbon degraded within the compost pile will be converted to CO2 which have biogenic origin.

Recycling. Recyclability refers to how effectively and efficiently a material can be extracted from recyclables (or the recovered content). In general, recyclability of these recycling materials is 80-90%. Significant amount of thermal energy is required for paper recycling. In General, paper industry used 96 % of thermal energy from imported coal and coal products to provide heat energy required for Paper recycling. Plastics, aluminums, and metal recycling processes are mainly consumed electricity as the major energy source. Based on literature, this is the electricity consumption rate for recycling.

Recycling means collecting materials from waste stream to reusable them in place of virgin inputs in the manufacturing process, rather than being disposed of and managed as waste. Recycling of materials from the municipal solid waste stream generally involves the following steps:

- Collecting the separated materials from individual households and transporting to a place for further treatment
- Sorting, baling, and bulking for onward transfer to re-processors (e.g., at a Materials Recycling

Facility (MRF))

- To sale marketable materials

In this scenario, materials including metals, glasses, papers and plastics, and woods (including some construction waste) are assumed to be sold as recyclable waste. As shown in Fig.3.3, metals, glass, and paper (24%-25% of the total waste, in winter and summer) are separated for recycling and organic and garden waste (18% to 20%) used for composting at the source. Generally, 200 to 300 kg of nature compost per ton of organic waste can be expected.

Scenario 4 (S4), Waste incineration (continuous-stoker incineration) and recycling.

Waste incineration. If waste is not recycled, CO_2 is emitted into the environment during coal mining and transportation. In additional, incineration can directly eliminate methane emissions from anaerobic degradation of waste in landfills, while displacing fossil fuel-based electricity generation. Waste incineration initially became a popular technology for treating bulky waste, since it has the potential for reducing the volumes of waste from 75% up to 90% (Charles et al., 2010).

Incineration is a waste treatment process that involves the combustion of substances contained in waste materials. Industrial plants for waste incineration are commonly referred to as waste-to-energy facilities. Incineration and other high-temperature waste treatment systems are described as "thermal treatment". Incineration of waste materials converts the waste into ash, flue gas and heat. The ash is mostly formed by the inorganic constituents of the waste and may take the form of solid lumps or particulates carried by the flue gas. The flue gases must be cleaned of gaseous and particulate pollutants before they are dispersed into the atmosphere. In some cases, the heat that is generated by incineration can be used to generate electric power. Incineration with energy recovery is one of several waste-to-energy technologies such as gasification, pyrolysis, and anaerobic digestion. While incineration and gasification technologies are similar in principle, the energy produced from incineration is high-temperature heat whereas combustible gas is often the main energy product from gasification. Incineration and gasification may also be implemented without energy and materials recovery.

Waste incineration with energy recovery is widely used in development countries. Continuous stocker incinerators without daily start-up and shutdown, in which movable fire grates move back and forth to feed waste downstream on the stokers for facilitating good combustion.

In developed countries, waste incineration and subsequent energy production are quite common methods of waste management. Since it is possible to incinerate all waste except ash, this method is highly economical in terms of electricity sales. In addition to reducing waste, waste incineration of continuous stoker to generate electricity can also reduce coal mining costs and ambient carbon dioxide emissions.

Currently, in the Mongolia the four major power plants generate heat and electricity from coal. Therefore, continuous stoker incinerators have been introduced in Ulaanbaatar. It was thought that the incineration facilities which were in the cold region or in the area where there were many buildings such as apartment houses and public facilities in the neighborhood utilized surplus heat positively. In Ulaanbaatar, the demand for heat is high because the winter season is long and very cold. Moreover, almost all apartments and buildings in the planned area are connected to the central heating system. If an incineration facility is installed, it must recover and supply heat positively.

S4 is focusing on high energy generation from the incineration plant. Flammable materials, such as wood, and materials, such as rubber that decomposes, can be burned for energy recovery. However, high energy production, organic waste should be separated from non-combustibles i.e., metal and glass. In this scenario, metals, glass, plastic, and leather (24%-25%) are separated for recycling. Organic waste, residual paper, plastic contaminated with other waste, and mixed wastes can be used in waste incineration plants (55%-60% of the total waste, in winter and summer), as shown in Fig.3.3 The schematic of SWM system at Ulaanbaatar.

3.2.2.3 Calorific value (CV)

CV is the amount of heat produced by the combustion of a fuel mass and is typically expressed in joules per kilogram. All elements considered to be fuels have a calorific value. There are two calorific values for fuels: higher and lower. Higher assumes that water vapor is totally condensed, and the heat produced is recovered. Lower assumes that the water vapor is retained but not the heat. In practice, the higher heating value of solid mixture, candidate to use as fuel in a thermal process, is determined by a calorimetric test bombing. On the other hand, it is possible to calculate higher heating value and lower heating value by using appropriate mathematical equations which are based on the chemical parameters of the waste

Table 3.3 Three component analyses of MSW of Ulaanbaatar (%) Source: JICA, 2017-2012

Component	Category	Winter				Summer			
		Water content	Combustible matter	Ash	Total	Water content	Combustible matter	Ash	Total
Kitchen waste	Apartment without dust chule	58.4	21.3	20.3	100	74.6	22.1	3.3	100
	Fruit stalls	54.5	33.3	12.2	100	86.1	11	2.9	100
	Vegetable stalls	52.1	19.7	28.2	100	72.6	13	14.4	100
	Restaurants	43.8	40.8	15.4	100	-	-	-	-
Paper	Apartment without dust chule	26.8	60	13.2	100	19.6	66.3	14.1	100
	Fruit stalls	33.4	58.1	8.5	100	56.9	36.5	6.6	100
	Restaurants	37.1	52.3	10.6	100	-	-	-	-
	Vegetable stalls	-	-	-	-	24.5	49.6	25.9	100
Wood	Apartment without dust chule	24.2	56.4	19.4	100	-	-	-	-
	Fruit stalls	-	-	-	-	50.9	42.7	6.4	100
Textile	Apartment without dust chule	14	47.4	38.6	100	-	-	-	-
	Vegetable stalls	-	-	-	-	12.1	78.8	9.1	100
Plastics	Apartment without dust chule	11.9	75.9	12.2	100	41.4	49.4	9.2	100
	Vegetable stalls	2.5	69.1	28.4	100	10	63.8	26.2	100
Rubber and Leather	Fruit stalls	-	-	-	-	3.8	52.4	43.8	100

in wet or in dry basis respectively.

The calorific value of MSW have been estimated by using waste quality analysis sheet developed by Kitakyushu City Environmental Preservation Association. In this sheet waste composition and three composition data are required. In Mongolia, Japan International Cooperation Agency (JICA) worked on Ulaanbaatar's Solid Waste Management from 2005 to 2012 and made significant contribution including waste composition survey, chemical and physical analysis also three component analysis. In this study used three component parameters of waste to calculate calorific value, calculated as follows (Eq 3.4):

$NCV = 45B - 6W$ Eq (3.4)

Where NCV is net calorific value; B is combustible content in dry matter of waste; W is moisture content of waste.

Energy Indicator. **T**he burn out efficiency of combustion also included in the calculation. The recovery of secondary products or energy from waste substitutes primary production and can thus contribute to the reduction of resource/fuel consumption and emission releases. Then, one of the important indicators which present energy recovery potential is an energy indicator. The energy indicator is calculated as following Eq (3.5)

$$\text{Energy Indicator} = \frac{Electricity(kWh)}{waste\ treated\ in\ each\ technology\ (ton)} \quad \text{Eq (3.5)}$$

As reported in literature, grid electricity consumption for operational activities at incineration plant electricity consumption is 66 kWh per ton of mixed waste. Diesel fuel is consumed for initial combustion of waste and fuel consumption for initial combustion is 0.01L per ton of waste. External energy consumption for waste incineration plant grid electricity is 66.8kWh per ton waste and diesel 157L per ton of waste (Cherubini et al, 2008).

This estimation is based on the Ministry of the Environment, Japan Environmental Reclamation and Resource Recycling Bureau, High-efficiency waste power generation facility maintenance manual (revised March 2018). Power generation efficiency is limited to facilities with a power generation efficiency of 23% or higher. Considering the prediction of combustible waste generation in the future, we assumed that 1000 tons per day in the waste incinerator is required in S4. In addition to reducing waste, incineration to generate electricity can also reduce coal mining costs and ambient carbon dioxide emissions. For electricity and heat waste incineration average efficiency of electricity recovery from waste incineration is 15-30%. Part of generated electricity is utilized for on-site activities which amounts to 20-50% depending on the management practices (IPCC). In developing countries, its hard-to-find consumers for heat. Therefore, only electricity can be assumed with an average electrical efficiency 20%.

The power generation efficiency is calculated based on the "waste calorific value" and "external fuel input amount" when the turbine generator rated output is set. Using the definition of power generation efficiency, it is calculated using the following formula Eq (3.6).

$$PE(\%) = \frac{PO \times 100\ (\%)}{EI(waste+EF)} = \frac{PO\ (kW)\ x\ 3600\ (kJ/kWh)\ x\ 100\ (\%)}{WCV\ (kJ/kg)\ x\ FS\ (t/day) \div 24\ (h)\ x\ 1000\ (kg/t) + EFCV\ (kJ/kg)\ x\ EFIA\ (kg/h)} \quad \text{Eq (3.6)}$$

Where, PE-Power efficiency, PO-Power output, EI-Energy input, EF-External fuel, WCV-Waste calorific value, FC-Facility scale, EFCV-External fuel calorific value, EFIA-external fuel input amount.

In Mongolia, 1 kWh of electricity produces 0.054 USD, and it is using to calculate economic efficiency. Issuance requirements for each facility scale, power generation efficiency is 20%. The main preconditions for calculating power generation efficiency are as follows (Eq.3.7).

$$\text{Power efficiency USD/kg} = 2000 kcal/kg \times \frac{1}{860} kWh/kcal \times 20\% \times 0.054 USD/kWh \quad \text{Eq (3.7)}$$

- Lower calorific value of 1 waste: 8,800kJ/kg
- Combustion air ratio: 1.4~1.5
- Steam conditions: 400°C, 4 MPaG
- Condenser type: Air-cooled
- Exhaust gas treatment: Dry exhaust gas treatment
- Exhaust gas reheating for catalyst: None (uses a low-temperature catalyst of about 185°C)
- White smoke prevention condition: None

GHG emissions in incineration process. Consistent with the IPCC Guidelines, only CO2 emissions resulting from the incineration of carbon in waste of fossil origin (e.g., plastics, certain textiles, rubber, liquid solvents, and waste oil) should be included in emissions estimates. The carbon fraction that is derived from biomass materials (e.g., paper, food waste, and wooden material) is not included. Incineration of waste produces emissions of CO2, CH4 and N2O. Emissions of CH4 are not likely to be significant because of the combustion conditions in incinerators (e.g., high temperatures and long residence times). Normally, emissions of CO2 from waste incineration are significantly greater than N2O emissions. As shown in Eq (3.8) the activity data are the waste inputs into the incinerator,

$$CO_2 Emission \left(\frac{1000 Ton CO_2}{Year}\right) = IW \left(\frac{Ton\ Waste}{Year}\right)$$

$$\times DMC\ of\ Waste \times CF\ of\ Dry\ Waste \times FCF of\ Waste \times OX \times \frac{44}{12} \times 10^{-3} \quad \text{Eq (3.8)}$$

and the emission factor is based on the carbon content of the waste that is of fossil origin only. Eq (3.9), (3.10) are applied for calculation of GHG emissions in incineration process according to IPCC 2006: which IW (incinerated waste), DMC (dry matter content), CF (carbon factor), FCF (fraction of carbon

$$CH_2\ Emission \left(\frac{1000 Ton CO_2}{Year}\right) = IW \left(\frac{Ton\ Waste}{Year}\right) \times EF_{CH_4} \left(\frac{gr\ CH_4}{Ton\ Waste}\right) \times 10^{-9} \quad \text{Eq (3.9)}$$

$$N_2O\ Emission \left(\frac{1000 Ton N_2O}{Year}\right) = IW \left(\frac{Ton\ Waste}{Year}\right) \times EF_{N_2O} \left(\frac{gr\ N_2O}{Ton\ Waste}\right) \times 10^{-9} \quad \text{Eq (3.10)}$$

Table 3.4 Fossil based CO2 emissions during the combustion of waste Source IPCC

MSW component	Dry matter content in % of wet weight	Total carbon content in % of dry weight		Fossil carbon fraction in % of total carbon		DOC % content of wet waste	Oxidation factor in % of carbon input	Fossil Carbon in wet waste %
	Default	Default	Range	Default	Range			
Paper/cardboard	90	46	42 - 50	1	0 - 5	41.0	100	0.414
Textiles	80	50	25 - 50	20	0 - 50	32.0	100	8
Food waste	40	38	20 - 50	-	-	15.2	100	0
Wood	85	50	46 - 54	-	-	42.5	100	0
Garden waste	40	49	45 - 55	0	0	19.6	100	0
Nappies	40	70	54 - 90	10	10	25.2	100	2.8
Rubber and Leather	84	67	67	20	20	45.0	100	11.256
Plastics	100	75	67 - 85	100	95 - 100	0.0	100	75
Metal	100	NA	NA	NA	NA	NA		NA
Glass	100	NA	NA	NA	NA	NA		NA
Other, inert waste	90	3	0 - 5	100	50 - 100	0		0

factor) and OX (Oxidation factor) indicate incinerated waste, dry matter content, fraction of carbon content, fraction of fossil carbon content and oxidation factor, respectively.

The oxidation factor of incineration is generally assumed to be unit in the tool. Dry matter content, total carbon content and the fraction of fossil carbon in total carbon content are calculated as follows:

$$DMC = \sum_i WF_i \times dmc_i$$

$$CF = \sum_i WF_i \times CF_i$$

$$FCF = \sum_i WF_i \times FCF_i$$

Which $WF_i, dmc_i, CF_i, and\ FCF_i$ present fraction of component i in waste, dry matter of component i in the waste (fraction), carbon content of component i in the waste (fraction) and fossil carbon content of component i in the waste (fraction), respectively.

In the tool, food, paper and cardboard, wood, textiles, rubber and leather, plastics, metal, glass, garden and park wastes, nappies and other (e.g., ash, dirt, dust, soil, electronic waste) are the components which form the MSW as shown Table 3.4.

3.2.2.4 Waste Transportation and Collection

It has been pointed out that the collection, transportation, and treatment of waste consumes a large amount of fossil fuels and electricity from the grid, which causes greenhouse and GHG emissions.

Table 3.5 Waste transportation distance, amount of waste.

City waste transport	Waste amount	Transport distance	Fuel consumption
	t/day	km/day	liter/day
Winter	2697.3	30355.8	8782.5
Summer	3445.5	38775.7	11218.6

The city waste collecting trucks and other transportations now used are mostly second handed techniques from the foreign project. Older trucks have high fuel consumption rate and high emissions.

As shown in Table 3.5, Calculation was done based on data from the 2018 Waste Disposal Report published by Ulaanbaatar Waste Management Department. In Ulaanbaatar, 250 trucks transport waste to 6 districts of the city every day. GHG was calculated based on the fossil fuel consumption data for waste collection and transportation, as shown below.

Fuel (units/day) = Number of vehicles / Number of total trips per vehicle per day / Average fuel efficiency (Units L or kg/trip).

Fossil fuel consumption in S2, S3 and S4 (same type of vehicle) = fossil fuel consumption in S1 (L)/amount of waste collected in S1 x amount of waste collected in S2, S3 and S4.

Waste transportation system consumes fossil fuels (gasoline, diesel and CNG) to transport of waste from the source to the treatment / disposal facilities. By considering the fossil fuel consumption, GHG emissions of waste transportation are calculated as follows. The following Eq (3.10) is used to calculate the amount of GHG emitted in Ulaanbaatar during waste transportation:

$$GHG\ Emission_T = \frac{Fuel_{(L/day)} \times NCV_{(MJ/L)} \times EF_{(kg/MJ)}}{AOW_{(t/day)}} \qquad \text{Eq (3.10)}$$

Fuel $_{(L/day)}$-total amount of diesel consumption, NCV_{FF-} NCV_{FF}-net calorific value of fossil fuel consumed, *EF* (CO_2, CH_4, N_2O) - emission factor of old trucks fuel), *AOW* - amount of waste use for (Waste transportation of composting, recycling, MBT and Incineration, t/day)**,** MSW and EF indicate annual municipal solid waste volume and emission factor, respectively. In Eq (3.10), the pollutants include CO2, CH4 and N2O species (GHG). Using the Table 3.2, the emission factors and fuel efficiencies are calculated as default values which are old truck vehicles. As reported in literature, GHG emissions from grid electricity production 1.061 CO_2 kg-eq/kWh. Old trucks diesel fuel consumption is 0.125 L per ton of waste and electricity consumption are 2.5 kWh per ton of waste at the transfer station (Diaz and Warith, 2006).

3.3 Result and discussion

3.3.1 GHG emission and Recovery raw material

Recovery raw material. We compared all scenarios for environmental impact relative to the recovery of raw material and landfill volume can reduce, as seen in Table 3.6. If the goal is recovery of raw material, the most effective and best option is S4, and 2022.9 t/day (winter) and 2408.7t/day (summer) of waste reduced and recycled by waste incineration. This study was to estimate the amount of recovery of raw materials and the GHG emissions for four different waste management options, as seen in the Table 3.6. S3, can cut the amount of waste transportation cost to landfills, as well as the disposal method cost. Also has the advantage of prolonging the life of the landfill.

GHG emission from Scenarios. As seen in Table 3.6, Considering the GHG emissions from each scenario, the S2 (recycling and composting) has low GHG emissions 164 kg of CO2-eq/t, however S1 (landfill) produce GHG emit into the environment 587.4 kg of CO2-eq/t. S4 (waste incineration) produce 74.6 kg of CO2-eq/t, GHG emissions during the recycling and waste generation processes are equivalent to the amount of GHG emitted during the mining and process of natural raw materials such as coal etc. For both these scenarios it is estimated that GHG emissions are reduced by over 50% compared to Scenario 3 and 4, the current system.

The avoided GHG emissions from Scenarios. The avoided emissions for S2, from compost like materials and RDF crude oil production -82.15 kg of CO2-eq/t, for 3, from recovery raw material -4.199.2 kg of CO2-eq/t, and for S4, from electricity production -488.5 kg of CO2-eq/t respectively reduced, as seen in Fig.3.4.

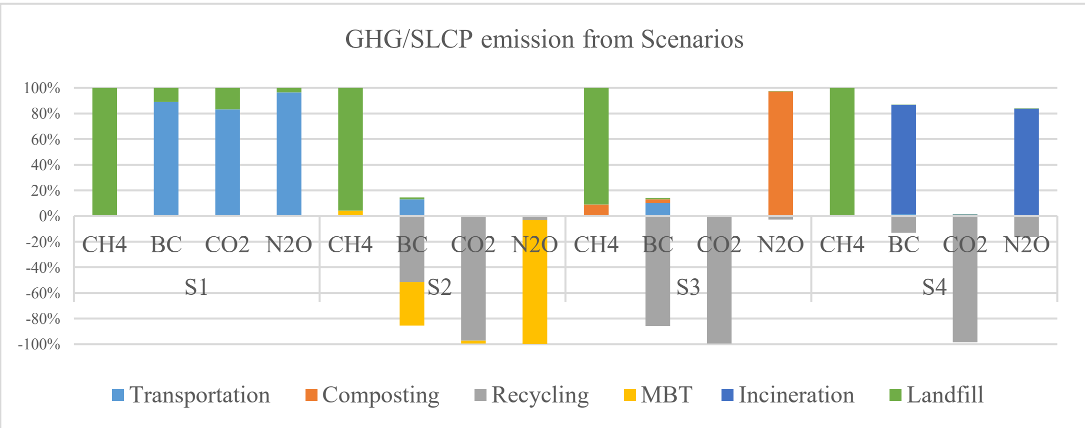


Fig.3.4 GHG emission from Scenarios

Table 3.6 Recovery of raw material and GHG emission (Environment factor)

Scenario	Recovery of raw material	GHG Emission	Recovery of raw material	GHG Emission
	t/day	kg of CO2-eq/t	t/day	kg of CO2-eq/t
	winter		summer	
S1 (LF)	0	587.4	0	746.1
S2 (MBT)	1483.5	164.0	2061.3	207.3
S3 (Rec, Comp)	701.2	748.3	997.8	945.1
S4(Inc)	2022.9	74.6	2408.4	93.1

Discussion. Comparing the environmental impact in the scenarios, BC, CO_2, H_2O avoided emissions are reduced by 20% to 90 % in S2, S3, and 4 (MBT and recycling). That is, methane gases originating from paper are decreasing while GHG emissions originating from landfill are increasing. As seen in Fig.3.4. The amount of summer waste is 21% higher than in winter, and GHG emission from waste transportation is increasing in summer season due to transportation distance and the amount of fuel consumed.

If the primary goal is a reduction of GHG emissions, the most effective scenarios are S2. If the primary goal is a reduction of landfill volumes, S4 is the most effective option.

For the S2 has the lowest BC emissions and it may be the best option. In contrast, GHG emissions of S1 are over the current system, because plastic, which would be a source of methane in landfill. In S2, RDF is produced so landfill volumes are reduced by the amounts of paper and plastic used for the RDF, but the landfill volume reduction effect is not large. Also, other GHGs emissions is concerned, S4 has lowest net GHG emissions. Waste incineration technological option used in this S4 is the most appropriate choices in the city. To sum up, the scenario which can recover most energy most efficiently is the waste incineration as S4, while the scenario which can reduce quantity of both GHG emissions.

3.3.2 Calorific value.

The study considering waste incineration and estimated calorific value content separately in winter and summer season. For the S4 is separated of metal and glass from waste and other

amount of waste used to be energy recovery. Separation of these materials from waste is improving calorific value of municipal solid waste as well as encouraging sustainability. Residual paper, plastic

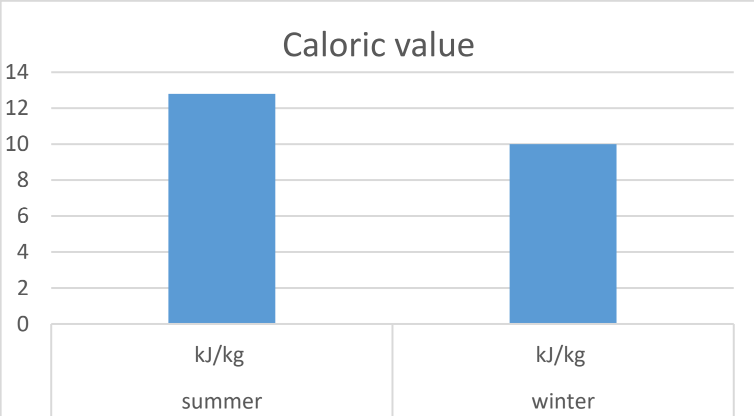


Fig.3.5 Caloric value in S4

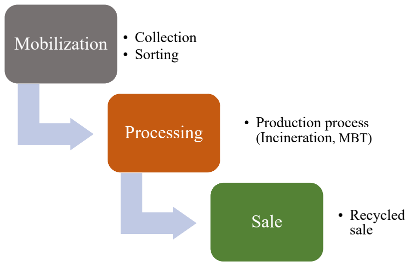
contaminated with other waste, and mixed wastes can be used in Waste incineration plants, 60% to 70% of the total waste. Ash (14%) from Ger areas will be removed by landfill method, in the winter season. The study assumed that ash will be transporting to landfill site directly. The amount of solid waste transported in winter is 21% less than in summer. Therefore, the amount of caloric value from the waste Incinerator is different in between winter and summer.

The result shows that calorific value has been estimated 12.8 kJ/kg in summer and 10 kJ/kg in winter season. According to the World Bank Technical paper of Municipal Solid Waste Incineration, waste for incineration must meet certain basic requirements. In particular, the energy content of the waste, the so-called lower calorific value (LCV), must be above a minimum level. In this technical paper of the World Bank, minimum level of calorific value must be 7 kJ/kg for successful projects. The result shows that in both season winter and summer, calorific value of municipal solid waste is above of minimum level which implies that Incineration projects could be successful.

3.4 Life Cycle Cost Analysis

LCCA is the process for evaluating the total financial cost of an asset or investment over its service life. LCCA includes the initial cost (capital expenditure) plus the future costs of the asset like operational costs (e.g., utilities), maintenance costs, repair, and replacement. Based on city state budget data, Life Cycle Cost Analysis for each waste treatment option and includes Cost benefit analysis that considers the total cost of the investment, return on investment, and payback period to recoup the investment.

Opportunities for the recycling process are subject to the interplay of market forces which ultimately dictate whether a free-market system can be done profitably on a commercial basis, or whether additional economic or regulatory support in the form of incentives is required to establish a viable system. The principal stages in the Recycling process (Inc, MBT) are like those involved in any material recycling operation, and can be summarized as follows:



It is first necessary to mobilize the recyclable fraction before subsequent processing to produce a saleable recycled one. The overall economics of the process is given by the following equation:

Net cost of a Recycling process (Inc, MBT, Compost) = Gross costs of recycling – Income from the sale of the product

Where

Gross costs of recycling = Mobilization costs +Processing costs

3.4.1 Cost-benefit analysis.

CBA is a sustainability business case framework to quantify in currency terms the financial, social, and environmental impacts resulting from an investment. CBA expands LCCA by looking at the environmental & social costs and benefits of a decision, as well as pure financial impacts. CBA expands LCA by monetizing the environmental & social impacts so their significance can be put into a LCCA framework that decision-makers understand. Cost-benefit analysis is assessed positive and negative economic and physical effects independently or support simulation and optimization models for systems analysis Well-defined cost-benefit models may translate environmental aspects into economic terms.

In this study, IPCC-2006 package was used to calculate the economic factory of each waste treatment option. In this calculation, also using Electricity and fuel consumption for waste treatment operational activities (Table 3.2). Calculation based on data from the Ulaanbaatar Waste Department from 2011 to 2018, the state budget revenue and expenditure for waste disposal were analyzed. As seen in Fig.3.6. State budget cost and revenue for waste disposal, the total Solid Waste Management budget, of which 35.4% is used for street sweeping, 37.3% on waste transport, final waste disposal 3%, and any remaining

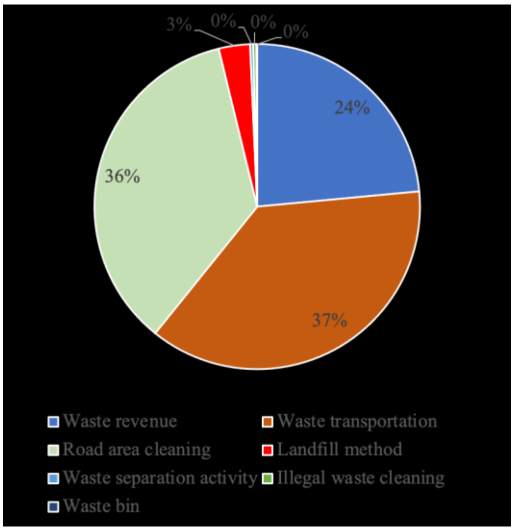


Fig. 3.6. State budget cost and revenue for waste disposal

small amount (0.8%) for waste separation activity, waste bin and Illegal waste cleaning. Households and enterprises have been paying waste transportation payment, every month. This is 23.5% of total waste management budget and the municipal own-source revenue. Also, calculation based on data Predicted values for waste generation volumes in city, 2020 to 2030 (Fig.3.2), and depending on population growth, the costs of and revenue from waste disposal will increase and are used to make economic calculations for each scenario.

We calculated and compared which waste treatment is profitable and suitable in city. BRC was used in this study to determine the value of the benefits of activity from an overall perspective. The total cost and benefit are defined in two components presented in the following Eq (3.11):

$$\text{BRC} = \frac{\text{Total benefit}}{\text{Total cost}} \qquad \text{Eq (3.11)}$$

CBA should be greater than 1 for a good investment. Another indicator is "Payback Period (PBP)" which refers to the period of time required for the return on an investment. This indicator which is considered as a proxy for repay time of the sum of the original investment defines as follows (Eq 3.12):

$$\text{Payback Period} = \frac{\text{Capital invests}}{\text{Periodic cash flow}} \qquad \text{Eq (3.12)}$$

Calculated of total costs and benefits, following items considered as cost and benefit items:

Cost Items:

a) Fixed Costs

- Land Acquisition Cost
- Equipment and Technology Acquisition Cost
- Construction and Installation Cost

b) Running Costs

- Transportation Cost
- Operational Cost
- Maintenance Cost

Benefit Items:

- Revenue from waste incineration (energy recovery)
- Revenue from electricity production (energy recovery)
- Revenue from tipping fee
- Revenue from sale of recovered/recycled materials (recycling)
- Revenue from sale of produced materials (compost)
- Benefit from avoided landfilling

Cost and Benefit items are not considered depend on technology type. Table 3.7 and 3.8 summarizes the benefit items for different technologies included in the tool. Applying discount rates to determine

Table 3.7 Cost items for different technologies in the tool

Cost	Technology	S1-Landfill 100%	S2-MBT Recycling	S3-Recycling Composting	S4-Incineration Recycling
Fixed Costs	Land Acquisition	Yes	Yes	No	Yes
	Equipment and Technology Acquisition	No	No	No	Yes
	Construction and Installation	Yes	No	No	Yes
Running Costs	Transportation	Yes	Yes	Yes	Yes
	Operational	Yes	Yes	No	Yes
	Maintenance	Yes	Yes	No	Yes

Table 3.8 Benefit items for different technologies in the tool

Technology Revenue	S1-Landfill 100%	S2-MBT Recycling	S3-Recycling Composting	S4-Incineration Recycling
Heat production	No	No	No	No
Electricity production	No	No	No	Yes
Tipping fee	Yes	Yes	Yes	Yes
Sale of recovered/recycled materials	No	Yes	Yes	Yes
Sale of produced materials	No	Yes	No	Yes
Avoided landfilling	No	Yes	Yes	Yes
Transportation cost save	No	No	Yes	No

Table 3.9 Cost and revenue of Scenarios (Economic factor)

Scenario	Cost	Revenue	New employers	Cost	Revenue	New employers
	USD mill/day			USD mill/day		
	winter			summer		
S1 (LF)	0.05	0.01	0	0.06	0.01	0
S2 (MBT)	0.05	0.03	7	0.06	0.04	7
S3(Rec, Comp)	0.05	0.01	0	0.06	0.02	0
S4(Inc)	0.05	0.04	10	0.06	0.05	10

the net present value of cashflows. Utilizing various discount rates depending on various situations.

3.5 Result and discussion

We estimated in city waste treatment budgets, expenditures required, transportation and new investments, and waste treatment in cost and save. In this research estimated Cost-benefit analysis for the above four scenarios, running from 2020 to 2030.

S1, Current management. As noted, a 100% landfill method costs USD 0.05 mill/day (winter), USD 0.06 mill/day (summer) with a corresponding revenue of USD 0.01 mill/day (winter and summer). This revenue was generated by the monthly payments collected from households and businesses.

S2, MBT method and recycling. Construction cost is USD 3.1 mill/year, and in 2030, the total annual costs are USD 0.05 mill/day (winter), USD 0.06 mill/day (summer) with a revenue of USD 0.03 mill/day (winter), USD 0.04 mill/day (summer).

S3, Recycling and composting. The disposal cost is USD 0.05 mill/day (winter), USD 0.06 mill/day (summer) with a revenue of USD 0.01 mill/day (winter), USD 0.02 mill/day (summer). Although half of the population lives in Ulaanbaatar, recycling plants are unlikely to be economically viable because of the low volume of recycled waste generated and the high cost of transporting recycled waste from rural areas.

S4: Waste incineration and recycling. The total annual cost is USD 0.05 mill/day (winter), USD 0.06 mill/day (summer) and the revenue are USD 0.04 mill/day (winter), USD 0.05 mill/day (summer). Construction cost is USD 3.5 mill/ year, and the waste incineration plant will use its own electricity to dehumidify the waste. However, to efficiently produce energy, glass and can waste should be separated.

3.5.1 Benefit-cost ratio.

Calculating cost-benefit analysis for multiple options and each option may have a different cost and different benefit. Level-setting different options by calculating the cost-benefit ratio. This is performing sensitivity analysis to understand how slight changes in estimates may impact outcomes.

If the BCR is equal to 1.0, the ratio indicates that the NPV of expected profits equals the costs. If a project's BCR is less than 1.0, the project's costs outweigh the benefits, and it should not be considered.

The BRC is used in cost-benefit analysis to describe the connection between the costs and benefits of a potential scenario. The Benefit-Cost-Ratio is determined by dividing total cash benefit of a scenario total cash cost.

A reading over 1.0 suggests that on a broad level, it will be financially successful; a reading of 1.0 suggests that the benefits equal the costs; and a reading below 1.0 suggests that the costs trump the benefits.

Based on data the current waste management, cost benefit ratio of the future scenarios (S2, S3, S4) are presented in Table 3.10 cost-benefit ratio result values from 2020 to 2030. In result, for S4, BCR is less than 1.0. If S1(current management) is compared to S4, the BCR for S4 is closer to 1.0. In the result, it is not economically beneficial.

However, S1(current waste management) revenue for 23% of total of cost, while for S4, revenue expected to be increasing to 93%.

The resulted BCR, the possibility of changing the management system that incurs losses each year to cover the costs of waste transportation, waste sorting, and recycling can be offset by waste management activities rather than the state budget.

Table 3.10 Benefit-cost ratio

Scenario	Benefit-cost ratio	
	winter	summer
S1 (LF)	0.23	0.22
S2 (MBT)	0.77	0.71
S3(Rec,Com)	0.37	0.41
S4(Inc)	0.93	0.89

CHAPTER IV

4. Multi Criteria Decision Analysis of the solid waste management system in Ulaanbaatar city

4.1 Multi Criteria Decision Analysis (MCDA)

MCDA is a method that involves the application of advanced analytical methods to make better decisions; it is often considered a subfield of mathematics. Operations research arrives at optimal or near-optimal solutions in complex decision-making scenarios; it gives decision-makers the ability either to choose the "best" outcome or to enhance the likelihood of a given set of desired outcomes. (Hazelrigg, 2003).

MCDA estimation can be used in waste management as it is used to assess environmental risks and economic benefits, and to weigh them against one another to develop policy and planning (J B Yang, J Wang, D L Xu, B G Dale, O. Kieran, T Ruxton, 2009).

A waste treatment system is a complex interaction between many factors including government policy decisions, the environment, socioeconomics, citizens' comfort, public health and safety, operation of companies, and the need to pay equal attention to all factors. A waste treatment system is a complex set of many factors, including government policy decisions, the environment, socioeconomics, residents' comfort, health, safety, and the operation of companies and need to pay attention all factors. Besides that, the waste structure, size, transportation and delivery time of waste, and the costs associated with waste treatment, influence policy decisions, as well as external factors such as the socio-economic development of the region.

One of the strategic directions that municipal authorities can choose is to implement separate collection and waste recycling systems that could help in reducing the amount of waste for landfilling,

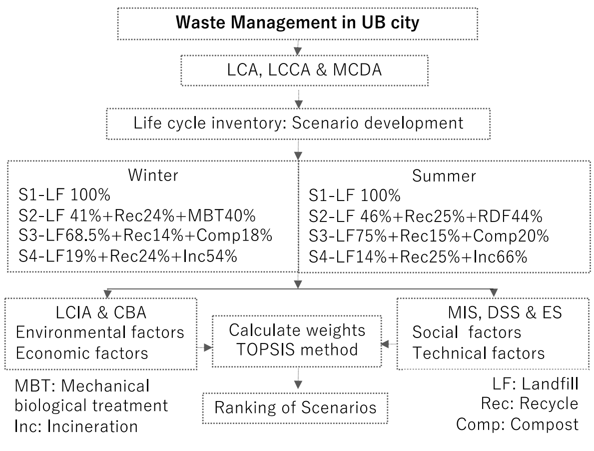


Fig. 4.1 Flow chart of proposed method for waste management alternatives

decrease the frequency of transport to the landfill and overall costs of disposal, while at the same time generating benefits for collection companies. In a modern challenging environment, decision-makers often need fast and effective tools to quickly model and optimize several decision alternatives and then compare them according to various preconditions or performance criteria. The selection of the most efficient scenario requires responsible administration to implement detailed screening of needs and desired development directions, followed by a decision on the implementing measures. Very often different scenarios affect a different range of populations, relate to diverse problems, vary in cost levels and time needed to become effective, and most often they have conflicting objectives within the selected set of criteria. A waste treatment system is a complex interaction between many factors including government policy decisions, the environment, socioeconomics, citizens' comfort, public health and safety, operation of companies, and the need to pay equal attention to all factors. Additionally, the size, transportation costs, and delivery time of waste influence policy decisions. These factors change as the economy develops, as do waste management methods and management costs.

The original in this study may lie in the use of the TOPSIS analysis to determine the potential impacts of environmental, technical, and socio-economic factors, which were analyzed for each waste disposal method to develop and select the best option, in Ulaanbaatar city.

4.1.1 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is one of the multiple criteria decision-making methods that first introduced by (Yoon and Hwang. The TOPSIS technique selects a strategy that is concurrently closest to the positive ideal solution and furthest from the negative ideal solution. The positive ideal solution enhances value requirements while minimizing efficiency, while the negative ideal alternative maximizes cost requirements while eliminating value of the system. TOPSIS leverages characteristic metadata, gives alternate cardinal scores, and does not need characteristic desire to be consistent (Behzadian et al., 2012; Putra et al., 2021).

The positive ideal solution is defined as the sum of all the best value that can be achieved for each attribute, while the negative ideal solution consists of all the worst value obtained for each attribute. TOPSIS takes into account the distance of the positive ideal solution and the distance to the negative ideal solution, by taking into account the relative proximity to the positive ideal solution. Based on this comparison of relative distance, the alternative priority order can be achieved; this method is widely used to complete the decision-making. The TOPSIS method is simple, easy to understand, efficient computation, and can measure the relative performance of the alternative decision. Effective waste management requires the right tools to manage different phases of the planning process, such as supporting decision-making at different steps in the process. In this context, decision support systems and tools integrate environmental and socio-economic factors, compare, and select alternatives for waste management, ensure stakeholder involvement and participation, and communicate results transparently and provides specific functionality for visualization to waste managers and decision-makers (Young-Jou Lai, et al., 1994).

The interviews with experts have been used to find ideas related to the problem of waste management, and their suggestions to improve existing conditions has been used to develop a framework for municipal solid waste management, as seen in Fig. 4.1.

The TOPSIS method used the results of recovery raw material and GHG emission (see Table 3.6), waste treatment cost and revenue of sceneries (see Table 3.9), Expert performance evaluation of social and technical factors (see Table 4.3). The results of the environmental and economic factors were calculated using IPCC package, while the results of the social and technical factors were calculated by adding the scores given by the experts.

4.2.1. Assessment criteria and criteria membership functions definition Social and Technical factors

In this study, a multi-criteria decision-making method is used for evaluating the performances of Social and Technical factor. Expert surveys used two indicators within the social factor: Achievement of WMS and Social acceptance. For the Technical factor, scores of 1-9 were used for the introduction

Table 4.1 Summary of selected criteria

Type of criteria		**Criteria**
LCA	Environmental	Recovery of raw materials (t/day)
		GHG emissions (kg of CO2-eq/t)
LCCA	Economic	Annual operation costs (USD mill/day)
		Annual revenue from waste treatment (USD mill/day)
MCDM	Social	Number of new employees
		Achievement of WMS
		Social acceptance
	Technical	Length of time required for the introduction of the scenario
		The ability to meet the requirements in terms of maintenance
		Availability of space for the accommodation of possible new equipment

time scenario, Qualified requirement ability, and Equipment Space See Table 4.1. As the economy develops, these factors change, and so do waste management methods and management costs. In a modern challenging environment, decision-makers often need fast and effective tools to quickly model and optimize several decision alternatives and then compare them according to various preconditions or performance criteria. Specifically, efficient solid waste management requires responsible administration to implement detailed screening of needs and desired development directions, followed by a decision on the implementing measures. Such a process results in a number of various solid waste management scenarios, often with mutually conflicting objectives or expected results. These scenarios affect a different range of populations, relate to diverse problems, and vary in cost levels and time needed to become effective. When selecting only one from various scenarios, different groups of decision-makers are involved. Decision-making has to take into account usually conflicting technological, economic, social, and environmental objectives. Single-criterion decision-making based on available financial resources as a sole criterion does not respond to such requests.

4.2.2 Management information system, decision support system and expert systems

Consists of different methods applied to exchange and manage information; used to help in decision making. A questionnaire-style interview has been conducted with experts to explore ideas related to the problem of waste management and to gather their suggestions regarding the improvement of existing conditions to develop a framework for municipal solid waste management. These interviews attempt to improve the condition of municipal solid waste management, considering appropriate methods for future decision-making that combines the diverse issues involved in prioritizing Municipal

Table 4.2. Scores for the importance of variable

Scale	Scale Definition of Importance Scale
1	Equally Important Preferred
2	Equally to Moderately Important Preferred
3	Moderately Important Preferred
4	Moderately to Strongly Important Preferred
5	Strongly Important Preferred
6	Strongly to Very Strongly Important Preferred
7	Very Strongly Important Preferred
8	Very Strongly to Extremely Important Preferred
9	Extremely Important Preferred

Table 4.3 Expert's performance evaluation of Social and Technical factor

Scenario	Social			Technical		
	Employees	Achievement of WMS	Social acceptance	Introduction time scenario	Qualified requirement ability	Equipment space
S1 (LF)	0	1	2	1	2	2
S2 (MBT)	8	4	6	2	3	4
S3 (Rec,Comp)	0	6	7	3	4	3
S4(Inc)	10	7	4	4	5	7

Solid Waste (MSW) management scenarios. Data were collected from May–September 2021 and were analyzed using the MCDM method. By using interview-style surveys, the opinions of 10 waste management experts were gathered. The experts surveyed included waste management professionals from governmental (Ulaanbaatar City Waste Management Department) and non-governmental organizations (Mongolian National Recycling Association and Waste Management Association) and academia (Mongolian National University and Mongolian University of Science and Technology) and researchers from the fields of economics and environmental science in Mongolia. Among the experts surveyed, there were 6 waste management professionals from governmental and non-governmental organizations and universities, and 4 researchers were from the fields of economics and environmental science. In Table 4.2, the scale ranges from 1–9, where one implies that the two elements are either the same or are equally important. Each decision maker entered their desired amount for each member and their individual judgments have been converted into group judgments using their geometrical average.

4.2.3 Solving MCDM problem using the TOPSIS method

The TOPSIS method used the results of recovery of raw material and GHG emission (see Table 3.2), waste treatment cost and revenue of sceneries (see Table 3.8), and Expert performance evaluation of social and technical factors, in Table 4.3. The results of the environmental and economic factors were calculated using the IPCC package, while the results of the social and technical factors were calculated by adding the scores given by the experts.

Following the creation of the first decision matrix, the method starts with the normalization of the decision matrix. Step 2 involves the construction of a weighted normalized choice matrix, followed by Step 3's determination of the positive and negative ideal solutions and Step 4's calculation of the separation steps for each option. The technique finishes by determining the coefficients of relative closeness. Alternative (or candidate) sets may be ranked by closeness coefficients in decreasing order.

Step 1. Convert raw material (X_{ij}) into standardized measures (r_{ij})

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{j=1}^{m} X_{ji}^2}}; j = 1,2,3,......,n; i - 1,2,3,.....m \qquad \text{Eq (4.1)}$$

Step 2. Multiply the column of the normalized decision matrix by the corresponding weight w_i

Estimate the weighted normalized matrix:

$$V_{ij} = r_{ij} w_j; j = 1, 2, 3, ..., n; i = 1, 2, 3, ..., m \qquad \text{Eq (4.2)}$$

Step 3. The index K is a measure of profitability, and the set of the index is cost indicators that identify a positive and negative solution:

$$\left\{V_1^+, V_2^+, V_3^+, ..., V_n^+\right\} = \left\{\left(\underset{i}{Max} V_{ij} \,|\, j \in K|\right), \left(\underset{i}{Min} V_{ij} \,\middle|\, j \in K^j\right) i = 1, ..., m\right\}$$

$$\left\{V_1^-, V_2^-, V_3^-, ..., V_n^-\right\} = \left\{\left(\underset{i}{Max} V_{ij} \,|\, j \in K|\right), \left(\underset{i}{Min} V_{ij} \,\middle|\, j \in K^j\right) i = 1, ..., m\right\} \qquad \text{Eq (4.3)}$$

Step 4. Using the following equation to develop a distance measurement of both the most suitable (D^+) and the lowest (D^-):

$$D_i^+ = \left(\sum_{j=1}^{n} \left(V_{ij} - V_j^+\right)^2\right)^{0.5} i = 1,2,3,.....m$$

$$D_i^- = \left(\sum_{j=1}^{n} \left(V_{ij} - V_j^-\right)^2\right)^{0.5} i = 1,2,3,.....m \qquad \text{Eq (4.4)}$$

Step 5. Calculate the relative proximity to the most suitable solution

$$C_i = \frac{D_j^-}{D_j^- + D_j^+}; j = 1,2,3,....m; 0 \langle C_i \langle 1 \qquad \text{Eq (4.5)}$$

Step 6. Ranking the alternatives; higher the value of the index, the better the performance of the alternative.

4.3 Result in TOPSIS

Waste management alternatives are considered for obtaining the values of two economic sub-criteria, including initial investment and operation cost by measuring actual data from Ulaanbaatar city. Therefore, the interview attempts to improve the condition of municipal solid waste management considering appropriate methods for future decision-making that combines the diverse issues involved in prioritizing MSW management scenarios. These problems have been considered by the LCA method in order to find out the potential impacts of different waste management methods and MCDM. Alternative scenarios were ranked through a TOPSIS.

Table 4.7 demonstrates the ranking of the SWM alternatives according to the TOPSIS methods with different weights.

Results showed that S2 (MBT) and S3 (compost and recycling) were in the second and third ranks, respectively. The S1(current management) occupies the last position due to being economically unprofitable the experts did not set priorities. Second ranks, (S2, MBT method) RDF is in competition with inexpensive coal, reliable supply of good quality, and low-cost RDF would have to be ensured. Therefore, in order to make high-quality and stable RDF, papers and plastics must be finely sorted out from other wastes. However, such high-quality sorting is not expected at present in Mongolia. According to the order of importance obtained in Table 4.7, the method of Waste incineration and Recycling has been identified as the most appropriate method occupying the first position.

The waste incineration that also produces electricity was the optimum option for MSW management considering the criteria. However, using combustion requires installing systems for controlling the environment in which the costs and complexities are equivalent or may be higher than a combustion system. Therefore, the major reason for preferring waste incineration is the resulting revenue from electricity. Although the high costs of implementation in the long term this method improves the management of MSW.

4.3.1 Calculate criteria weights

a) Table 4.4. Normalized Matrix of Recovery of raw material and GHG emission.

First, using equation (1) and calculations from data in Table 3.6 (i.e., recovery of raw material and GHG emission). The criteria values are given in Table 4.4. Next, using equations (2), (3), and (4) and data from the Criteria values, we calculate weighted normalized matrix. Also seen Table 4.4, we calculate the ideal best and worst value: V+, V- (max and min from alternative and criteria).

b) Table 4.5. Normalized Matrix of Annual Cost and Revenue.

a) Table 4.4. Normalized Matrix of Recovery of raw material and GHG emission.

Scenario	The criteria value				Ideal best and worst value			
	Recovery raw material	GHG Emission	Recovery raw material	GHG Emission	Recovery raw material	GHG Emission	Recovery raw material	GHG Emission
	winter		summer		winter		winter	
S1(LF)	0	0.2	0	0.2	0	0.1	0	0.1
S2(MBT)	0.7	0.5	0.7	0.6	0.3	0.2	0.3	0.3
S3(Rec, Comp)	0.3	0.2	0.3	0.1	0.1	0.1	0.1	0.1
S4(Inc.)	0.7	0.9	0.7	0.8	0.3	0.4	0.3	0.4
V-					0	0.1	0	0.1
V+					0.3	0.4	0.3	0.4

b) Table 4.5. Normalized Matrix of Annual Cost and Revenue.

Scenario	Criteria value				Ideal best and worst value			
	summer		winter		summer		Winter	
	costs	revenue	costs	revenue	costs	revenue	costs	revenue
S1 (LF)	0.5	1.5	0.6	1.8	0.3	7.4	0.3	9.1
S2 (MBT)	0.5	0.3	0.5	0.2	0.3	0.2	0.3	0.1
S3 (Rec, Comp)	0.5	0.4	0.5	0.5	0.3	0.2	0.2	0.2
S4 (Inc)	0.5	0.9	0.5	0.9	0.3	0.5	0.2	0.4
V-					0.3	7.4	0.2	9.1
V+					0.3	0.4	0.3	0.4

c) Table 4.6. Normalized Matrix of Social and Technical factor.

Scenario	Criteria value						Ideal best and worst value					
	Social factor			Technical factor			Social factor			Technical factor		
	Employees	Achievement of WMS	Social acceptance	Introduction time scenario	Qualified Requirement ability	Equipment space	Employees	Achievement of WMS	Social acceptance	Introduction time scenario	Qualified requirement ability	Equipment space
S1(LF)	0	0.1	0.2	0.2	0.3	0.2	0	0.1	0.1	0.1	0.1	0.1
S2(MBT)	0.6	0.4	0.6	0.4	0.4	0.5	0.2	0.2	0.2	0.1	0.2	0.1
S3(Rec,Comp)	0	0.6	0.6	0.6	0.6	0.3	0	0.2	0.3	0.2	0.2	0.1
S4(Inc.)	0.8	0.7	0.4	0.7	0.7	0.8	0.2	0.3	0.2	0.2	0.3	0.2
V-							0	0.1	0.1	0.1	0.1	0.1
V+							0.2	0.3	0.2	0.2	0.3	0.2

First, using equation (1) and calculations from data in Table 3.9 (i.e., Waste Treatment cost and revenue). The criteria values are given in Table 4.5. Next, using equations (2), (3), and (4) and data from the Criteria values, we calculate weighted normalized matrix. Also seen Table 4.5, we calculate the ideal best and worst value: V+, V- (max and min from alternative and criteria).

c) Table 4.6. Normalized Matrix of Social and Technical factor**.** First, using equation (1) and calculations from data in Table 4.2 (i.e., Social and Technical factor). The criteria values are given in Table 4.6. Next, using equations (2), (3), and (4) and data from the Criteria

values, we calculate weighted normalized matrix. Also seen Table 4.6, we calculate the ideal best and worst value: V+, V- (max and min from alternative and criteria).

Table 4.7 Ranking results TOPSIS method.

Scenario	PIS	NIS	Performance	Rank	PIS	NIS	Performance	Rank
	winter				summer			
S1(LF)	0.1	1.4	0.2	4	0.1	1.4	0.1	4
S2 (MBT)	0.5	1.1	1.3	3	0.7	0.9	1.7	3
S3(Rec, Comp)	1.1	0.7	2.3	2	0.9	0.7	2.3	2
S4(Inc.)	1.3	0.5	2.8	1	1.3	0.4	3.1	1

4.3.2. Alternative scenarios were ranked through TOPSIS.

Using equations (4) and (5), we calculate the positive ideal solution (PIS) and, the negative ideal solutions (NIS), which are computed via using the Euclidian Distance Approach and calculate performance scores that are developed based on the previous steps of the TOPSIS algorithm (see Tables 4.7). Also, Tables 4.7 (i.e., winter and summer) show the ranking of different disposal options using TOPSIS based on the multi-criteria in the model.

4.4 Thesis summarized result

- Recovery raw material: If the goal is recovery of raw material, the most effective and best option is S4, and 2022.9 t/day (winter) and 2408.7t/day (summer) of waste reduced and recycled by waste incineration.
- Life Cycle Impact Assessment result: For the S2 has the lowest BC emissions and it may be the best option. Also, other GHGs emissions is concerned, S4 has lowest net GHG emissions.
- Life Cycle Cost Analysis: However, S1(current waste management) revenue for 23% of total of cost, while for S4, revenue expected to be increasing to 93%.
- TOPSIS: Alternative scenarios were ranked through a TOPSIS.

Table 4.8 Result summary in a thesis.

	Scenario		S1	S2	S3	S4
1	LCI	SD	Landfill 100%	MBT 40%-44% Rec 24% -25% LF 41% - 46%	Comp 18%-20% Rec 14%-15% LF 68%-75%	Inc 54%-66% Rec 14%-15% LF 19%-24%
	Landfill volume reduced		0%	54 %-59%	25% -32%	76%- 81%
2	LCA	GHG emission	587 kg/t	164 kg/t	748 kg/t	75 kg/t
		Avoided GHG	0 kg/t	-82.2 kg/t	-4.199.2 kg/t	-488.5 kg/t
3	LCCA	BCR	S1>1(0.23)	S2 >1 (0.73)	S3 >1 (0.39)	S4 >1 (0.91)
	CBA (Rank)					closest to 1
4	MCDA	TOPSIS Rank	4	3	2	1

CHAPTER V.

5. CONCLUSION, DISCUSSION, CURRENT STATUS AND LIMITATION, RESEARCH NEEDS FOR THE FUTURE

5.1 Conclusion

This paper presents the application of the TOPSIS method to solve the problem of selecting the best alternative for solid waste management. Based on the results of research and discussion, conclusions can be drawn about waste management strategies in waste management. Several previous studies have analyzed this problem using different methods. Moreover, various criteria are used in determining the decision-making strategy, such as technical infrastructure, equipment, compliance level, regional vulnerability, and waste management system. To do so, waste disposal scenarios have been developed based on the type and amount of waste in Ulaanbaatar, and current revenues and costs of waste disposal have been estimated to identify the challenges facing waste management in Ulaanbaatar city. Urban waste collection and disposal are still managed by the old-fashioned small-scale management when the city's population was small. Waste is still disposed of by landfill, which is inefficient and causes huge losses every year. As the population grows, the amount of waste and the cost of disposal tends to increase. Results show that the overall cost of Ulaanbaatar's waste disposal cost has increased annually, mainly due to rising waste transportation costs and the area of the road to be cleaned. Waste fees are the main source of revenue from the waste management process but are less than the cost to create landfills. Considering the greenhouse gas emissions from each scenario, the current management has low GHG emissions. However, landfills not only pollute soil, water, and air but also fail to conserve natural resources. Although half of Mongolia's population lives in Ulaanbaatar, this recycling plant is unlikely to be economically viable due to the low amount of recyclable waste generated and the high cost of transporting recycled waste from rural areas. TOPSIS has calculated that waste incineration is the most cost-effective option in Ulaanbaatar city in terms of saving coal resources and reducing coal production, considering the feasibility and economic efficiency of waste disposal practices used in developed countries.

5.2 Discussion

The purpose of this study is to improve waste management in Ulaanbaatar. To do so, current revenues and costs of waste disposal have been estimated to identify the economic problems facing waste management in Ulaanbaatar city.

First, Urban waste collection and disposal is still managed by the old-fashioned small-scale management when the city's population was small. Therefore, waste is still disposed of by landfills, which is inefficient and causes huge losses every year. As the population grows, the amount of waste and the cost of disposal tends to increase. Results show that the overall cost of Ulaanbaatar's waste disposal cost has increased annually, mainly due to rising waste transportation costs and the area of the road to be cleaned. Waste fees are the main source of revenue from the waste management process but are less than the cost to waste transportation. Although half of Mongolia's population lives in Ulaanbaatar, this recycling plant is unlikely to be economically viable due to the low amount of recyclable waste generated and the high cost of transporting recycled waste from rural areas. As an economy develops, it can change waste management methods and management cost. Therefore, in this study, based on city budget data, were calculated the economic efficiency of each waste treatment option. Also, according to the Single stream system proposed in this study, the separate collection can be based on several scenarios depending on the ger and apartment area situation and available infrastructure. As well as it may involve waste separation in recycling yards, two bins municipal solid waste collection system for individual households, home composting, sorting stations, and a combination of these with the remaining fraction being disposed of at regional landfill. It can reduce ger household illegal dump site and environmental pollution.

5.2.1 Current status and limitation

This study has two significant limitations that should be considered in future research.

First, the value of the present study depended upon online interviews with waste management experts to characterize concepts related to waste management issues. Experts must consider generally conflicting technological, economic, social, and environmental objectives; consequently, this survey requires the participation of experts from varying fields. However, the number of experts participating in the survey was considered insufficient. A limitation of this study was the absence of Mongolian waste management experts.

Second, information on waste transportation routes and fuel consumption is unclear in some districts, making it difficult to analyze waste costs.

Third, the total of the solid waste management budget, most is used for street sweeping costs. However, a lack of detailed cost information is one of the main obstacles to improving waste management systems.

5.2.2 Research needs for the future

Further research regarding a continuous stoker incinerator is also installed to keep the temperature high. In Mongolia, payment of electricity is cheapest from 22:00 in the evening to 6:00 in the morning. In this calculation, the night rate was used. In addition, the use of power generation from waste incineration for industrial town was calculated. In future research, I think that we will consider variable output type power generation garbage incineration such as thermal power generation in addition to power generation in order to increase the income from garbage incineration.

Also, the Management Information System (MIS) would be essential to manage information flows from different sources, support large- scale systems analyze in search of some adaptive solid management strategies, and assess not only technology-based options but also market-based instruments. Besides, a circular economy and IoT systems is necessary. Automation and AI technology for monitoring trash and recycling sensors could provide signals when bins are full for efficient collection. Advanced GPS mapping, which optimizes truck routes, must be considered. The circular economy is an emerging economic system that addresses global environmental issues through sustainable practices, specifically those that eliminate waste disposal in landfills.

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Annex

Table A-1. Waste transportation fuel consumption and distance

17	Oct 14, 2018 10:30:27	18.8	42.9	61.7	2115.196	- (Lat:47.8971717, Lng:106.9018567)
18	Oct 14, 2018 16:45:45	3.3	41.8	45.1	2235.736	[Morin] - (Lat:47.83207, Lng:106.6827167)
19	Oct 16, 2018 10:25:57	30.3	22.6	52.8	2354.936	- (Lat:47.8976033, Lng:106.8999333)
20	Oct 16, 2018 18:45:58	3.1	27.4	30.6	2484.014	- (Lat:47.868845, Lng:106.7664017)
21	Oct 17, 2018 12:30:33	40.7	13	53.7	2582.207	- (Lat:47.8959167, Lng:106.8891117)
22	Oct 17, 2018 14:57:32	4.1	47.4	51.5	2613.817	- (Lat:47.8652783, Lng:106.7754467)
23	Oct 17, 2018 16:28:34	3.3	41.8	45.1	2634.13	- (Lat:47.8659767, Lng:106.7758517)
24	Oct 18, 2018 10:29:04	19.6	30.9	50.5	2709.765	- (Lat:47.880575, Lng:106.857075)
25	Oct 19, 2018 10:28:45	50.7	14	64.6	2932.328	- (Lat:47.8988067, Lng:106.894135)
26	Oct 19, 2018 15:25:49	3.9	42.1	46	3049.367	- (Lat:47.867385, Lng:106.776935)
27	Oct 20, 2018 10:31:56	29.7	14.2	43.9	3195.56	- (Lat:47.880175, Lng:106.8562867)
28	Oct 21, 2018 11:40:52	40.3	21.1	61.4	3356.955	- (Lat:47.8989683, Lng:106.8989683)
29	Oct 24, 2018 10:24:04	40.2	17	57.3	3619.239	- (Lat:47.8972533, Lng:106.902025)
30	Oct 24, 2018 21:08:16	5.6	21.2	26.8	3788.446	- (Lat:47.8611733, Lng:106.784355)
31	Oct 25, 2018 12:16:44	39.8	19.2	59	3824.171	- (Lat:47.892645, Lng:106.8743983)
32	Oct 26, 2018 11:07:52	29.6	33.2	62.7	3969.19	- (Lat:47.8984267, Lng:106.90164)
33	Oct 26, 2018 22:49:17	4	26.5	30.5	4159.429	- (Lat:47.9185283, Lng:106.8178)
34	Oct 27, 2018 09:47:45	39.4	28	67.4	4170.556	- (Lat:47.8991217, Lng:106.9055017)
35	Oct 28, 2018 10:21:24	29.4	32	61.4	4362.129	- (Lat:47.897275, Lng:106.9019183)
36	Oct 30, 2018 11:11:30	18.8	42.2	61	4465.009	- (Lat:47.90621, Lng:106.9112167)
37	Oct 31, 2018 11:00:32	28.5	30.5	58.9	4633.045	- (Lat:47.8850817, Lng:106.8635367)

Table A-2 Waste transportation fuel consumption

year	Minimum, L	Maximum, L	Average value, L
Oct 1, 2018	30.67141806	51.949	43.46768206
Oct 2, 2018	28.3107442	60.69913386	42.30074482
Oct 3, 2018	45.043	48.13677918	46.60442243
Oct 4, 2018	35.88	45.162	41.62761791
Oct 5, 2018	20.56439788	36.12	28.71240965
Oct 6, 2018	18.59294951	50.32260994	31.45419916
Oct 7, 2018	36.12	36.359	36.21999244
Oct 8, 2018	33.60451129	65.44012413	46.3689068
Oct 9, 2018	33.863	48.97139337	42.64674576
Oct 10, 2018	13.915	34.103	26.03801723
Oct 11, 2018	11.5804781	43.50069601	26.10085785
Oct 12, 2018	9.620758534	28.325	20.11339119
Oct 13, 2018	9.072547328	41.79335051	24.38908015
Oct 14, 2018	28.325	28.684	28.49735351
Oct 15, 2018	25.56135825	57.83585525	39.16275548
Oct 16, 2018	20.872	42.137	33.40021237
Oct 17, 2018	19.1297121	51.43861936	34.31972549
Oct 18, 2018	23.44358671	39.27145043	32.41452705
Oct 19, 2018	16.06656634	48.14159784	32.4276509
Oct 20, 2018	30.53014721	40.41	36.3474497
Oct 21, 2018	20.82107361	30.701	25.81807891
Oct 22, 2018	17.83148443	50.59198999	34.03457009
Oct 23, 2018	24.30729216	41.96099912	35.5719952
Oct 24, 2018	9.44246138	26.171	18.52274881
Oct 25, 2018	8.512411906	40.86321389	24.06152902
Oct 26, 2018	14.95902609	25.62293921	19.42057079
Oct 27, 2018	13.70507799	15.162	14.52807171
Oct 28, 2018	13.6958349	14.27130873	13.9940076
Oct 29, 2018	11.82412629	14.14369559	13.13215611
Oct 30, 2018	10.86106619	12.00699005	11.54070188
Oct 31, 2018	10.46409755	11.65677119	11.00040884
Amount	**8.512411906**	**65.44012413**	**29.48676343**

Table A-3 Landfill waste amount and disposal budget

LF	Types	January	February	March	April	May	June	July	August	September	October	November	December	Amount
Narangiin enger	Streat	2775.6	3424.6	5511.7	8898.9	9724.5	10534	6546	4604.8	4821.5	4884.3	4380.2	2692.5	68,798.41
	Apartment	7827.7	6879.1	9143.5	7995.8	7561.2	6823.3	7237.5	6604.2	8915.2	7767.9	7874.4	6812.1	91,441.75
	Ger area	19772.1	19898.8	23422.3	23363.9	22470.4	21049.7	20872	21741	26291.1	23480.7	23303.5	19862.4	265,527.97
	Other	6877.9	5892.1	10525.2	14448.9	15760.1	18015	4339.2	3866.8	5006.3	4394.9	4746.1	7159.1	101,031.78
	Amount	37253.3	36094.6	48602.7	54707.6	55516.2	56422	38994.6	36816.9	45034.1	40527.7	40304.2	36526.1	526,799.91
Moringiin davaa	Streat	410.3	406.8	413.5	922.6	2415.4	1761	235.4	1765.3	362.4	508.4	260.3	179.4	9,640.55
	Apartment	1479.3	1493.4	1635	1802.2	1611	1399.1	761.9	1390.3	1756.1	1743.6	1790.7	1471.1	18,333.35
	Ger area	8417.4	8368.1	8657.6	10973.1	17619.3	6770.8	2634	5761.2	6179	5820.5	7777.9	7365.9	96,344.52
	Other	6465.4	5410.8	20828.2	16258.9	17852.7	22718	5702.4	2456.9	2584.5	2620.9	2448.6	7229.8	112,576.80
	Amount	16772.3	15678.9	31534.2	29956.7	39498.3	32648.9	9333.6	11373.6	10881.9	10693.3	12277.4	16246.1	236,895.21
Tsagaan davaa	Streat	1492	1492	1415.3	8347.2	3173.9	2437.8	3427.5	3040.8	3422	2003.5	1142.8	1417.4	32,812.24
	Apartment	3758.5	3758.5	4405.2	4066.9	4051.5	388.5	4328.6	3844.4	4242.4	4322.6	4053.6	3532.7	44,753.37
	Ger area	12757	12757	13220.4	14124	11100.7	10290.4	12127.1	9946.5	13273.8	11681.9	10688.1	8438.7	140,405.42
	Other	10165.8	10165.8	11860.2	22688.4	27418.8	26054.1	5406.8	4763.2	6472.8	6477.4	5826.2	7497.9	144,797.22
	Amount	28173.3	28173.3	30901.2	49226.5	45744.9	39170.7	25290	21594.9	27410.9	24485.4	21710.7	20886.7	362,768.25
Amount of waste	Streat	4677.9	5323.3	7340.5	18168.7	15313.8	14732.7	10208.9	9410.9	8605.8	7396.1	5783.3	4289.2	111,251.20
	Apartment	13065.5	12131	15183.7	13864.9	13223.6	8610.9	12327.9	11838.9	14913.6	13834	13718.7	11815.9	154,528.40
	Ger area	40946.4	41023.8	45300.2	48461	51190.4	38110.9	35633.1	37448.7	45743.9	40983.1	41769.5	35667	502,277.91
	Other	23509.1	21468.7	43213.6	53396.3	61031.5	66787.1	15448.3	11086.9	14063.7	13493.2	13020.8	21886.8	358,405.80
	Amount	82198.9	79946.8	111038.1	133890.8	140759.3	128241.5	73618.2	69785.3	83326.9	75706.4	74292.4	73658.9	1,126,463.50
Waste budget	Narangiin/e Moringiin/d	142,990,264	128,619,742	163,332,008	189,389,620	196,777,997	193,150,560	140,482,750	120,905,129	99,381,640	156,060,596	158,871,840	137,656,441	1,728,236,947
	Tsagaan davaa	83,927,017	48,385,325	57,712,147	84,497,146	78,260,966	82,654,769	56,941,666	49,293,116	54,417,126	67,588,206	71,706,530	37,980,929	718,947,816

$$E7\begin{pmatrix}1.00 & 0.82 & 0.11 & 0.22 & 0.61 & 0.38\\ 1.22 & 1.00 & 0.13 & 0.29 & 0.75 & 0.46\\ 9.00 & 7.37 & 1.00 & 2.13 & 5.57 & 3.45\\ 4.21 & 3.45 & 0.46 & 1.00 & 2.60 & 1.61\\ 1.61 & 1.32 & 0.17 & 0.38 & 1.00 & 0.61\\ 2.60 & 2.13 & 0.29 & 0.61 & 1.61 & 1.00\end{pmatrix};\ E8\begin{pmatrix}1.00 & 1.19 & 0.13 & 0.79 & 0.57 & 0.32\\ 0.83 & 1.00 & 0.11 & 0.66 & 0.47 & 0.27\\ 7.51 & 9.00 & 1.00 & 5.94 & 4.27 & 2.43\\ 1.26 & 1.51 & 0.16 & 1.00 & 0.72 & 0.41\\ 1.75 & 2.10 & 0.23 & 1.39 & 1.00 & 0.57\\ 3.08 & 3.69 & 0.41 & 2.43 & 1.75 & 1.00\end{pmatrix};E9\begin{pmatrix}1.00 & 1.00 & 1.00 & 0.11 & 1.00 & 0.11\\ 1.00 & 1.00 & 1.00 & 0.11 & 1.00 & 0.11\\ 1.00 & 1.00 & 1.00 & 0.11 & 1.00 & 0.11\\ 9.00 & 9.00 & 9.00 & 1.00 & 9.00 & 1.00\\ 1.00 & 1.00 & 1.00 & 0.11 & 1.00 & 0.11\\ 9.00 & 9.00 & 9.00 & 1.00 & 9.00 & 1.00\end{pmatrix}$$

$$E10\begin{pmatrix}1.00 & 1.00 & 0.11 & 1.00 & 0.13 & 0.34\\ 1.00 & 1.00 & 0.11 & 1.00 & 0.13 & 0.34\\ 9.00 & 9.00 & 1.00 & 9.00 & 1.17 & 3.11\\ 1.00 & 1.00 & 0.11 & 1.00 & 0.13 & 0.34\\ 7.69 & 7.69 & 0.85 & 7.69 & 1.00 & 2.65\\ 2.89 & 2.89 & 0.32 & 2.89 & 0.37 & 1.00\end{pmatrix}$$

$$E1\begin{pmatrix}1.00 & 1.00 & 1.19 & 1.19 & 1.19 & 0.13\\ 1.00 & 1.00 & 1.19 & 1.19 & 1.19 & 0.13\\ 0.84 & 0.84 & 1.00 & 1.00 & 1.00 & 0.11\\ 0.84 & 0.84 & 1.00 & 1.00 & 1.00 & 0.11\\ 0.84 & 0.84 & 1.00 & 1.00 & 1.00 & 0.11\\ 7.56 & 7.56 & 9.00 & 9.00 & 9.00 & 1.00\end{pmatrix};\ E2\begin{pmatrix}1.00 & 1.18 & 0.13 & 1.00 & 1.00 & 0.27\\ 0.84 & 1.00 & 0.11 & 0.84 & 0.84 & 0.23\\ 7.61 & 9.00 & 1.00 & 7.61 & 7.61 & 2.08\\ 1.00 & 1.18 & 0.13 & 1.00 & 1.00 & 0.27\\ 1.00 & 1.18 & 0.13 & 1.00 & 1.00 & 0.27\\ 3.65 & 4.32 & 0.48 & 3.65 & 3.65 & 1.00\end{pmatrix};E3\begin{pmatrix}1.00 & 8.38 & 1.07 & 9.00 & 8.38 & 3.00\\ 0.11 & 1.00 & 0.12 & 1.07 & 1.00 & 0.35\\ 0.93 & 7.81 & 1.00 & 8.38 & 7.81 & 2.79\\ 0.11 & 0.93 & 0.11 & 1.00 & 0.93 & 0.33\\ 0.11 & 1.00 & 0.12 & 1.07 & 1.00 & 0.35\\ 0.33 & 2.79 & 0.35 & 3.00 & 2.79 & 1.00\end{pmatrix}$$

$$E4\begin{pmatrix}1.00 & 0.12 & 0.11 & 0.20 & 0.27 & 0.45\\ 8.05 & 1.00 & 0.89 & 1.64 & 2.21 & 3.64\\ 9.00 & 1.11 & 1.00 & 1.84 & 2.47 & 4.07\\ 4.88 & 0.60 & 0.54 & 1.00 & 1.34 & 2.21\\ 3.64 & 0.45 & 0.40 & 0.74 & 1.00 & 1.64\\ 2.21 & 0.27 & 0.24 & 0.45 & 0.60 & 1.00\end{pmatrix};\ E5\begin{pmatrix}1.00 & 1.64 & 0.23 & 0.27 & 0.18 & 0.52\\ 0.60 & 1.00 & 0.14 & 0.16 & 0.11 & 0.31\\ 4.30 & 7.09 & 1.00 & 1.18 & 0.78 & 2.25\\ 3.63 & 5.98 & 0.84 & 1.00 & 0.66 & 1.90\\ 5.46 & 9.00 & 1.26 & 1.50 & 1.00 & 2.86\\ 1.90 & 3.13 & 0.44 & 0.52 & 0.34 & 1.00\end{pmatrix};E6\begin{pmatrix}1.00 & 1.00 & 1.00 & 2.60 & 2.60 & 0.28\\ 1.00 & 1.00 & 1.00 & 2.60 & 2.60 & 0.28\\ 1.00 & 1.00 & 1.00 & 2.60 & 2.60 & 0.20\\ 0.38 & 0.38 & 0.38 & 1.00 & 1.00 & 0.11\\ 0.38 & 0.38 & 0.38 & 1.00 & 1.00 & 0.11\\ 3.45 & 3.45 & 3.45 & 9.00 & 9.00 & 1.00\end{pmatrix}$$

Fig.A-1 Pairwise comparison matrices from expert's preference relations, based on MCDA

Waste treatment type	MNT /year	USD/year
transportation	24,000,000,000.00	8,425,605.41
road area cleaning	22,800,000,000.00	8,004,325.14
Landfill	2,000,000,000.00	702,133.78
seperation	200,000,000.00	70,213.38
illegal waste transportation	200,000,000.00	70,213.38
waste bin	50,000,000.00	17,553.34
cost of amount	49,250,000,000.00	17,290,044.45
waste revenue	15,137,000,000.00	5,314,099.55

Fig. A-2 Waste treatment budget