LIFE CYCLE ASSESSMENT- BASED OPTIMAL ECONOMIC FOR SUSTAINABLE MUNICIPAL SOLID WASTE MANAGEMENT SYSTEM IN YANGON CITY, MYANMAR

BY

MS. MO MO

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF MASTER OF
ENGINEERING (ENGINEERING TECHNOLOGY)
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ENTITLED

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was approved as partial fulfillment of the requirements for
the degree of Master of Engineering (Engineering Technology)

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ABSTRACT

Municipal solid waste (MSW) management is one of the important global issues in this era. To minimize this problem, several techniques have been employed for escalating MSW. However, the emissions of the MSW management sector impact the environment and human health. This study mainly focuses on the MSW in the municipal area of the Yangon city, Myanmar on the characteristic of background information (center of economic zone, densely populated, rapid MSW generation and its composition, absence of collection system, unorganized recyclable materials, and current waste practicing). This research approaches the life cycle assessment (LCA) and cost-benefit analysis (CBA) method. A cradle to grave system boundary deals with a functional unit of 1 ton of MSW. The purpose of this study is to estimate the potential environmental impacts and the economic feasibility of MSW projects to propose sustainable MSW management system for Yangon city. The municipal area disposes approximately 93% of its generation to open dumping sites. This study analyzes the six environmental impacts using LCA and estimates the economic feasibilities of the project using CBA to support the decision-maker to choose the sustainable management system. The LCA results show that a BAU scenario is the highest environmental impact and scenario F would reduce the impacts than the other scenarios. The CBA results show that BAU is the lowest economically feasible option and scenario E is, on the other hand, the most economically feasible. By means of the LCA and CBA method, it can provide the important suggestion to pinpoint the upgrade MSW management in the municipal area to contribute to the National Solid Waste Management Strategy and Master plan of Myanmar.

Keywords: Environmental impacts, Economic feasibility, Life cycle assessment, MSW management,

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LIST OF SYMBOLS/ABBREVIATIONS

Symbols/Abbreviations	**Terms**
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
YCDC	Yangon City Development Committee
LCA	Life Cycle Assessment
FU	Functional Unit
LCI	Life-Cycle Inventory
LCIA	Life Cycle Impact Assessment
MRF	Material Recovery Facilities
INC	Incineration
AD	Anaerobic Digestion
BAU	Business as Usual
LFG	Landfill Gas
GWP	Global Warming Potential
CC	Climate Change
AC	Acidification Potential
HT	Human Toxicity Potential
POF	Photochemical Oxidation Formation
FE	Freshwater Ecotoxicity
SR	Sensitivity analysis Result
IPCC	Intergovernmental Panel on Climate Change

EEA	European Environment Agency
EQT	Emission Quantification Tool
SWDS	Solid Waste Disposal Site
MCF	Methane Emission Factor
CH_4	Methane
CO_2	Carbon dioxide
N_2O	Nitrous Oxide
DOC	Degradable Organic Carbon
EF	Emission Factor
CBA	Cost-Benefit Analysis
MMK	Myanmar Kyat
AHP	Analytic Hierarchy Process

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Municipal solid waste (MSW) management is a universal issue in this era. It is escalating due to the huge consumption of goods and energy of world population growth (Nanda & Berruti, 2020).The main sources of this MSW are commercial, residential, and institutional industries (Wang et al., 2015). According to the World Bank (2018), the annual total MSW generation was 1.3 billion tons in 2012; it is expected to reach 2.2 billion tons by 2025.However, it has already exceeded 2.2 billion tons in 2016 and is expected to reach 2.6 billion tons by 2030 and 3.40 billion tons by 2050 (Sharma & Jain, 2020).In addition, the waste is increasing threefold of the current volume by 2050 from lower-income countries (Kaza et al., 2018). Silva et al. (2021) demonstrated that 3.5 million metric tons of used masks were disposed off in landfills in developing countries in 2020 due to the covid-19 outbreak (Silva et al., 2021).In Myanmar, the total MSW generation was 10.5 million tons in 2019 and is anticipated to reach 213.2 million tons in 2025 (Fodor & Ling, 2019).

The organic waste is 70-80% of MSW in Asian cities and 30-50% in developed countries (Mishra et al., 2019; Treadwell et al., 2018).The most common waste management system (WMS) is open dumping in developing countries due to the inadequate budget for the waste management sector of local authorities (Ali et al., 2014). In Asian developing counties, the rate of MSW to open dumping is more than 50%, and 30% of MSW in landfilling (Dhokhikah & Trihadiningrum, 2012).The disposal of MSW to landfills is, in contrast, reduced from 32% in 2012, 23% in 2017, and 10% in 2019 in developed countries (Sauve & Acker, 2020).

According to Sharma and Jain (2020) and Medina-Mijangos et al. (2021), the handling systems of global waste treatment method in 2016 were open dumping of 33%, followed by 25.2% of unspecified landfill, 13.5% of recycling, 11.1 % of incineration, 7.7% of sanitary landfill, 5.5% of composting, 3.7% of controlled landfill, and 0.3% of others. In Yangon city of Myanmar, the most common waste disposal method is open dumping without engineered method. This common method contaminates the air, soil, and water by releasing harmful gases and leachates of liquid

(Iqbal et al., 2020; Rubinos & Spagnoli, 2018).According to Sadef et al. (2016) and Yukalang et al. (2018), this escalating of waste and uncontrol disposal methods affect gravely to social, economic, and environment in almost all developing countries.

The solid waste management sector contributes to global warming due to the release of greenhouse gas (GHG) (Wang et al., 2020). Kaza et al. (2018) stated that 5% of global GHG emissions come from the waste treatment sector. Yadav and Samadder (2018) mentioned that 11% of global CH_4 emissions are released from uncontrol waste disposal sites. GHG emissions also lead to climate change, and that proper MSW is needed to minimize this problem (Khandelwal et al., 2019; Perera, 2017).

Landfill fire is similar to open burning. Noxious fumes and particulate matter are released during the burning of MSW (Kumari et al., 2019).Poisonous fume, dioxin, and persistent organic pollutant are neurotoxicity and can damage the nervous system (Roig et al., 2013). Particulate matter is one of the harsh effects of environmental health due to toxic chemical particles and the mixing of various complex substances which can cause inhalation diseases (Roig et al., 2013).

All of the above environmental burdens are dependent on human activities, such as the exceeded derivation of natural resources, the operation of a large amount of industrialization process, combustion of waste, and production and consumption of fossil fuel and transportation. According to Cremiato et al. (2018), waste is a part of the global commercial series, and it can save energy by employing it as raw materials. Domestic waste can be used as secondary material by upcycling products to achieve environmental benefit. Jishkariani et al. (2020) proved that MSW is one of the supporting materials to produce energy locally. Several waste-to-energy technologies have been employed for waste treatment sectors (Sun, 2017). Myanmar already adopts the Waste Management Strategy and Master Plan (2018-2030) to upgrade its MSW (Thien et al., 2020). Thus, the waste management sector is necessary for the mitigation of environmental impact, not only for the local but also for the global by imposing waste management strategies.

Landfills without recovery energy and open dumping are the origin of GHG emissions which, lead to air pollution and impact on the environment and human health (Perrot & Subiantoro, 2018). Although anaerobic digestion has a lower potential impact, the higher amount of ammonia (NH_3) and the other concentrations such as, Zinc, Copper, and Manganese are produced that cause hazardous effects on the environment and human health (Logan et al., 2019).

This study, therefore, attempts to propose proper WMS options in Yangon city, Myanmar, using the life cycle assessment (LCA) and cost-benefit analysis (CBA) approaches. LCA method has been widely used in waste management studies (Assamoi & Lawryshyn, 2012; Logan et al., 2019; Mayer et al., 2019b). It is one of the most scientific and effective management tools for identifying environmental performance related to waste management strategies (Aryan et al., 2019; Cherubini et al., 2009).It can consider direct and indirect burdens of local and global impacts (Mayer et al., 2019a). It is used to evaluate adverse impacts from the current waste management practice, and compare with proposed different scenarios. CBA method, on the other hand, is used for the estimation of the economic feasibility of waste treatment projects. Six alternative scenarios including three wastes to energy treatment methods and three general treatment methods are identified. Six impact categories are analyzed, including 1) climate change, 2) terrestrial acidification, 3) human toxicity, 4) photochemical oxidant formation, 5) freshwater ecotoxicity, and 5) ozone depletion (Çetinkaya et al., 2018). All scenarios are compared using the environmental potential impacts based on a life cycle perspective. It is expected that the study results provide guidelines for WMS in Yangon city, Myanmar so that an effective plan can be initiated and implemented in the future.

1.2 Objectives

The objectives of this study are:

- To study and evaluate the adverse impacts of current waste management practice in Yangon city, Myanmar.
- To propose proper options for future MSW management systems by comparing environmental impacts from different alternative scenarios from a life cycle perspective, and estimating the optimal economy of each scenario.

- To support the implementation of the National Waste Management Strategies and Master Plan (2018-2030) of Myanmar.

1.3 Scope of the Study

This research study is defined as three boundaries. The study area of the research is Yangon, Myanmar (the research boundary), the proposed scenarios are within the described unit of time, year, etc. (the system boundary), and there are assessments of environmental impacts and economic analysis (the stretched boundary).

To estimate the waste management of Yangon city according to the objectives, the LCA and CBA methods are selected as decision tools.The LCA shows impacts that are affected by waste management, while the CBA informs projects with optimal costs for future waste management. Data are collected from the Environmental Conservation and Cleaning Department of Yangon City Development Committee (YCDC), such as waste generated and incinerated and current waste management in Yangon. Some data are carried out from literature studies, such as fuel consumption for MSW transportation and incineration.

Potential environmental impacts are estimated from six alternative scenarios using the LCA SimaPro version 7 software, ReCiPe midpoint method. Six impact categories, namely climate change (CC), human toxicity (HT), photochemical oxidant formation (POF), terrestrial acidification (AC), ozone depletion (OD), and freshwater ecotoxicity (FE) from the current and proposed scenarios are accessed from life cycle perspective framework. It is expected that the study results identify suitable WMS for the study area, and highpoint processes to upgrade the waste treatment methods, such as recycling, incineration, and composting.

1.4 Significance of the Study

The LCA method is used as a decision-making tool in this study for the implementation of the waste-to-energy scheme, and the other conventional systems by analyzing with its four stages (Aryan et al., 2019; Cherubini et al., 2009). In Myanmar, there is almost non-existing literature concerning LCA research (Yadav and Samadder, 2017). The common use of WMS in Myanmar is open dumping. In Yangon city, only one waste-to-energy (incineration) plant has been implemented in recent years to reduce the methane emissions from landfills (Corporation, 2018).The anaerobic digestion, gasification, pyrolysis, refuse direct fuel, are not yet implemented in Myanmar due to budget problems (Tun and Juchelková, 2018). Therefore, LCA and CBA results in this study can be used as a guideline for future WMS in Yangon city, Myanmar.

CHAPTER 2
LITERATURE REVIEW

2.1 Country Profiles of Myanmar and its Aims of Waste Management Strategy

The Republic of the Union of Myanmar has located between South and Southeast Asia as the bridge land, which is the largest country in mainland Southeast Asia. It shares borders with Bangladesh, China (PRC), the Republic of India, Laos, and Thailand, covering an area of 676,576 square kilometers (Aung, 2019). (Figure 2.1) It is composed of seven regions and seven states. It is famous for its rich natural resources, such as oil and gas, precious stone and gems, various minerals, teak and forest products, and hydropower potential (Simpson & Farrelly, 2020). According to the Department of Population, Ministry of Immigration and Population (2015), Myanmar has a population of about 51.48 million, and that 75% of the population live in urban areas.

In Myanmar, the agriculture sector is the backbone of the country’s economy. According to World Bank (2018), Myanmar is a lower-middle-income country with $ 1445 per capita and the GDP annual growth rate of 8.3% and 8.4% increase in 2016/2017 (Aung et al., 2017).The country is driven by services, industries, and agriculture (Saw & Ji-Qing, 2019).

Myanmar has faced environmental impacts, especially climate change due to the extraction of natural resources. In addition, due to the escalating of waste coupled with poor governance, the two largest cities, Yangon, and Mandalay are significantly deficient (Simpson & Farrelly, 2020). These lead to health issues that are needed to be managed properly. In Myanmar, the National Waste Management Strategy and Master Plan has been released in 2020 to achieve zero waste, resource-efficient, and sustainable society by 2030 (Thien et al., 2020).

Figure 2.1 Map of Myanmar

2.2 Characteristics of MSW in Myanmar

MSW is defined as domestic and non-hazardous wastes, which mainly comes from households, commercials, offices, public areas, businesses, and gardens/yards (Wei et al., 2017), (Van Fan et al., 2018). It consists of a high ratio of organic waste, however, the composition of the MSW may differ based on sources of waste generated, weather and economical status of the country, culture, environment, and socioeconomic (Wei et al., 2017; Van Fan et al., 2018; Yadav & Samadder, 2017; Dong et al., 2018; Abylkhani et al., 2019).The generated MSW is solely based on the proportion of population and GDP growth of the countries (Rajaeifar et al., 2017).

The composition of MSW is very imperative for the selection of WMS including, the promotion of 3Rs practice for MSW, treatment by thermal or biological technology (Nabavi-Pelesaraei et al., 2017). As usual, combustible waste is collected for the thermal process, and organic waste is chosen for biological treatment (Dong et al., 2018).

The composition of MSW in Myanmar is 77 % organic and followed by plastic and paper, respectively (see Figure 2.2) (Fodor & Ling, 2019; Møller, 2020).

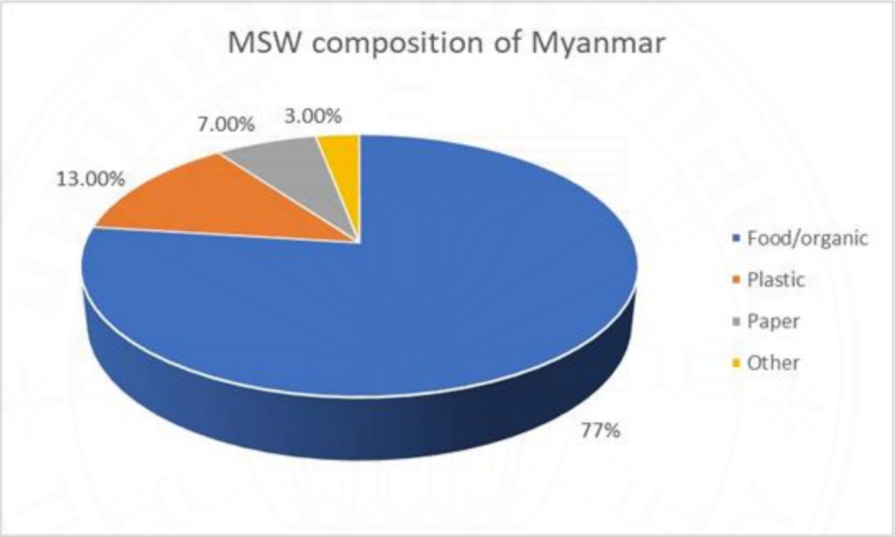


Figure 2.2 MSW compositions in Myanmar **(**Fodor & Ling, 2019)

2.3 Background of Yangon City and the Status of Solid Waste Management

Yangon is the first largest city with high industrialization and dense population. The entire city consists of four districts, namely the eastern, western, southern, and northern districts with a total of 45 townships and population of 7.36 million people (Wang et al., 2018).The municipal area of Yangon city is called the Yangon City Development Committee (YCDC), which consists of 33 townships.The population of the YCDC is 5.2 million people and covers an area of 598.75 square kilometers (Tun et al., 2018). YCDC has authority for the waste management sector and is responsible for administration, financing, planning, and urban service (Yee, 2019). According to Fodor & Ling (2019), the total amount of waste generated in

YCDC was 0.26 kg per capita per day in 2010-2011, and was increased to 0.5 kg per capita per day in 2019-2020 (see Figure 2.3).

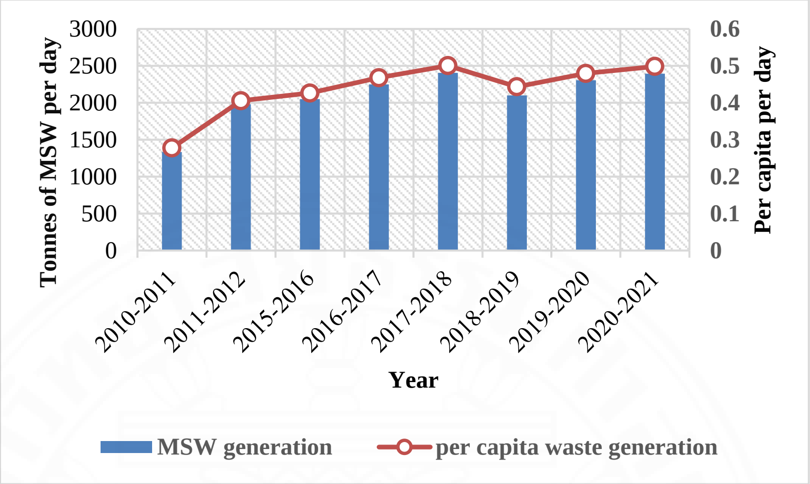


Figure 2.3 Total amount of waste generation in Yangon City during 2010-2020 (Fodor & Ling , 2019; YCDC, 2020)

The common use of waste disposal method is uncontrolled open dumping sites in the study area. Three waste collection methods are performed in the YCDC area, including 1) door-to-door collection with a bell-ringing warning system, 2) collection from the trash bins, road sweeping and collected waste from temporary storage (curbside collection), and 3) collection from improper dumping of roadside (Win et al., 2019). Waste is segregated and collected by curbsides, containers, tri-cycles, and small tippers for the narrow streets in the study area. This method solely depends on labor activities (Fodor & Ling, 2019; Premakumara et al., 2017). The other type of waste collection is “on-called” services whereas when the polluter informs to dispose of the waste, the respective municipal authority has responsible to go and collect directly to send the final disposal site from industries and embassies. The collected efficiency was about 92%, whereas the rest are moved to the formal and informal recycling and illegal dumpings (Tun et al., 2018).

The collection activities are done twice a day. In general, 60% of MSW are from households, 15% are from markets, and 10% are from commercial (Win et al., 2019). The domestic waste is collected by YCDC, while the Ministry of Health manages pathogenic waste, and respective hospitals' hazardous waste from industries is managed by the Ministry of Industries (Premakumara et al., 2017). The wastes are separated into wet and dry wastes (Tun et al., 2018).

According to the Environmental Conservation and Cleaning Department (2020), the total collected amount of MSW is 2552.47 tons/day from which 60 tons/day are sent to the energy plant and the rest are sent directly to two open dumping sites i.e., waste from western and northern districts to Htain Pin SWDS and waste from eastern and southern districts to Htawei Chaung SWDS).Only one power plant produces electricity of 700 kW daily (Tun et al., 2018).This amount of waste represents 92 % of collection efficiency, in which only 5% of them are used in formal and informal recyclable activities, and the rest go to the illegal dumpings (see Figure 2.4) (Tun & Juchelková, 2018).Recycled materials include plastic, paper, glass, and metal in which a large number of the materials are plastic and paper, respectively (Tun et al., 2018).

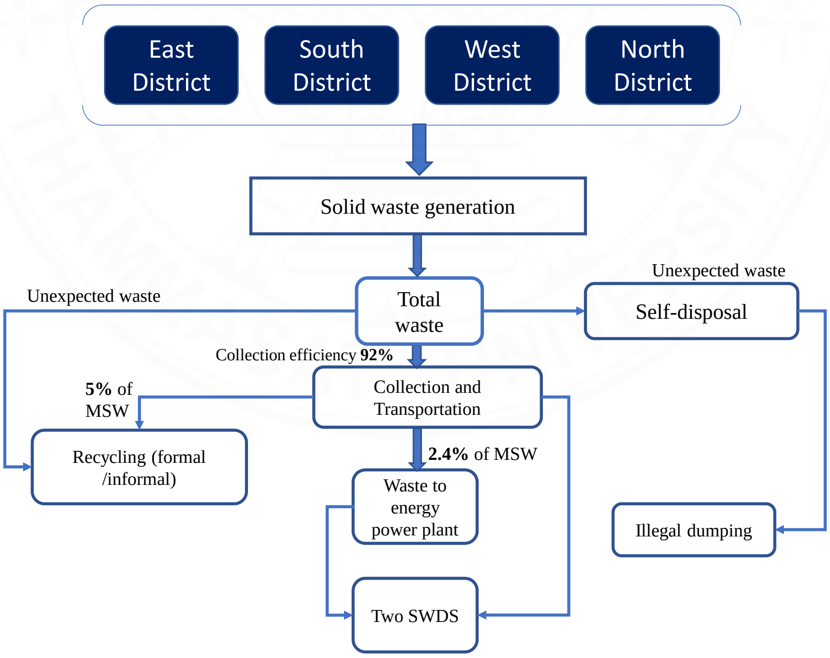


Figure 2.4 Current MSW flow of Yangon city (YCDC, 2020)

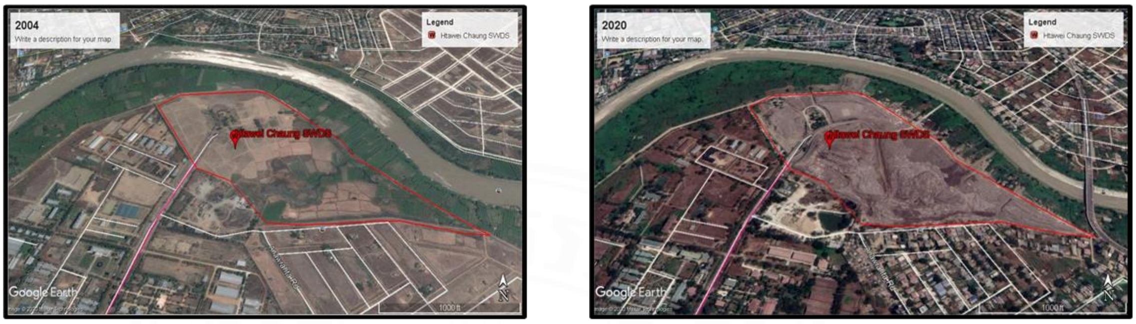
2.4 Yangon MSW Management, Challenges, and Relative Problems

Yangon city is facing severe environmental impacts on human health due to poor waste management, unsound regulations on solid waste, and weak enforcement of existing relative regulations (Premakumara et al., 2017). Currently, Myanmar is facing medical and industrial waste management due to the YCDC can only collect and manage MSW from the hospitals and industries (Aung et al., 2019).The lack of adequate infrastructure for waste segregation and lack of 3Rs practices and public awareness for waste management lead to indiscriminate littering, resulting in environmental and public health problems (Fodor & Ling, 2019; Farzadkia et al., 2021).

(a) In 2003 (b) In 2020

Figure 2.5 Htein Pin Solid Waste Disposal Site

For source-separated recycling materials, municipal collectors separate the recyclable materials by hand and manual tools (rakes) (Premakumara et al., 2017). A small recycling shop is located near the final disposal site in Yangon city, so it is assumed the same distance from the collection point to the final disposal site. Since the common practice is uncontrolled open dumping, a huge amount of waste (around 93 %) is dominant in disposal sites, causing landfill fire and releasing dense smoke and noxious fume (Thien et al., 2020). With the increase of MSW, the proper MSW management is operated (Sununta & Sampattagul, 2019).However, the absence of systematic waste collection and disposal, aging vehicles, unorganized recycling material, massive waste generating, poor governance, and the common use of improper open dumping sites are caused ineffective MSW management in Yangon city. The changing conditions of the two disposal sites in Yangon city are as shown in Figure 2.5 and 2.6.



(a) In 2004 (b) In 2020

Figure 2.6 Htawei Chung Solid Waste Disposal Site

Figure 2.7 Aging vehicles and poor waste segregation

There are many challenges for waste management in Yangon city, such as lack of detailed planning for WMS, transportation, aging and non-specialized vehicles for waste collection, poor technical skill, waste segregation, lack of reliable data, and improper disposal sites (see Figure 2.7) (Jain, 2017). All of those are mainly from the insufficient budget for MSW management (Tun & Juchelková, 2019).

A large portion of organic wastes in Yangon city form leachate in disposal sites (Møller, 2020). If a biological treatment system is installed for the organic waste, it will decrease the environmental impacts through the reduction of waste volume by the production of biogas and compost products. This research, therefore, focuses on the estimation and evaluation of potential environmental impacts using the LCA and CBA methods to support the decision-maker to achieve the best practical method.

2.5 Law, Rule, and Regulation Related to Waste Management in Myanmar

Laws related to waste management in Myanmar include the Underground Water Act (1930), Environmental Policy (1994), Myanmar Agenda 21 (1997), National Sustainable Development Strategy (2009), Environmental Conservation Law (2012), Environmental Conservation Rule (2014), and Environmental Impact Assessment Procedure and National Environmental Quality Emission Guideline (2015).

In 2020, National Waste Management Strategy and Master Plan has been released with the collaboration with UNEP – IGES, in which there are six goals:

- Goal A aims to extend the sound waste collection and eliminate uncontrolled disposal and open burning.
- Goal B aims to extend sustainable and environmentally sound management of industrial and other hazardous waste.
- Goal C aims to prevent waste through 3Rs (reduce, reuse, and recycle)
- Goals D, E, and F aim to implement sustainable finance mechanisms, awareness-raising compliance, and monitoring enforcement.

For the regional level, the City of Yangon Municipal Act (1922), City of Yangon Development Law (1990), Yangon City Development Law (2013), and Yangon City Development Committee Law (2018) are established to support the national levels (Premakumara et al., 2017). Nonetheless, the laws are not strongly implemented and are unclear to regulate environmental protection, solid waste management, and the dearth of the 3Rs policy (Borongan & Okumura, 2010; Tun & Juchelková, 2019).

2.6 Life Cycle Assessment and Relevant Literature

LCA is one of the evaluation tools for recognizing and assessing the environmental problem/burden related to all steps of the production process from cradle to grave (e.g. the production of energy and power from waste to dispose of residual wastes) (Aryan et al., 2019; Lundie & Peters, 2005; Nabavi-Pelesaraei et al., 2019). Coello et al. (2018) stated that the LCA model can support the decision-maker as a tool to evaluate the impacts of waste management. Mayer et al. (2019) added that LCA can be used for computing environmental impacts from local to global impact.

LCA is increasingly used for consoling environmental impact from waste management (Assamoi & Lawryshyn, 2012; Nabavi-Pelesaraei et al.,2019). According to Cremiato et al. (2018), LCA is used for the comparison and evaluation of alternative scenarios of MSW. LCA can not only indicate the malpractice and proper system for MSW management but also give the information from an integrated point of view (Nabavi-Pelesaraei et al., 2017; Van Fan et al., 2018; Yano & Sakai, 2016). It can identify the maximum potential environmental impacts of a product, material, process, and activity (Aryan et al., 2019). As a result, LCA can be used for the decision-making of WMS (Koci & Trecakova, 2011).

Many researchers prove that the current WMS has a higher environmental impact due to the common use of uncontrolled landfills. The lower negative environmental impacts are found in the process with the combination of material recovery facilities and composting (Khandelwal et al., 2019a). Hoornweg & Bhada-Tata (2012) and Rodic-Wiersma (2013) stated that recycling is the general waste disposal hierarchy of waste strategy that can reduce the high impact of GHG emissions and quantity of waste disposal.

Recycling is one of the most advantageous methods that can reduce waste generation and environmental impacts (Farzadkia et al., 2021). Ayodele et al. (2018) and Sadef et al. (2016) stated that it can save energy that contributes to economic benefit for developed and developing countries. Khandelwal et al. (2019) added that the environmental impact can be reduced by the increment of the recycling rate. However, proper recycling practice in developing countries is not achieved (Farzadkia et al., 2021).Rana et al. (2019) also mentioned that recycling is an effective management system that can recover resources. According to Solis & Silveira (2020), 65% of MSW and 55% of plastic waste should be recycled by 2035 in European Union Strategy.

Incineration releases SO_2 and NO_x that can cause acidification and human toxicity (Yay, 2015). Istrate et al. (2020) stated that although incineration has human toxicity 100% higher than landfills, it can be neutralized by an intensification on other effects, including acidification, eutrophication, and human health. Incineration can reduce GHG emissions by replacing with other effects that can be reduced with the avoidance of energy recovery.

Onwosi et al. (2017) and Sadef et al. (2016) proved that composting process is the appropriate method because of the reduction of GHG emissions by producing compost products. This process can recycle the organic waste by the reproduction of organic substances as fertilizer with high nutrient content of biodegradable wastes. Rana et al. (2019) added that composting process can eradicate the methane emission from forming global warming potential (GWP).

The anaerobic digestion (AD) process can reduce GWP by 80% than composting process by replacing fuel consumption (Kristanto & Koven, 2020). Al-Rumaihi et al. (2020) proved that the AD process can reduce ozone and fossil fuel depletion by almost 100% by using heat and power with biogas (Al-Rumaihi et al., 2020b). AD process can reduce GWP by the production of biogas from its process (Istrate et al., 2020; Rolewicz-Kalińska et al., 2020).

Many researchers prove that landfills have higher environmental impacts than others due to the release of higher methane, carbon dioxide, and leachate (Khandelwal et al., 2019a; Thushari et al., 2020b; Nabavi-Pelesaraei et al., 2017). Yadav& Samadder (2018) added that landfills have higher GWP, human toxicity (HT), photochemical oxidant formation (POF), and eutrophication (EP). Thushari et al. (2020) stated that if the energy recovery efficiency increases, the environmental benefit will increase. Istrate et al. (2020) mentioned that energy recovery from landfills can reduce environmental impacts by capturing CH_4, converting CH_4 to CO_2 through combustion, and avoiding CH_4 emissions from landfills. In many research studies, landfills contribute to human toxicity impacts from leachate with heavy metals; as a result, landfills cause more impacts than thermochemical waste to energy techniques (Istrate et al., 2020; Hadzic et al., 2018).

In this study, the LCA method is applied to achieve the goal of a sustainable way for society and the environment (Yıldız-Geyhan et al., 2019). It can support the decision-maker for the implementation of sustainable waste management by comparing different scenarios from an environmental perspective (Hadzic et al., 2018).

2.7 Research Methodology

2.7.1 LCA Method

The LCA method comprises four phases (see Figure 2.8):

- Goal and scope definition: This phase define the reasons for carrying out the study. Intended application, study area and data sources, assumption, limitations, lifetime, system boundary, and the functional unit must be cleared in this stage.
- Inventory analysis: Row materials and energy inputs are collected for the input data inventory and calculated for output data inventory, such as products and coproducts, and emissions to conduct the next stage.
- Impact assessment: The impacts are categorized with the results of the inventory stage by using impact assessment methods.
- Interpretation: This phase confirms that the results from the inventory analysis and impacts assessment or both are consistent with the first stage, goal, and scope definition to reach the conclusion and recommendation (see Figure 2.8) (Nabavi-Pelesaraei et al., 2019).

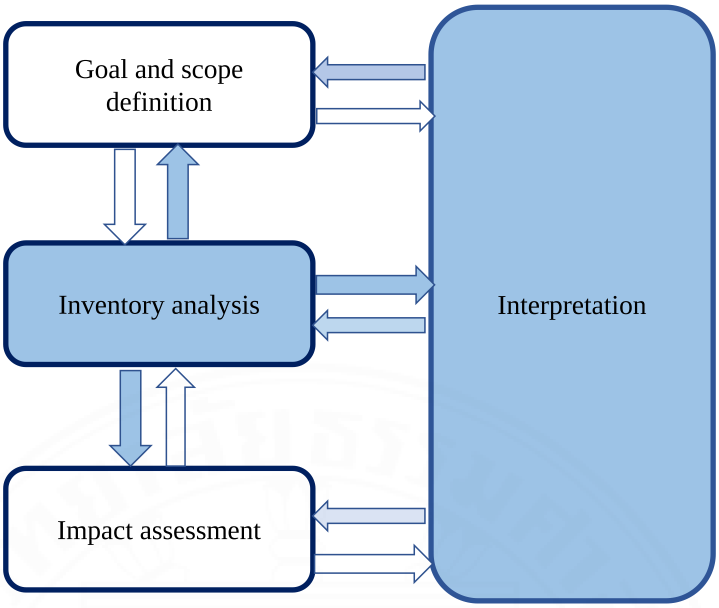


Figure 2.8 LCA framework

2.7.1.1 Goal and Scope Definition

Goal and scope definition aim to support and hold up the species of life cycle consideration of different scenarios. In this stage, the goal and areas are considered. The cradle to grave system boundary is identified, and accordingly, the functional unit is defined. The data sources, limitations, and lifetime are also important to be cleared in this stage (Nabavi-Pelesaraei et al., 2019; Dong et al., 2018).

2.7.1.1.1 Functional Unit

The functional unit (FU) in this study is one ton of MSW for the LCA method (Iqbal et al., 2019; Iqbal et al., 2020). This FU is used for the total amount of waste to scrutinize environmental potential impact from alternatives in the LCA approach at a particular time (Nabavi-Pelesaraei et al., 2019). It is used for MSW management, such as biological, thermo- chemical, and conventional treatments.

2.7.1.1.2 System Boundary

The system boundary is the connection between input and output or the consequence of the WMS (Cleary, 2009). The cradle to grave system boundary starts from waste collection, transportation, treatments, and final disposal, as shown in

(Figure 2.9). The waste and energy are considered as raw materials based on the potential environmental impacts and the energy output is based on the inventory energy, which is diesel. Electricity is called upstream production and can be considered as the calculation type of 'cradle to grave' (Nabavi-Pelesaraei et al., 2017; Iqbal et al., 2019). Energy consumption and final fuel for treatment are considered, but not for construction and service, and GHG emissions from these facilities in this system boundary (Udomsri et al., 2011; Takata et al., 2013; Yano et al., 2016). Landfills are considered as the final process (Nabavi-Pelesaraei et al., 2017).

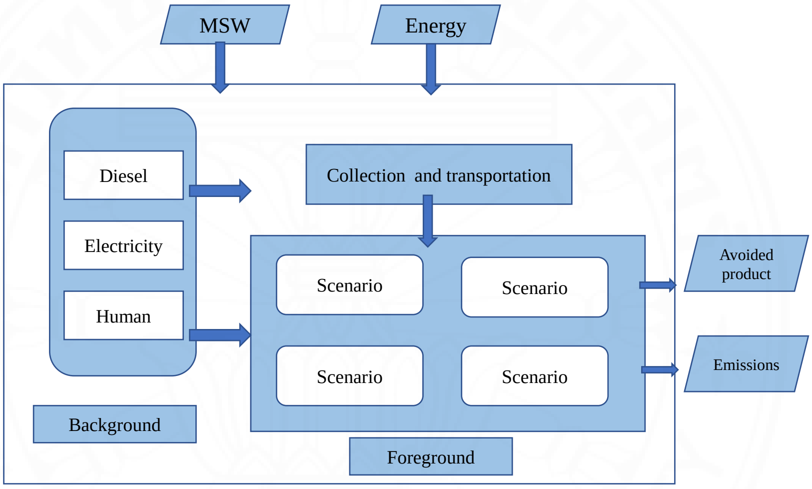


Figure 2.9 The system boundary of the WMS

2.7.1.2 Inventory Analysis

Inventory analysis works with the collected data to obtain the goal for LCA studies (Aryan et al., 2019). It plays a crucial role to achieve the high quality of LCA because the emissions include water, air, and soil, and product that includes electricity, digestate, compost, and the energy consumption are based on the inventory data (Mayer et al., 2019b). The estimation of future MSW management depends on the life cycle inventory (Mayer et al., 2019b). This stage depends on the study area, environment, economy, and social conditions (Nabavi-Pelesaraei et al., 2019; Assamoi & Lawryshyn, 2012).

2.7.1.3 Impact Assessment

Impact assessment aims to categorize impacts and understand the estimation of environmental hotspots and impacts formation (Assamoi & Lawryshyn, 2012). It provides the estimation of the environmental impact of all waste management scenarios. It can protect the environmental strength to attain the entire sustainable ecological assessment (Cleary, 2009; Mayer et al., 2019b). In LCA studies, the most common choice of the impacts is global warming potential, eutrophication, and acidification (see Figure 2.10) (Cleary, 2009).

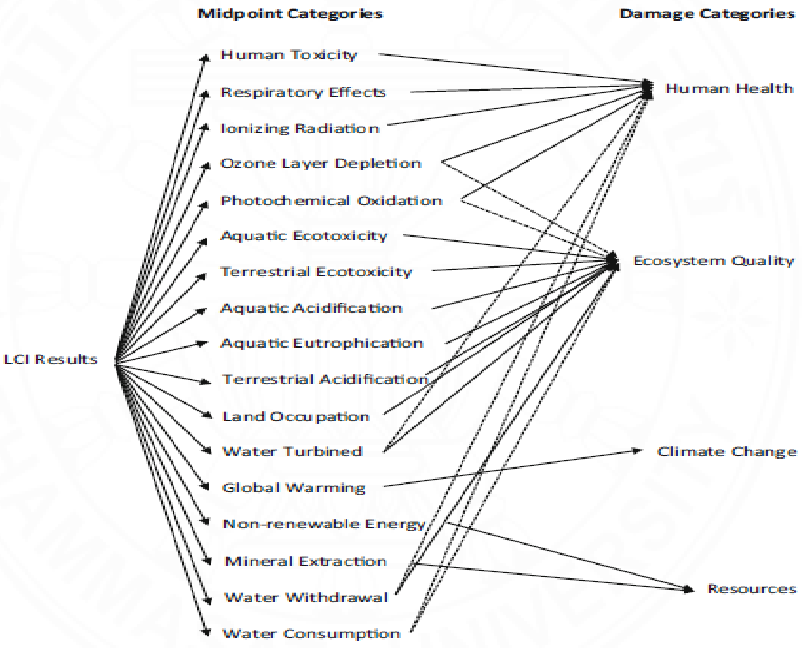


Figure 2.10 Impact categories from life cycle inventory data (Çetinkaya et al., 2018)

2.7.1.4 Interpretation

This phase confirms of inventory analysis and impact assessment are consistent with the goal and scope to gain conclusions and recommendations (Assamoi & Lawryshyn, 2012). LCA allows for the evaluation of the environmental consequences of the process, products, and services. However, the outcome of the LCA depends on the verdict of the methodology including the source of inventory data and supposition of the study (Assamoi & Lawryshyn, 2012). It depicts the results and sensitivity analysis (Coelho et al., 2018). Sensitivity analysis aims to identify the key parameter of waste management options to find the robustness of LCA results and accurate result of MSW management (Dong et al., 2018; Coelho et al., 2018). It estimates the result by changing the input data (Yano et al., 2016; Tabata & Okuda, 2012).

2.7.2 CBA Method

The economy is the primary issue for the implementation of waste management projects in developing countries due to the insufficient budgetary of the local authority. Zulkepli et al. (2017) mentioned that the CBA method can provide the design of projects by statistics of optimal economic. It aims to regulate the lucrative income of projects to provide the estimation of unforeseen risks of projects (Medina-Mijangos et al., 2021). The objective of the CBA method is to achieve the sustainable waste project sector with the optimal economic, social, and environment (Nesticò et al., 2018; Medina-Mijangos et al., 2021). It can provide the decision-maker with the choice of the optimal cost of sustainable waste management projects (Nie et al., 2018). Azis et al. (2021) proved that in the CBA method, net present value (NPV), internal rate of return (IRR), and payout time (POT) are commonly used for the estimation of capital for the waste management sectors.

2.7.2.1 Net Present Value (NPV)

Net present value (NPV) considers the difference between the total profit and total discounted cost (Cudjoe et al., 2020). If the NPV value is positive, this project will be profitable and if the value is negative, the project will not be profitable. In the other words, if the NPV is adequately high, the project is the economic feasible (Nesticò et al., 2018).The NPV value must be greater than zero for possible and consistent projects. The NPV method is as shown in Equation 2.1.

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+i)^t}, \tag{2.1}$$

where B_t is the project benefit in year t, C_t is the project's cost in year t, i is the discount, and t is the total number of years for life span.

2.7.2.2 Internal Rate of Return (IRR)

The internal rate of return (IRR) is the annual growth, which represents the annual amount of return on the initial investment cost (Khalid et al., 2020). If the amount of IRR is larger than the capital cost, then the project is acceptable (see Equation 2.2).

$$IRR = L + \frac{N_L}{N_L - N_H} \times (H - L), \tag{2.2}$$

where L is the lower discount rate, H is the higher discount rate, N_L is the NPV with the lower rate, and N_H is the NPV with a higher rate (Khalid et al., 2020).

2.7.2.3 Payout time

The payout time (POT) is the period for the total investment cost of a scheme to be exceeded by the revenue's profit (Azis et al., 2021). It is the time required to recover the initial cost, and that must be shorter than the duration of the project's timeframe (see Equation 2.3) (Rosasco & Perini, 2018).

$$POT = I/C, \tag{2.3}$$

where POT is the payout time, I is the income of projects, and C is the investment cost.

CHAPTER 3

EXPERIMENTAL PROGRAMS

3.1 LCA Analysis

The four main phases comprise LCA (1) goal and scope definition, life cycle inventory analysis, Impact assessment, and interpretation (Finkbeiner et al., 2006; Liikanen et al.,2018). The four phases are determined by the attitude of MSW management but the logical method is cramped because it can be exorbitant and prolonged (Nabavi-Pelesaraei et al., 2019). LCA offers an evaluation for environmental emissions of air, water, and soil by computing with equivalence factors to classify the various impacts (Singh & Basak, 2018). Six impact categories are classified including climate change (CC), acidification (AC), photochemical oxidant formation (POF), ozone depletion (OD), freshwater ecotoxicity (FE), and human toxicity (HT) by using SimaPro software ReCiPe method.

3.1.1 Goal and Scope Definition in this Study

The main goal of this study is to estimate the adverse impact of current MSW management practices and propose the proper WMS by comparing it with proposed alternative scenarios. The scope is in terms of three different boundaries including a physical system, which is presented from waste collection to the final disposal site, and transport, treatments, and disposal of wastes (Coventry et al., 2016). The time horizon for all scenarios is the year 2020. Upstream (raw material extraction and production of the products) and downstream (disposal of the products) are included in this research. The study area, data sources, functional unit, system boundary, and limitation are comprised (Iqbal et al., 2020). All alternative scenarios are evaluated based on the process-based LCA (Standardization, 2006). A cradle to grave unit process is approached, including the exploitation of raw material (MSW) to production (treatment of waste), distribution (products e.g. biogas, digestate, and compost) and finally to the disposal site (residues) (Coventry et al., 2016).

3.1.1.1 Study Area and Data Sources in this Study

The study area is Yangon city, as it is densely populated, is a commercial center, has high MSW generation, and has uncontrolled open dumping sites (Phyu, 2019). The specific study area is the municipal area of Yangon i.e., Yangon City Development Committee (YCDC), which consists of 33 townships with an area of 598.75 square kilometers and a population of about 5.2 million people (see Figure 3.1) (Tun et al., 2018).

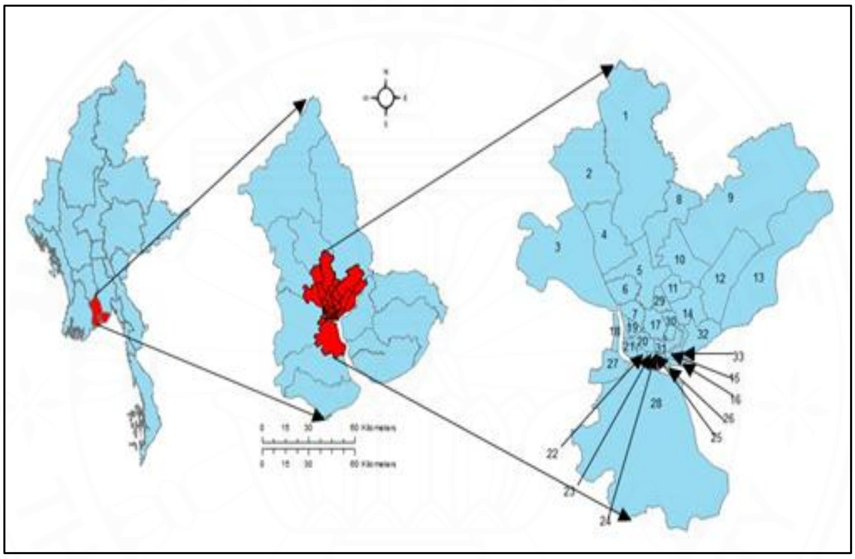


Figure 3.1 The location of YCDC

The total collected amount of MSW is 2552.47 tons/day, from which 60 tons/day are sent to the energy plant and the rest are sent directly to the open dumping sites, (see Table 3.1).

Table 3.1 MSW information in the study area (YCDC,2020)

Parameter	Value
Population	5.2 million people
MSW generation rate	0.5 kg/capita
Total MSW generated	2552.47 tons/day
Total MSW incinerated	60 tons/day

Some data are carried out from previous studies (Menikpura, 2013; Tun & Juchelková, 2018). A large portion of waste is organic materials followed by plastic and paper (see Table 3.2) (Tun & Juchelková, 2018).

Table 3.2 The composition of MSW in the study area (Tun & Juchelková, 2018)

Waste type	Composition of MSW in the study area (% by mass)
Food	44
Plastic	16
Paper	8
Green leaves	8
Leather and rubber	5
Glass	4
Metal	3
Textile	2
Glue	1
Other	9

3.1.1.2 Functional Unit in this Study

The functional unit (FU), is the MSW that is expressed in a ton of each assumption. It aims to support a reference to which input and output data are normalized and is used as daily generated waste in Yangon city (Saer et al., 2013). The all alternatives scenario’s environmental potential impacts are demonstrated qualitatively in this LCA study. Therefore, the consumption and demand of the amount of activity rate, and environmental emissions are computed based on one ton of MSW.

3.1.1.3 System Boundary in this Study

The system boundary is a critical role in the LCA method. It limits the proposed treatment process within the LCA study to a comprehensive extent. As illustrated in Figure 3.2, a cradle to grave system boundary, starting from waste collection and transportation, treatments (recycling, composting, incineration, and anaerobic digestion) to final disposal sites (landfills) within the system boundary are considered (Nabavi-Pelesaraei et al., 2017; Iqbal et al., 2019).Waste generation source is the cradle, while collection and transportation are the intermediate facilities, and the treatment scenarios are the grave parts. It considers the energy consumption of raw material to final use. Although emissions from different waste scenarios are not considered, emissions from transportation of waste to treatment facilities and landfills are considered (Nabavi-Pelesaraei et al., 2017).

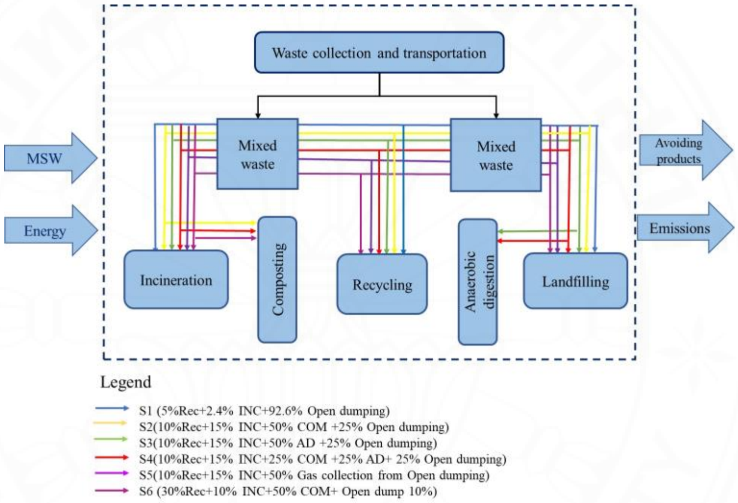


Figure 3.2 The system boundary of the study

3.1.1.4 Waste Management Options in this Study

The scenarios are designed to estimate potential environmental impacts and compare all scenarios to achieve environmentally friendly options for future waste management. In this study, recycling, composting, incineration, anaerobic digestion, and landfill with CH_4 collection methods are designed to eliminate the uncontrol disposal and illegal dumping of waste (Nanda & Berruti, 2021).

3.1.1.5 Scenarios Designation

The LCA is performed for six alternative scenarios which are designed to evaluate the environmental potential impact for Yangon city (see Figure 3.3). Scenario

A represents the current MSW management and the rest are proposed different portions of WMS with the distance from collection to disposal site of 33 km. MSW transportation is modeled in all scenarios and is assumed the same fuel consumption. Recycling and incineration are set as a part of all scenarios. A high grade of recycling (30%) has been chosen combined with composting in scenario F. Uncontrolled open dumping is set up for all scenarios except scenario E.

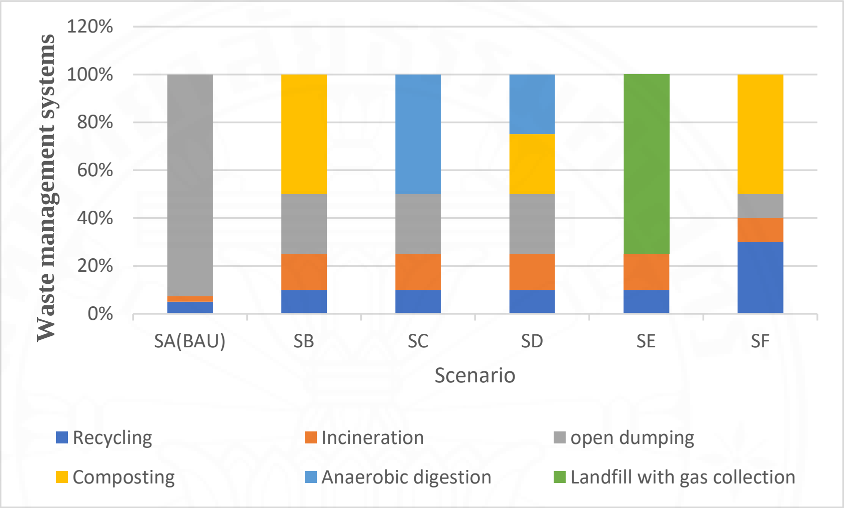


Figure 3.3 Scenario's designation

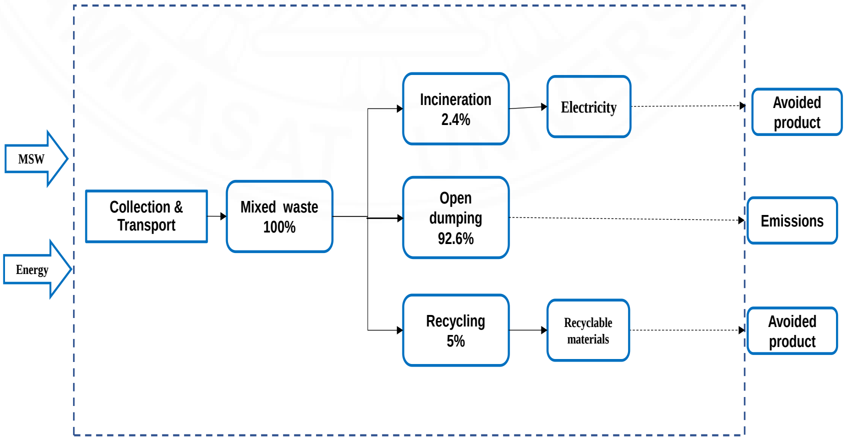


Figure 3.4 MSW process flow of scenario A (BAU)

Scenario A is regarded as business as usual (BAU), which is current waste management practice. In this scenario, 2.4 % of MSW are sent to the energy plant, 5% are collected by informal collectors from the final disposal site, and the rest of 92.6% are disposed off into the uncontrolled open dumping sites (see Figure 3.4).

Scenario B is assumed that the recycling rate and incineration rates increase from 5% to 10% of MSW, and 2.4% to 15% of MSW, respectively to observe the mitigation impacts from improved recycling and incineration rates. Recycling is the most critical process to reduce environmental contamination and hazardous waste for Myanmar's industrial waste and MSW management (Ko, 2014). As organic waste takes the highest portion of MSW, 50 % of MSW is assumed to compost after the recyclable and combustible wastes are increased (see Figure 3.5). The composting process can reduce GHG emissions, and it is an affordable method for developing countries (Hoornweg & Bhada-Tata, 2012).

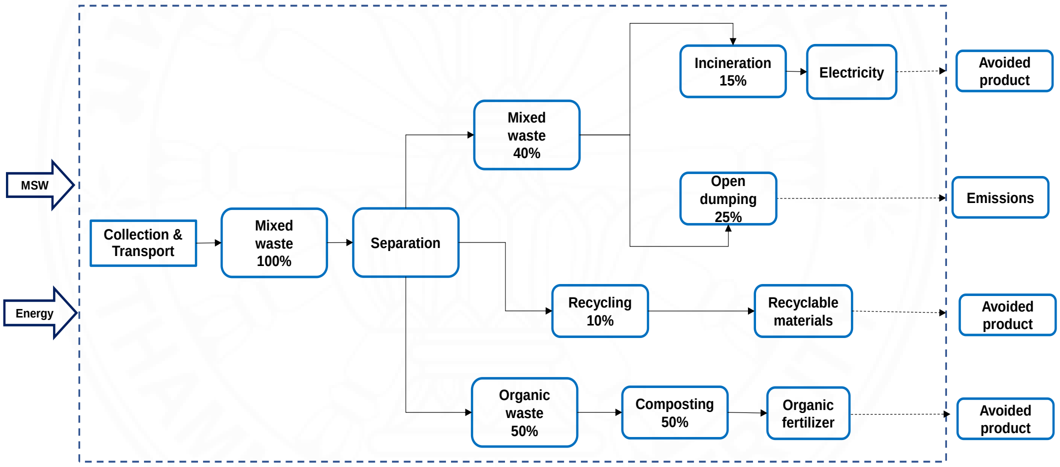


Figure 3.5 MSW process flow of scenario B

Scenario C considers the anaerobic digestion process of 50% of MSW and the same recycling, incineration, and open dumping rates as in scenario B to compare the environmental impacts from the two biological treatments as shown in Figure 3.6. The anaerobic digestion process is one of the most suitable waste-to-energy (WtE) technology because of the less environmental impact than the other WtE technologies (Kristanto and Koven, 2020). It can reduce GWP, ozone depletion, and fossil depletion by almost 100% due to the replacement of fuel use (Al-Rumaihi et al., 2020b; Kristanto & Koven, 2020).

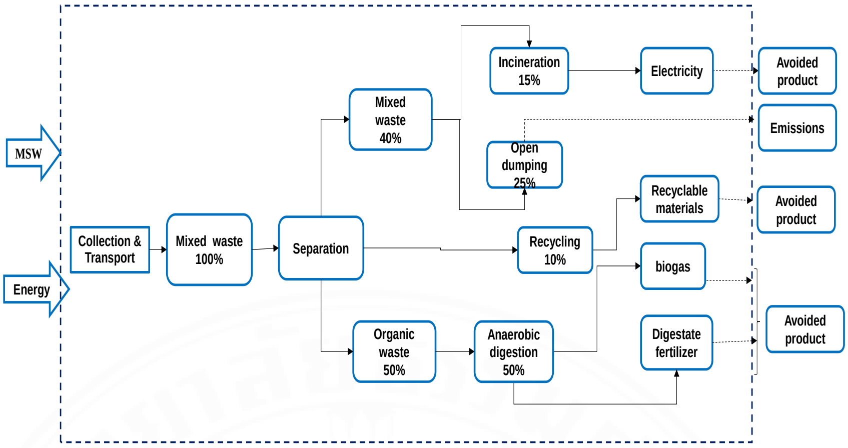


Figure 3.6 MSW process flow of scenario C

Scenario D is assumed to share the rate of the two organic treatment systems: 25% composting and 25% anaerobic digestion to adjust the potential environmental impact without changing the assumption of recycling and incineration rates. It can evaluate the effectiveness of the combination of the two biological treatment methods as they can produce not only the biogas from the AD process for its requires energy, but also the local demand of compost products (Vilaysouk & Babel, 2017). These two biological methods are the most common for organic materials and the circular economy of biological ideologies by the production of avoided products (see Figure 3.7) (Slorach et al., 2019).

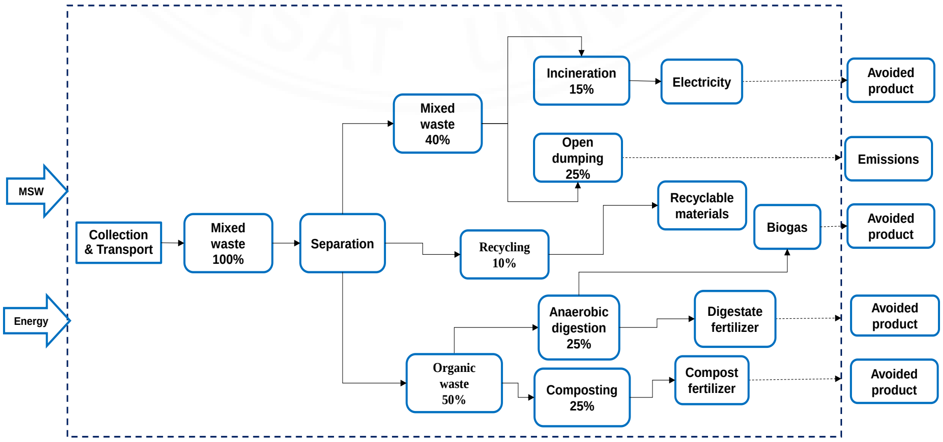


Figure 3.7 MSW process flow of scenario D

Scenario E is supposed to capture 50% of methane (CH_4) emissions to recover the energy and control emissions, and odor, and encourage the implementation of sanitary landfills. This is because 30% of global methane emissions were released from landfills and open dumpings than from scientific landfills (Cudjoe et al., 2020; Yadav & Samadder, 2018). Hoornweg et al. (2012) mentioned that the collection of gas from the landfilling process can reduce GHG emissions. For this reason, scenario, E is proposed to yield biogas instead of releasing it to the environment. According to Intharathirat and Salam (2016) and Sauve & Van Acker (2020), only 50-75% of emissions can be captured from landfills, so that the collection rate of 50% is assumed in this study (see Figure 3.8).

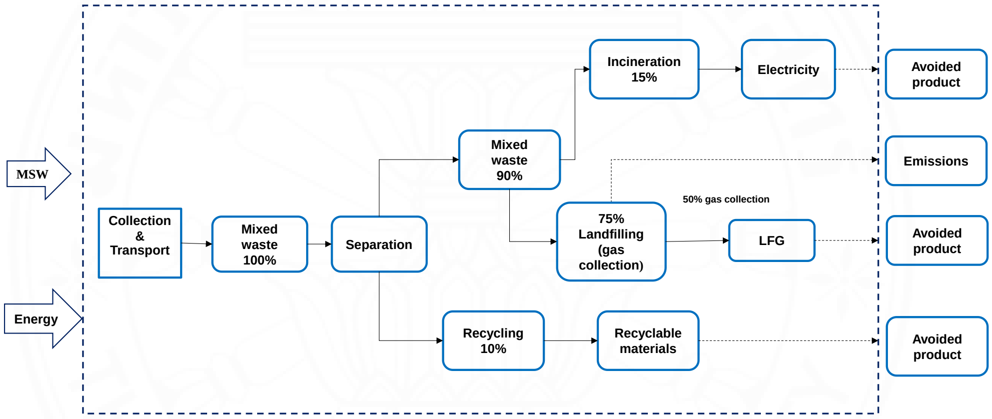


Figure 3.8 MSW process flow of scenario E

Scenario F is designed to increase the recycling rate from 10% to 30% of MSW to reduce the environmental impacts from the improved recycling rate, promote the 3Rs policy, and implement Goal C of the National Waste Management Strategy and Master Plan of Myanmar (2018-2030) (Thien et al., 2020). With this, 50% of MSW is composted and 10% of combustible waste is incinerated. Afterward, the rest 10% of waste and the residues from treatments are sent to the final disposal sites (see Figure 3.9). The comprehensible decision is achieved from the information of compostable and recyclable material relating to the affordable techno-economic resources (Diaz et al., 2020).

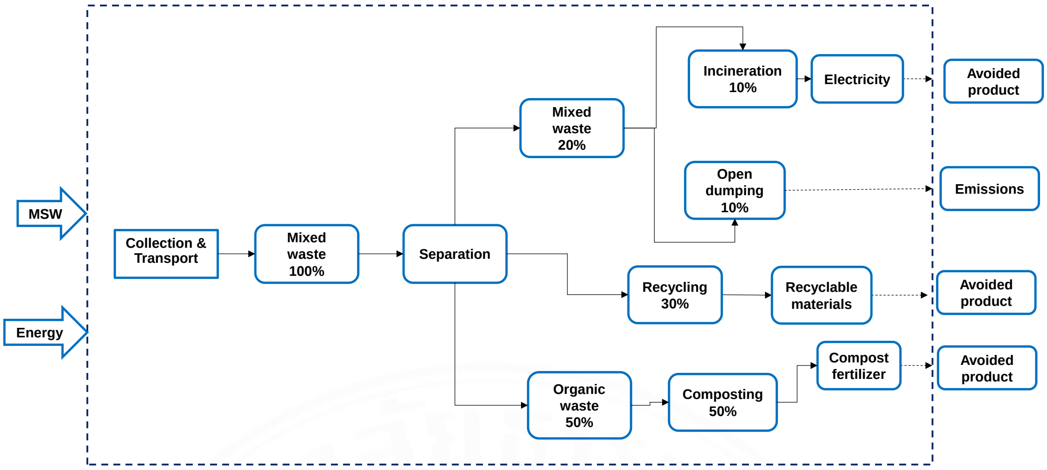


Figure 3.9 MSW process flow of scenario F

All alternative scenarios embraced the incineration method, as it is widely used to achieve energy and reduce the volume of waste (Sununta & Sampattagul, 2019). This WtE process is the way to get sustainable and renewable energy sources (Win et al., 2019). Despite the release of GHG emissions, this method can reduce the volume of waste for the demand of landfill countries and the production of electricity for local demand.

3.1.1.6 Limitation

LCA method focuses on the evaluation of the environmental impact of waste management for all scenarios, in which recycling, incineration, anaerobic digestion, composting, open dumping, and landfill with the gas collection are combined. In this research, emission from waste transportation is considered, but not in the waste collection as it is managed by human labor. Energy and emission are also not considered during treatment construction.

3.1.2 Life-Cycle Inventory

The life cycle inventory is the phase of collecting data related to all inputs (MSW, fuel, energy, and water) and outputs (emissions, products, and residues) of

MSW management. It provides the related impacts of different assumptions by the inventory results (Aung et al., 2020; Mayer et al., 2019a).

The primary and secondary data are required for this stage to analyze the impact categories for the LCA study. The country's specific data such as waste generated, incinerated, and transferred distance are collected from the Environmental Conservation and Cleaning Department of Yangon city to build the life cycle inventory. The inventory data is mainly attained from many studies and SimaPro 7.3.3 databases (Chanchampee, 2010; Menikpura & Sang-Arun, 2013; Tun et al., 2018; Polruang et al., 2018; Thushari et al., 2020a; Belboom et al., 2013; Iqbal et al., 2010; Tun & Juchelková, 2018, and Khandelwal et al., 2019a).

Emissions from waste treatments are calculated using emission factors from Intergovernmental Penal on Climate Change (IPCC) 2006 and European Environment Agency (EEA) 2019 Guideline. Emissions from the recycling process are modeled using SimaPro software. The model used is process-based LCA.

3.1.2.1 Life Cycle Inventory Calculation

3.1.2.1.1 Transportation

In this sector, emissions are calculated by two methods: IPCC (2006), and EEA (2019), which focus on the fuel sold and default value with emission factors estimated to emitted to the atmosphere.

Based on IPCC (2006), emissions are calculated based on Equation 3.1.

$$Emissions = \sum_a [Fuel_a \times EF_a], \tag{3.1}$$

where *Emissions* is the emission in (kg), $Fuel_a$ is the fuel consumption (TJ), EF_a is the emission factor (kg/TJ), and a is the fuel type (e.g petrol, diesel, LPG, natural gas).

EEA (2019), on the other hand, suggests emissions calculated based on Equation 3.2.

$$E_i = \sum_j \left(\sum_m \left(FC_{j,m} \times EF_{i,j,m} \right) \right), \tag{3.2}$$

where E_i is the emission of pollutant i (g), $FC_{j,m}$is the fuel consumption, in which j is the vehicle type and m is fuel (kg), and $EF_{i,j,m}$is the fuel sold specific emission factor of analyzing parameter i for vehicle type j and fuel (mg/kg).

3.1.2.1.2 Open Dumping and Landfilling

Although CH_4 emissions can be obtained over the estimated value of actual value using the IPCC default method, this approach is plausibly suitable for the cities where accurate and reliable data are unavailable (Paredes et al., 2019). The estimation of methane gas generated from the landfill site and open dumping is based on the IPCC method in this study (see Equation 3.3),

$$CH_4\,Emissions = [MSW_T \times MSW_F \times MCF \times DOC \times DOC_F \times F \times \left(\frac{16}{12}\right) - R](1 - OX). \tag{3.3}$$

The methane emission depends on the amount of MSW generation (MSW_T), and the other default parameters are recommended by the IPCC, such as MSW_F of 0.53, degradable organic carbon (DOC) of 0.118 which is derived from the formula of IPCC default value listed in Table 3.3, methane correction factor (MCF) of 0.8, unmanaged-landfill as shown in Table 3.4, DOC_f of 0.5, F of 0.5, oxidation factor of 0, and R of 0 as no energy recovery (recommended by IPCC).

Table 3.3 Fraction of degradable organic carbon (IPCC,2006)

Parameter	Waste flow	DOC (wet weight) %
A	Food	15
B	Paper/cardboard	40
C	Textile	24
D	Garden waste	20

Table 3.4 Oxidation factor (IPCC,2006)

Oxidation Factor (OX) for SWDS	
Type of site	Oxidation factor (OX) default value
Unmanaged and uncategorized solid waste disposal site	0
Managed covered with CH_4 oxidizing material	0.1

3.1.2.1.3 Incineration

The GHG emissions of this model count on the amount of the rate of incinerated MSW (SW_i). For the emission of CO_2, the value of dry matter content, a fraction of carbon in the dry matter, a fraction of fossil carbon in the total carbon, and oxidation factor are derived with the default value as recommended by the IPCC (2006) (see Equation 3.4).

$$CO_2 Emissions = \sum_i (SW_i \times dm_i \times CF_i \times FCF_i \times OF_i) \times 44/12, \tag{3.4}$$

where CO_2 emissions is the CO_2 emissions in inventory year (Gg/yr), SW_i is the total amount of incinerated MSW (wet weight) (Gg/yr), i is the type of waste, dm_i is the dry matter content of incinerated waste (wet weight) in the waste (wet weight) (Gg/yr), CF_i is the fraction of carbon in the dry matter (total carbon content), FCF_i is the fraction of fossil carbon in the total carbon, (fraction), and OF_i is the oxidation factor.

The CH_4 emissions and N_2O emissions rely on the incinerated MSW rate (IW_i) and the default value of aggregate methane emissions factor (EF_i), aggregate N_2O emissions factor, and conversion factor (10^{-6}) as recommended by the IPCC (2006), see Equation (3.5) - (3.6) and Table 3.5.

$$CH_4 Emissions = \sum_i (IW_i \times EF_i) 10^{-6}, \tag{3.5}$$

where CH_4 emissions is the CH_4 emissions in inventory year (Gg/yr), IW_i is the amount of incinerated MSW (wet weight) (Gg/yr), EF_i is the aggregate CH_4 emissions factor (kg CH_4/Gg) (default value of 60 for batch type incinerator), and 10^{-6} is the conversion factor from kilogram to gigagram.

$$N_2OEmissions = \sum_i (IW_i \times EF_i) 10^{-6} \tag{3.6}$$

Where N_2O emissions is the N_2O emissions in inventory year (Gg/yr), IW_i is the amount of solid waste of type i incinerated or open-burned (Gg/yr), EF_i is the aggregate N_2O emissions factor (kgCH_4/Gg) (default value of 60 for batch type incinerator), and 10^{-6} is the conversion factor from kilogram to gigagram.

Table 3.5 CH_4 and N_2O emissions factors for incineration

Types of waste	Emissions	Type of incineration	Emission factor	Weight basis
MSW	CH_4	Batch-type incineration	(60kg/Gg waste incinerated on a wet weight basis)	Wet weight
MSW	N_2O	Bath-type incineration	(60g N_2O/t MSW incinerated)	Wet weight

The GHG emissions such as NOx, CO, SO_2, and PM are, on the other hand, estimated based on the EEA method. They depend on the amount of MSW activity rate (AR) and the emission factors as recommended in the EEA Guideline (2019) (see Equation 3.7).

$$E_{pollutant} = AR_{production} \times EF_{pollutant} \tag{3.7}$$

Where E $_{\text{pollutant}}$ is the emission of the specified pollutant, $AR_{production}$is the activity rate for the waste incineration, and $EF_{pollutant}$ is the emission factor for the pollutant.

3.1.2.1.4 Composting

The biological treatment process is based on the inventory data from the literature and solely depended on the MSW composition of the country. In the treatment process, the GHG emissions (CH_4 and N_2O) are estimated by IPCC (2006) default method. Since CO_2 has a biogenic origin, it is ignored in this process. Composting process is in scenarios B, D, and F in this study. This model depends on the mass of treated MSW (M_i) and the default value of emission factor of GHG as recommended by IPCC (2006) (see Equation 3.8 and 3.9).

$$CH_4 Emissins = \sum_i (M_i \times EF_i) \times 10^{-3} - R \tag{3.8}$$

Where $CH_4 emissins$ is total CH_4 emissions in inventory year (Gg CH_4), M_i is the mass of organic waste treated by biological treatment type i (Gg), EF_i is the emission factor for treatment i (g CH_4/kg), i is the composting or anaerobic digestion, and R is the total amount of CH_4 recovered in the inventory year (Gg CH_4).

$$N_2O\ Emissions = \sum_i (M_i \times EF_i) \times 10^{-3} \tag{3.9}$$

Where N_2O Emissions is the total N_2O emissions in inventory year (GgN_2O), M_i is the mass of organic waste treated by biological treatment type i (Gg), $EF_i$is the emission factor for treatment i (g N_2O /kg), and i is the type of waste treatment.

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3.1.2.1.5 Anaerobic Digestion

The amount of air emissions is calculated as described in Equation 3.10

$$CH_4 Emissins = \sum_i (M_i \times EF_i) \times 10^{-3} - R, \tag{3.10}$$

where CH_4 Emissions is total CH_4 emissions in inventory year ($GgCH_4$), M_i is the mass of organic waste treated by biological treatment type i (Gg), EF_i is the emission factor for treatment i (g CH_4/kg), i is the composting or anaerobic digestion, and R is the total amount of CH_4 recovered in the inventory year (Gg CH_4).

3.1.2.2 Assumptions and Input Inventories

3.1.2.2.1 Waste Collection, Transportation, and Electricity Mix Generation

Road transportation is a source of environmental impacts that releases emissions during the transportation from waste collection to treatment plants and final disposal sites. Diesel consumption for transportation was 128704 liters (L) and gasoline was 900 L for 46500 tons per month of waste transportation from downtown to solid waste disposal sites in 2012 (Menikpura, 2013).Therefore, the diesel fuel consumption of waste transportation is estimated to be on average 7657.41 L/day (3 L/ton of MSW) for 33 km distances of all processes. MSW transportation is carried out from the SimaPro database, which considers a 16-ton van truck, no-load for transport, direction, the weight of the material being transported, fuel consumption, and the distance from the material pick-up location (see Table 3.6).

Myanmar’s electricity generation capacity is 12247 GWh in which 63% of sources are from hydropower, 32% are from gas, 3% are from coal, and 2% are from diesel (Nam et al., 2015; Saw & Ji-Qing, 2019; Dobermann, 2016). Electricity requirements are carried out from the literature and modified using hydropower at reservoir power plant/CHS (cascade type-hydropower stations) in the SimaPro database. This is because the majority of energy used in Myanmar is hydropower, and the plants are cascade-type hydropower stations in runoff river type (Saw & Ji-Qing, 2019). Inventory data for electricity production and consumption in Myanmar are modified from the SimaPro database, as they are not available.

Table 3.6 Inventories of the transportation process

Parameter	unit	Amount	Source
Energy use			
Diesel	L/ton	3	(Menikpura, 2013)
Emissions to air			
CO_2	kg/ton	8.44	**(**Calculation of emissions based on IPCC 2006)
CH_4	kg/ton	4.446E-04	**(**Calculation of emissions based on IPCC 2006)
N_2O	kg/ton	4.46E-04	**(**Calculation of emissions based on IPCC 2006)
CO	g/ton	19.329	(Calculation of emissions based on EEA 2019)
NO_x	g/ton	85.09	(Calculation of emissions based on EEA 2019)
PM	g/ton	2.397	(Calculation of emissions based on EEA 2019)
NH_3	g/ton	0.033	(Calculation of emissions based on EEA 2019)

3.1.2.2.2 Incineration Process

The incineration process is proposed in all alternative scenarios. The efficiency of energy recovery is assumed as 280 kWh/ton for all alternatives (Tun et al., 2018). The net calorific value of waste is 4 MJ/kg (Tun & Juchelková, 2018). Diesel consumption is 0.4 kg per ton of waste, and electricity consumption is 20 % of electricity produced (Thushari et al., 2020a; Intharathirat et al., 2016; Corporation, 2018). The type of incineration is bath-type incineration and the product is electricity generation (see Table 3.7).

Table 3.7 Inventories of Incineration

Parameter	Unit	Amount	Source
Input energy			
Diesel	kg/ton	0.4	(Thushari et al., 2020a)
Electricity	kWh/ton	86.4	(Thushari et al., 2020a)
Avoided product			
Electricity	kWh/ton	193.6	(Tun et al., 2018)
Emissions to air			
CH_4	kg/ton	0.060	(Calculation of emissions based on IPCC 2006)
CO_2	kg/ton	171.73	(Calculation of emissions based on IPCC 2006)
N_2O	kg/ton	0.060	(Calculation of emissions based on IPCC 2006)
NO_x	g/ton	1071	(Calculation of emissions based on EEA 2019)
CO	g/ton	41	(Calculation of emissions based on EEA 2019)
PM	g/ton	3.0	(Calculation of emissions based on EEA 2019)
SO_2	g/ton	87	(Calculation of emissions based on EEA 2019)
NH_3	g/ton	3.0	(Calculation of emissions based on EEA 2019)
HCl	kg/ton	0.024	(Chanchampee, 2010)
Dioxins	kg/ton	5.06 E-7	(Chanchampee, 2010)

3.1.2.2.3 Composting Process

In this study, emissions from composting are calculated using the IPCC method and data from previous researches on composting plants in Thailand (Iqbal et al.,2010). Diesel and electricity consumptions are 1.3 L/ton and 5.6 kWh/ton, respectively (Thushari et al., 2020a). It can produce compost product of 540 kg per ton of MSW (Rajcoomaret al., 2017; Verma et al., 2016; Belboom et al., 2013; Yadav & Samadder, 2018) (see Table 3.8).

Table 3.8 Inventories of composting

Parameter	Unit	Amount	Source
Input energy			
Diesel	L/ton	1.3	(Thushari et al., 2020a)
Electricity	kWh/ton	5.6	(Thushari et al., 2020a)
Emissions to air			
CH_4	kg/ton	4	(Calculation of emissions based on IPCC 2006)
N_2O	kg/ton	0.2387	(Calculation of emissions based on IPCC 2006)
NH_3	kg/ton	0.32	(Han et al., 2019)
Avoided product			
Compost product	kg/ton	540	(Rajcoomar et al., 2017).
Emissions to water			
BOD	kg/ton	9.43E-1	(Iqbal et al., 2010)
COD	kg/ton	0.125E+00	(Iqbal et al., 2010)
TS	kg/ton	1.22E+01	(Iqbal et al., 2010)

3.1.2.2.4 Anaerobic Digestion

In anaerobic digestion, CH_4 emissions are calculated by the IPCC method, and the value of the N_2O emission factor is neglected.This process is proposed in scenarios C, and D. In this study, biogas of 137.51 m^3 /ton of organic mixed MSW and digestate 200 kg/ton of MSW are assumed to be generated using Emission Quantification Tool (EQT), which is consistent with IPCC (2006) (Premakumara et al., 2018).Electricity and diesel consumption are 50 KWh/ ton and 0.05 L/ton, respectively (Polruang et al., 2018; Li & Feng, 2018; Chanchampee, 2010). The related data are collected from the research studies in Thailand, that has similar MSW compositions (see Table 3.9).

Table 3.9 Inventories of anaerobic digestion

Parameter	Unit	Amount	Sources
Input energy			
Diesel	L/ton	0.05	(Chanchampee, 2010)
Electricity	kWh/ton	50	(Li & Feng, 2018)
Diesel burned in the chopper	MJ/ton	1.82	(Modified database)
Emissions to air			
CH_4	kg/ton	0.7992	(Calculation of emissions based on IPCC 2006)
N_2O	kg/ton	N/A	
SO_2	kg /ton	0.042	(Chanchampee, 2010)
Avoided product			
Biogas	m^3/ton MSW	137.51	(Calculated from EQT)

Digestate	kg/ton MSW	200	(Calculated from EQT)
Emissions to water			
BOD_5	kg/ton	0.00372	(Polruang et al., 2018)
COD	kg/ton	0.01104	(Polruang et al., 2018)
Suspended solids	kg/ton	0.00462	(Polruang et al., 2018)
Phosphorous, total	kg/ton	0.00048	(Polruang et al., 2018)
Nitrogen, total	kg/ton	0.00396	(Polruang et al., 2018)
NH_3	kg/ton	3.25E-3	(Kirkwood, 2004)
TKN	kg/ton	5.20E-3	(Kirkwood, 2004)

3.1.2.2.5 Recycling Process

A recycling system for mixed plastic, glass, paper, one-layer cardboard, and mixed metal cans is selected in this study. Emissions from each type of recyclable and virgin resources are calculated based on the country-specific information from a previous research study (Tun et al., 2018).The compositions of the recyclable mix and the recyclability of the different materials are composed of important factors to assess the number of materials that can be recovered from recycling. In Yangon city, about 31% of MSW are recyclable materials, which is 791.2657 tons/day. The recyclable mix consists of four major categories that are glass, plastic, paper, and metal, respectively (Tun & Juchelková, 2018).The recyclability of those materials from one ton of paper, plastic, glass, and metal for minimum efficiency rate are 85%, 69.68%, 60.29, and 98% respectively(see Table 3.10) (Cui & Sošić, 2019).

Table 3.10 Inventories of recycling (Cui & Sošić, 2019; Tun & Juchelková, 2018; Thushari et al., 2020a)

Material	Unit	Amount	Energy use	Recycling efficiency
Glass	kg/ton	39.9	33.9	0.85
Plastic	kg/ton	150	105	0.6968
Paper	kg/ton	70	42.2	0.6029
Metal	kg/ton	20	19.6	0.98

3.1.2.2.6 Open Dumping and Landfill with CH4 Recovery

Open dumping is proposed in all alternative scenarios except scenario E. Air emissions are emitted directly into the atmosphere due to the lack of an engineered landfill method. In scenario E, it is assumed that 50% of the landfill gas is captured, and 50% is emitted directly into the atmosphere because it can produce methane around 100 m^3 per ton of MSW (wet waste) and landfill biogas is roughly 100-170 m3 per ton of MSW of wet waste (Intharathirat & Salam, 2016; Yay, 2015). Electricity consumption for landfills is 2.5 kWh per ton of MSW and diesel consumption is 0.6 L/ton of MSW (Thushari et al., 2020; Saheri et al., 2012).The air emissions are calculated using the IPCC method and some related data are collected from d research studies from Malaysia that has the same amount of generated waste and compositions of MSW. The electricity demand for gas collection is 0.12 kWh per ton of MSW and the avoided product, electricity grid is 106 kWh per ton of MSW (see Table 3.11 and 3.12).

Table 3.11 Inventories of open dumping

Parameter	Unit	Amount	Source
Input energy			
Diesel	L/ton	2	(Maalouf et al., 2019)
Emissions to air			
CH_4	kg/ton	16.96	(Calculating of emissions based on IPCC)

CO_2	kg/ton	4.61E+00	(Saheri et al., 2012)
N_2O	kg/ton	1.03E-04	(Saheri et al., 2012)
HCl	kg/ton	3.97E-05	(Saheri et al., 2012)
HF	kg/ton	4.19E-06	(Saheri et al., 2012)
NO_x	kg/ton	7.40E-02	(Saheri et al., 2012)
SO_x	kg/ton	7.04E-03	(Saheri et al., 2012)
Total HC	kg/ton	9.50E-04	(Saheri et al., 2012)
Total NMVOC	kg/ton	6.22E-03	(Saheri et al., 2012)
Total Metals	kg/ton	3.88E-06	(Saheri et al., 2012)
Benzene	kg/ton	2.00875E-4	(Chiemchaisri et al., 2019)
Toluene	kg/ton	1.0675E-4	(Chiemchaisri et al., 2019)
o-Xylene	kg/ton	4.8375E-5	(Chiemchaisri et al., 2019)
Emissions to water			
BOD	kg/ton	5.37E+00	(Saheri et al., 2012)
COD	kg/ton	1.44E+01	(Saheri et al., 2012)
N	kg/ton	5.63E+00	(Saheri et al., 2012)
NH_3	kg/ton	4.73E+00	(Saheri et al., 2012)
P	kg/ton	3.17E-02	(Saheri et al., 2012)
PO_4	kg/ton	1.13E-05	(Saheri et al., 2012)
Total metals	Kg/ton	7.81E-3	(Saheri et al., 2012)
Benzene	kg/ton	2.47E-05	(Chiemchaisri et al., 2019)
Toluene	kg/ton	8.775E-05	(Chiemchaisri et al., 2019)
m/p Xylene	kg/ton	1.235E-05	(Chiemchaisri et al., 2019)
Lead	kg/ton	1.3E-06	(Chounlamany et al., 2019)
Nickel	kg/ton	6.5E-06	(Saetang et al., 2009)

Cadmium	kg/ton	2.405E-06	(Tränkler et al., 2001),
Chromium	kg/ton	5.07E-05	(Chounlamany et al., 2019)

Table 3.12 Inventories of landfilling with CH_4 recovery

Parameter	Unit	Amount	Source
Electricity demand for landfilling	kWh/ton	2.5	(Thushari et al., 2020a)
Electricity demand for gas collection	kWh/ton	0.12	(Chanchampee, 2010)
Diesel	L/ton	0.6	(Saheri et al., 2012)
Avoided product			
Electricity	kWh/ton	106	(IPCC calculation)
Emissions to air			
CH_4	kg/ton	8.48	(Calculation of emissions based on IPCC)
CO_2	kg/ton	1.68E+01	(Saheri et al., 2012)
N_2O	kg/ton	2.23E-04	(Saheri et al., 2012)
HCl	kg/ton	5.33E-04	(Saheri et al., 2012)
HF	kg/ton	5.58E-05	(Saheri et al., 2012)
NH_4	kg/ton	1.27E-05	(Saheri et al., 2012)
NO_x	kg/ton	1.85E-01	(Saheri et al., 2012)
SO_x	kg/ton	2.51E-02	(Saheri et al., 2012)
Total HC	kg/ton	4.08E-04	(Saheri et al., 2012)
Total NMVOC	kg/ton	2.67E-03	(Saheri et al., 2012)
Total Metals	kg/ton	1.12E-04	(Saheri et al., 2012)
Benzene	kg/ton	2.00875E-04	(Chiemchaisri et al., 2019)

Toluene	kg/ton	1.0675E-04	(Chiemchaisri et al., 2019)
o-Xylene	kg/ton	4.8375E-05	(Chiemchaisri et al., 2019)
Emissions to water			
BOD	kg/ton	1.07E-01	(Saheri et al., 2012)
COD	kg/ton	2.89E-01	(Saheri et al., 2012)
N	kg/ton	5.63E-02	(Saheri et al., 2012)
NH_3	kg/ton	6.02E-02	(Saheri et al., 2012)
P	kg/ton	3.17E-04	(Saheri et al., 2012)
PO_4	kg/ton	1.63E-04	(Saheri et al., 2012)
Total metals	kg/ton	4.20E-03	(Saheri et al., 2012)
Benzene	kg/ton	2.47E-05	(Chiemchaisri et al., 2019)
Toluene	kg/ton	8.775E-05	(Chiemchaisri et al., 2019)
m/p xylene	kg/ton	1.235E-05	(Chiemchaisri et al., 2019)
Lead	kg/ton	1.3E-05	(Chounlamany et al., 2019)
Nickel	kg/ton	6.5E-06	(Saetang et al., 2009)
Cadmium	kg/ton	2.405E-06	(Tränkler et al., 2001)
Chromium	kg/ton	5.07E-05	(Chounlamany et al., 2019)

3.1.3 Impact Assessment

Impact assessment aims to select, classify, and evaluate the impact categories from the results of the life cycle inventory by processing data (Silva et al., 2021). The output inventory results are evaluated using SimaPro Software 7.3.3, ReCiPe midpoint characterization method). The investigation focuses on selected categories including climate change, terrestrial acidification, human toxicity, photo oxidant formation, ozone depletion, and freshwater ecotoxicity. SimaPro software is the most popular and widely used LCA method of MSW (Rana et al., 2019).

3.2 CBA Method for MSW

The cost-benefit analysis (CBA) method is used for the estimation of the economic aspect of a waste management project whether the proposed project is feasible or not. It is the formal technique to support the authority's decision-making (Mishan & Quah, 2020). It focuses on the capital cost, operational cost, and net benefit to analyze the optimal condition of MSW treatment projects. Capital cost includes the cost of mechanical, electrical and civil and the related with the construction of the project and the operational cost is the variable cost includes the cost of personal expense, utility cost, maintenance/management cost and the any other expenses, and the income is the financial earned from the co-product of projects (Sharma & Chandel, 2021). The assumptions are as follows:

- Recycling and open dumping are not considered for economic analysis because the waste recycling system is still complex, including the unorganized waste fractions, selling price, inaccurate data.
- The disposal cost, which is an accumulation waste of treatment to dispose of landfill, is not considered.
- The land cost and construction of projects are not considered.
- External, social impact and environmental costs from air pollution are not considered due to a lack of monetary assessment.
- The revenue and operational cost are constant because the government's budget is insufficient and the increasing amount of personal expenses is very low.

The three formulas of CBA are used including net present value (NPV), internal rate of return (IRR), and payout time (POT). The NPV considers the measure of both cash inflow and outflow to examine net cash flow. If the NPV value is negative, the project is not profitable, and the benefit is positive, the project is feasible (Cudjoe et al., 2021). IRR method is defined as the rate of return of a specific investment and PoT is the required period to achieve the rate of the initial investment.

The main income is obtained from selling electricity to the grid, and digestate and compost fertilizer (Ascher et al., 2020). The tipping fee is considered as revenue for all projects because it is mainly dependent on the economic feasibility by increasing the NPV values (Ascher et al., 2020; Indrawan et al., 2020). The tipping fee for households and businesses is 2.4 USD/ton, and 5.1 USD/ton, the fee gate for landfill is 3 USD/ year respectively(World Bank Group, 2019). The currency of USD is converted to the year 2021. The working day is 310 in a year. The lifetime/duration of all projects is estimated to be 15 years.

The three main investment analysis parameters; NPV, IRR, and POT are used to estimate the viability of the projects as shown in Equations 3.11-3.14.

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+i)^t}\,, \tag{3.11}$$

where B_t is the project lucrative in year t, C_t is the project's cost in year $t,$ i is the discount, and t is the total number of years for life span.

$$IRR = L + \frac{N_L}{N_L - N_H} \times (H - L)\,, \tag{3.12}$$

where *L* is the lower discount rate, *H* is the higher discount rate, N_L is the NPV with the lower rate, and N_H is the NPV with a higher rate (Khalid et al., 2020).

$$\sum_{J=1}^{N} C_J \,/ (1 + IRR)^\wedge j\,, \tag{3.13}$$

where *I* is the Initial investment, *C* is the net cash flow which contains the income and expenses of the operating process, and *j* is the number of years.

$$POT = I/C\,, \tag{3.14}$$

where *I* is the initial investment cost and *C* is the net income from operating the project.

3.2.1 Inventory Data for CBA

The three main criteria including initial investment cost, operation, and maintenance (O&M) cost, and income of the projects are carried out from the studies. The data of incineration projects and national average interest rate are carried out from the final report of waste to energy plant for Yangon city in Myanmar (corporation, 2018). The average interest rate of Myanmar is 5.5% per year. The relevant data for composting, anaerobic digestion, and landfill with energy recovery are carried out from the previous researches of MSW management projects in Thailand. The compost and digestate fertilizer price is the current market price of Myanmar (YCDC,2017) (see Table 3.13)

Table 3.13 Inventory data for cost-benefit analysis method

Project	Cost	Value	Unit	Reference
Incineration	Investment	16000	USD/ton	(Corporation, 2018)
	O &M	15.4	USD/ton	
	Revenue	0.33 (electricity)	MWh/ton	
Composting	Investment	17509.52	USD/ton	(Sun et al., 2020).
	O &M	26.72	USD/ton	
	Revenue	540 (compost)	kg/ton	
Anaerobic digestion	Investment	46220.68	USD/ton	(Sun et al., 2020), (Huiru et al., 2019)
	O &M	12.61	USD/ton	
	Revenue	77.72 (electricity)	kWh/ton	
		200 (digestate)	kg/ton	
Landfill	Investment	14075.52	USD/ton	(Pawananont & Leephakpreeda, 2017)
	O &M	2.06	USD/ton	
	Revenue	106 (electricity)	kWh/ton	

Note: The selling price of electricity is 0.082 USD/kWh (Van Seventer, 2021)
The selling price of compost fertilizer is 51.52 USD/ton (YCDC,2017)

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Life Cycle Impact Assessment Results

The influence analysis shows how each scenario stimulates six impacts namely climate change (kg CO_2 eq/ton of MSW), terrestrial acidification (kg SO_2 eq/ton of MSW), human toxicity (kg1,4-DB/ton of MSW), photo oxidant formation (kg NMVOC eq/ton of MSW), ozone depletion (kg CFC-11/ton of MSW), and freshwater ecotoxicity (kg 1,4-DB/ton of MSW). These impact categories depend on the designation of the WMS (Sauve et al., 2020). They are analyzed using SimaPro software, ReCiPe Midpoint (H) method.

LCA model shows the characterization results for six categories from different scenarios. It reveals each potential impact of a specific unit, and depicts the influence of the potential environmental impacts through six potential impacts (Behrooznia et al., 2018). The negative value of characterization results represents the environmental benefit, on the contrary, the positive value is the deterioration of environmental benefit on potential impacts (Zaman, 013). The avoidance potential impacts of each recyclable material are considered in the same amount of virgin material.

4.1.1 Climate Change Potential

Figure 4.1 illustrates the climate change potential of the designed scenarios. The highest climate change impact, 437.3618 kgCO_2 eq/ton of MSW, is obtained in the BAU scenario. This is because approximately 93% of mixed waste in open dumping and releases a high amount of CH_4 emissions into the atmosphere. This has been confirmed by Kaushal & Sharma (2016) that open dumping generates high CH_4 emissions. In BAU, the lowest CO_2 emission is obtained due to the small amount (2.4%of MSW) is incinerated. These impact results are mainly prejudiced by the disposal of all wastes in an open dumping site. The second highest climate change potential occurs in scenario E. 97% of impacts are from the landfills because 50% of landfill gas is recovered for energy, and half of the CH_4 emissions are released into the atmosphere. The rest of climate change impacts are from incineration and transportation. CO_2 emissions are accounted for only in the incineration process because biogenic CO_2 is not accounted for GWP (Ogle et al., 2015).

Scenarios B, C, and D have no significant amount of climate change impacts with the value of 110.55 kgCO_2 eq/ton of MSW, 76.87 kgCO_2 eq/ton of MSW, and 93.71 O_2eq/ton of MSW, respectively. This is due to the effectiveness of the biological treatment method. The lowest climate change impacts are in scenario F with 30% recycling, 50% of composting, 10% of incineration, and 10% of open dumping. This is the best in GHG emissions reduction.

The biological treatment in scenarios B, C, and D results in lower GHG emissions when compared with scenario A(BAU). Scenario E (gas collection from landfill) can reduce 60% of impacts, likewise, scenario F can reduce 100 % of impacts when compared with scenario A(BAU). It is thus cleared that gas collection from landfills and an increase of the recycling rate lead to the lowest climate change potential.

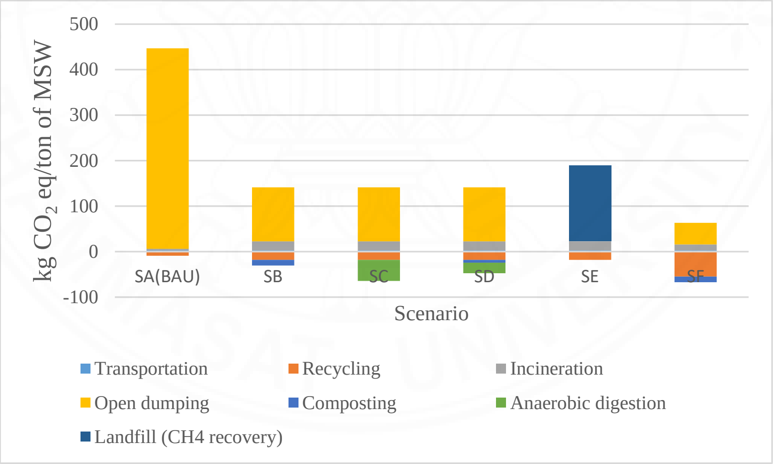

Figure 4.1 Climate change potential of different scenarios

4.1.2 Terrestrial Acidification Potential (AC)

The acidification (AC) potential is caused by the combustion of fossil MSW in the incineration process (Suwan et al., 2012). Figure 4.2 shows the highest acidification potential, 0.100572 kg SO_2 eq/ton of MSW, from scenario E followed by scenario A(BAU). In scenario E, approximately 95% of impacts are from the incineration process, and the second contributor is MSW transportation. BAU has lower impacts than scenario E due to the lower rate of incineration. This is because NO_X and SO_X are released when the fossil is combusted. In this option, 60% of impacts are from open dumping and 28% are from MSW transport as NO_2 and SO_2 are released from the combustion of diesel fuel. This is confirmed by Nasution et al. (2018) and Zaman, (2013) that transportation generates emissions. Sauve et al. (2020) added that the key factor in the formation of AC is transportation (Sauve & Van Acker, 2020). Although BAU has a lower rate of incineration than scenario E, it still has high AC impacts due to the lack of process to produce avoided products.

The least AC impact, -0.13818 kg SO_2 eq/ton of MSW, is from scenario F due to the avoidance products of the composting process and increase of recycling rate. Scenario E has the avoidance products by a collection of landfill gas which can reduce energy consumption. It can be said that a lower level of impacts can be achieved with biological treatments, as shown in scenarios B, C, and D (see Figure 4.2) (Singh & Basak, 2018).

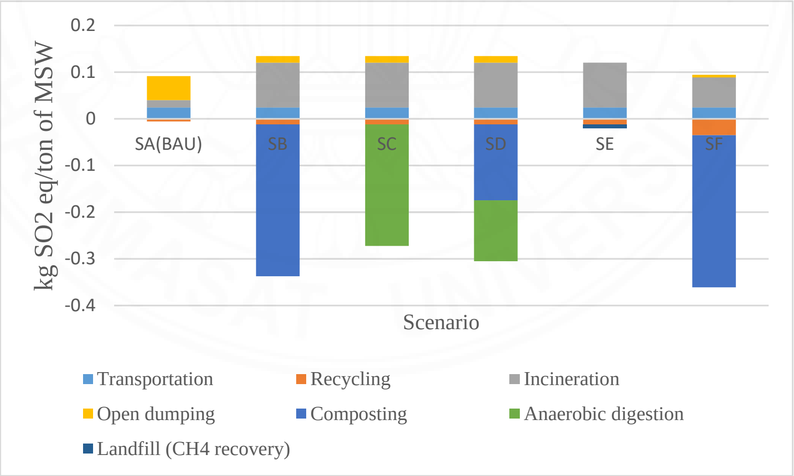

Figure 4. 2 Terrestrial acidification potential of different scenarios

4.1.3 Ozone Depletion Potential (OD)

The LCA results show that ozone depletion cannot be significantly found in all scenarios. Figure 4.3 illustrates that the highest ozone depletion, which is 7.24E-6 kg CFC-11 eq/ton of MSW, is found in the BAU scenario due to the high rate of MSW in uncontrolled open dumping sites. Nabavi-Pelesaraei et al. (2017) and Kaushal & Sharma (2016) stated that the main reason for GWP is the ozone layer depletion impacts. It can also be formed by uncontrol landfills (Sauve & Van Acker, 2020). The second highest OD impact is scenario B, as the composting process requires treatment facilities and waste transportation. In general, a net contribution to ozone depletion can be found in all scenarios despite lower impacts. The least ozone depletion impact, which is -6.305E-6 kg / CFC-11 eq/ton of MSW, in scenario E can be reduced by a collection of CH_4 from landfilling (Singh & Basak, 2018). In this case, the emissions from incineration do not contribute to ozone depletion (Chaya & Gheewala, 2007).

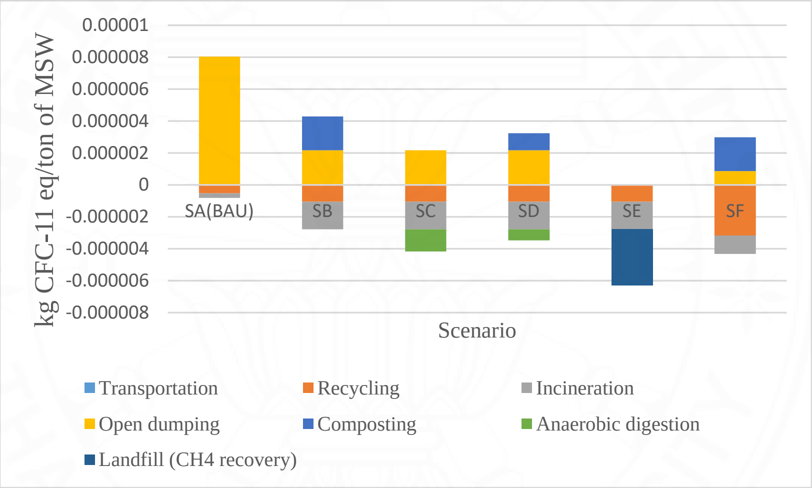

Figure 4.3 Ozone depletion potential of different scenarios

4.1.4 Human Toxicity Potential (HT)

Uncontrolled open dumping is the major source of human toxicity impacts due to the indiscrimination of uncategorized waste and direct emissions, especially particulate matter (PM) (Hadzic et al., 2018; Sauve & Van Acker, 2020). Heavy metals, such as zinc, lead, nickel, mercury, dioxin, copper, chromium, and barium (water emission), and volatile organic compound (VOC) are the main contributors of human toxicity impacts and its higher emissions are mainly emitted from uncontrolled landfills (Yay, 2015; Medina-Mijangos et al., 2021). Antimony and selenium lead to human toxicity through groundwater pollution, and heavy metal emissions from incineration are the majority of human hazard (Medina-Mijangos et al., 2021). Figure

4.4 illustrates that the highest human toxicity impacts are mainly caused by MSW transportation due to the use of diesel fuel. Many researchers conclude that diesel fuel consumption has significant environmental impacts on waste collection and transportation (Al-Rumaihi et al., 2020b; Nabavi-Pelesaraei et al., 2017; Achawangkul et al., 2016). In this result, BAU reveals the highest human toxicity impacts of 4.0835 kg 1, 4- DB eq/ ton of MSW, followed by scenario E. It can be concluded that the increase in emissions from BAU is strongly related to the increase in the amount of waste transferred to the uncontrolled disposal sites. Human toxicity impacts are found in almost every scenario because MSW transportation is counted in all scenarios. Scenarios B, C, and D have lower impacts due to the increased rate of biological treatment methods. The lowest impacts of -4.3237 kg 1, 4- DB eq/ ton of MSW are observed in scenario F with a high recycling rate. As many chemicals are used in the manufacturing of papers and plastics, scenario F lead to the lack of toxic substances into the environment.

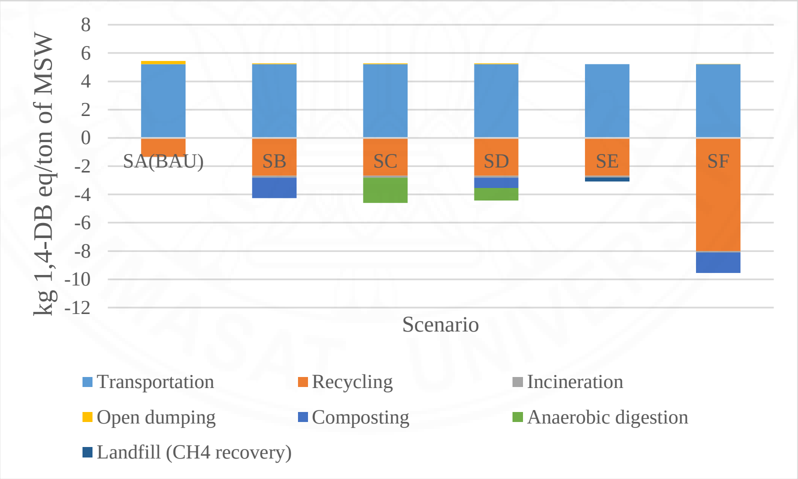

Figure 4.4 Human toxicity potential of different scenarios

4.1.5 Photochemical Oxidant Formation Potential (POF)

The POF is mainly contributed by uncontrolled open dumping sites. Figure 4.5 demonstrates that the highest POF impact is 0.2872 kg NMVOC eq/ton of MSW, which is obtained from the BAU scenario due to the releasing of a large amount of methane gas from uncontrolled open dumping sites. The degradation of MSW in landfills also mainly contributes to this impact by releasing CH_4 emissions as shown in scenario E (Liamsanguan & Gheewala, 2008). In this scenario, 87% of impacts are obtained from open dumping sites. It releases half of CH_4 emissions from landfills, whereas 20% of impacts are from landfills, 17% are from transportation, and the rest are from the incineration process. However, incineration is better than open dumping when compared with BAU, as methane emissions is less (Yadav & Samadder, 2018). Scenarios B, C, and D have lower POF than the BAU due to the avoided products from the biological treatment process. The lowest POF impact is obtained from scenario F, which is– 0.09 kg NMVOC eq/ton of MSW. Although scenario C reduces POF, it can contribute to forming POF because of the release of NO_x from biogas combustion (Istrate et al., 2020). Among six options, scenario F is the best option because of the highest recycling rate of MSW.

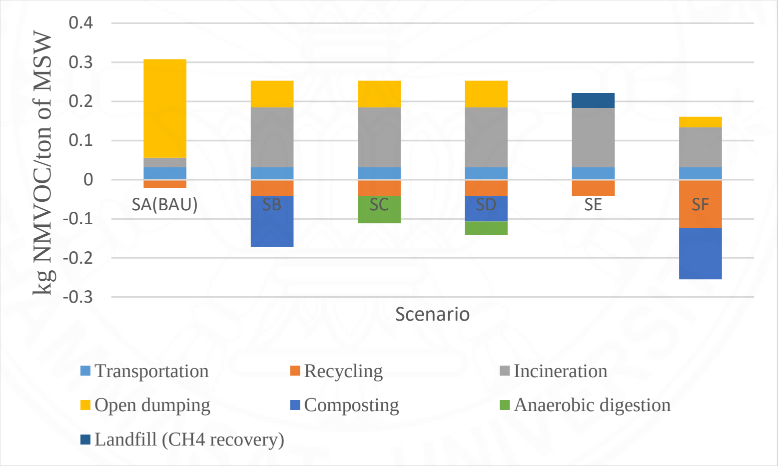

Figure 4.5 Photochemical oxidant formation potential of different scenarios.

4.1.6 Freshwater Ecotoxicity (FE)

The risk of human health is related to the polluted water from landfills causing many health problems such as respiratory, diarrheal diseases, cancer, nervous system, and circulatory disease (Qadri et al., 2020). The formation of freshwater ecotoxicity is mainly contributed by uncontrolled landfills (González-García et al., 2021). Yadav and Samadder (2018) proved that open dumping releases more impacts than the scientific landfill. Figure 4.6 shows that the highest freshwater ecotoxicity impacts of

3.2019 kg 1, 4- DB eq/ ton of MSW are at the BAU scenario, in which 100% impacts are from the open dumping site. Scenarios B, C, and D have lower freshwater ecotoxicity impact due to the grouping of only 25% of MSW to open dumping. The lowest FE impact, which is -0.0766 kg 1, 4- DB eq/ ton of MSW in scenario E because of the sanitary landfill. The second lowest impact scenario is scenario F with the combination of composting, 10% open dumping, and the highest recycling rate.

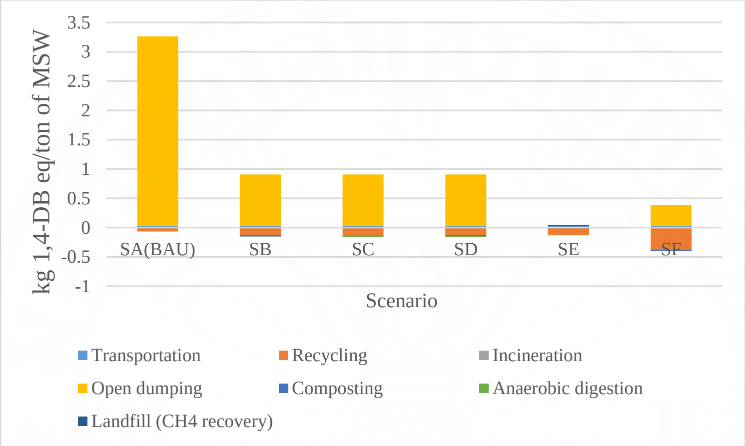

Figure 4.6 Freshwater ecotoxicity potential of different scenarios.

Table 4.1 Environmental impact ranking of six scenarios of characterization results

Environmental impact category	**SA(BAU)**	**SB**	**SC**	**SD**	**SE**	**SF**
Climate change	6	4	2	3	5	1
Photochemical oxidant formation	6	2	4	3	5	1
Human toxicity	6	4	2	3	5	1
Terrestrial acidification	5	2	4	3	6	1
Ozone depletion	6	5	2	4	1	3
Fresh water ecotoxicity	6	5	4	3	2	1
Avg. environmental score	5.8	3.6	3	3.1	4	1.3
Environmental ranking	6	4	3	3	4	1

legend

🟩 Best
⬜
🟨
🟧
🟧
🟥 worst

The summary of the six environmental impact results of all six scenarios is as shown in Table 4.1. It is found that scenario F is the least impact scenario.

4.2 Interpretation of the Results

This phase aims to assess possible changes of amendments of the scheme that can induce its environmental benefit and can select the proper option (Cremiato et al., 2018). Six alternative scenarios are analyzed to determine the potential environmental impacts to achieve a sustainable WMS. Investigation from the inventory analysis and impact assessment phase or both are found steady with the goal and scope of the study, contributing to the decisions and commendations (Assamoi & Lawryshyn, 2012).

4.2.1 Sensitivity Analysis of LCA results

Sensitivity analysis is a crucial step to assess the robustness and reliability of the LCA results (Ferronato, 2021; Suwan et al., 2012). It is used to evaluate the variation of the results, which is instigated by altering the input parameters (Wang et al., 2020). It gives not only the robustness of results but also guides the development of future research (Aisha Al-Rumaih et al., 2020).

In this study, sensitivity analysis is performed by changing the recycling efficiency rate in each scenario. The former deals with recycling efficiency rate for 85% of glass, 69.68% of plastic, 60.29% of paper, and 98% of metal respectively. Sensitivity analysis is performed by increasing each input parameter by 100% individually to evaluate the consequences of the environmental impacts. The results are as shown in Table 4.2 and Figure 4.7.

Table 4.2 Summary of the characterization environmental impacts in the sensitivity analysis

Impact	SA	SB	SC	SD	SE	SF
CC	437.36	110.554	76.877	93.715	170.494	-4.201
HT	4.083	1.006	0.670	0.838	2.139	-4.323
POF	0.287	0.080	0.141	0.110	0.180	-0.093
OD	7.243E-06	1.52E-06	-2E-06	-2.4E-07	-6.30E-06	-1.3E-06

AC	0.085	-0.203	-0.138	-0.170	0.100	-0.267
FET	3.201	0.751216	0.743	0.747	-0.076	-0.022
CC	429.905	95.640	61.963	78.802	155.580	-48.942
HT	2.309	-2.542	-2.878	-2.710	-1.409	-14.970
POF	0.264	0.035	0.096	0.065	0.135	-0.229
OD	6.84E-06	7.17E-07	-2.8E-06	-1E-06	-7.1E-06	-3.7E-06
AC	0.059	-0.255	-0.190	-0.222	0.048	-0.256
FET	3.162	0.673	0.665	0.669	-0.154	-0.422

Note: Climate change (kg CO_2 eq/ton), human toxicity (kg 1,4-DB eq/ton), photochemical oxidant formation (kg NMVOC eq/ton), ozone depletion (kg CFC-11 eq/ton), terrestrial acidification (kg SO_2eq/ton), freshwater ecotoxicity (kg 1,4-DB eq/ton)

Notably, all environmental impacts decrease in all scenarios, especially in scenario F. In scenario F, the Recycling efficiency rate (100%) can decrease 44% of climate change impact, 10% of human toxicity impact, and 40% of freshwater ecotoxicity from the reference rates. The key contributor to the environmental benefit of scenario F is the higher recycling efficiency rate, which can reduce the amount of fossil fuel used in other processes. The use of the higher recycling rate also could be well counterpoised the fuel consumption and extra fuel demand in processing raw material for incineration and composting process in scenario Therefore, it is necessary to upgrade the recycling rate to achieve environmental benefits.

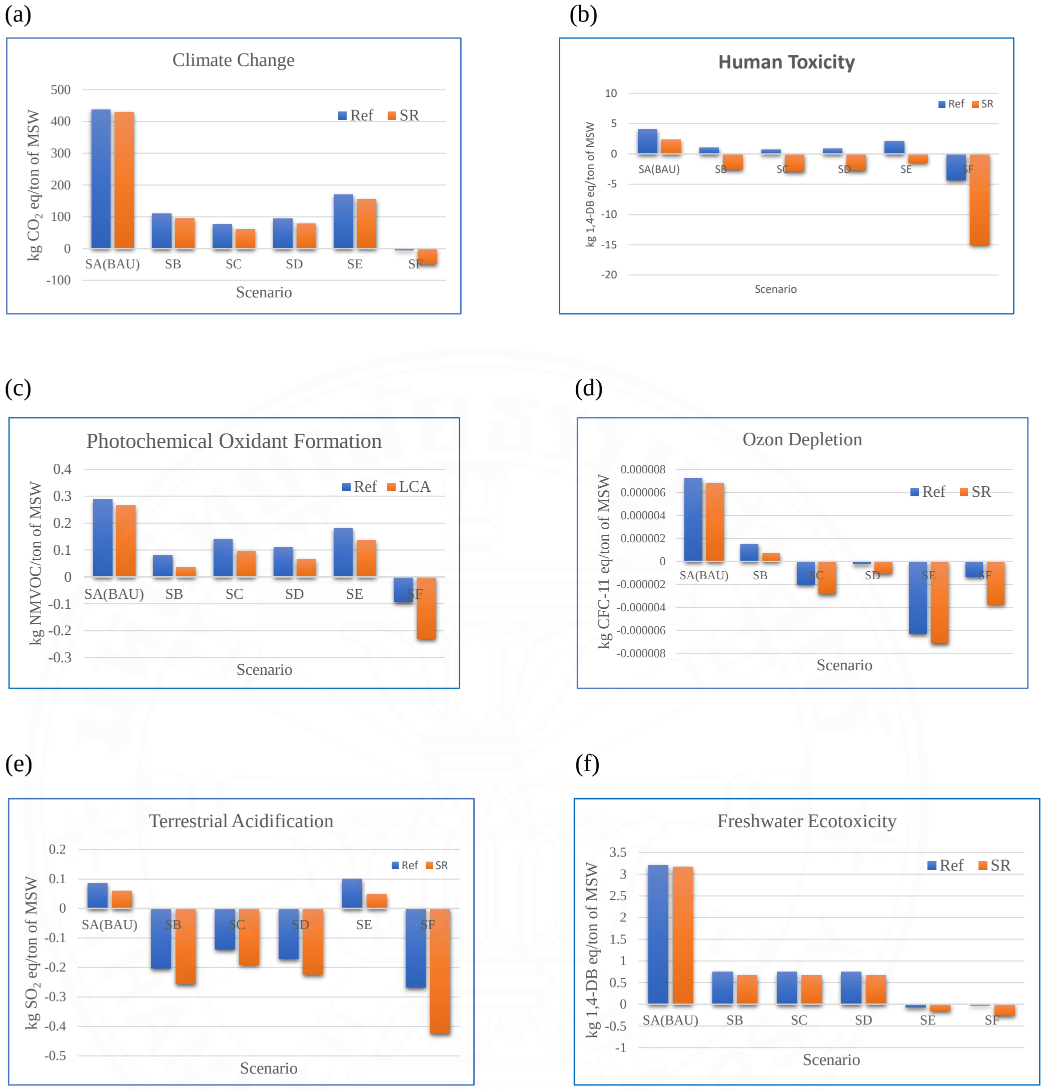

Figure 4.7 Effects of changing the recycling efficiency rates on recyclable materials to selected impacts; (a) climate change (b) human toxicity (c) photochemical oxidant formation (d) ozone depletion , (e) terrestrial acidification , and (f) freshwater ecotoxicity

Sensitivity analysis is also performed by changing CH_4 collection rate on scenario E. The gas collection rates are changed to observe climate change and photochemical oxidant formation impacts. In this analysis, 10%, 20%, and 30% increase in gas collection rate (i.e., 60%,70%, and 80%) at the reference scenario. Figure 4.8 shows that the climate change decreases by 21% at 10% increase in collection rate, while it decreases by 41%, and 62% at 20% and 30% increase in collection rate, respectively. Meanwhile, the photochemical oxidant formation decreases by 6.1%, 13.8%, and 21% respectively. It can be concluded that there is increase in collection rate, it will become more environmental benefit. This reveals the fact that a higher collection rate could be well counterbalanced the production of biogas to produce electricity and sale to the grid and for its energy consumption.

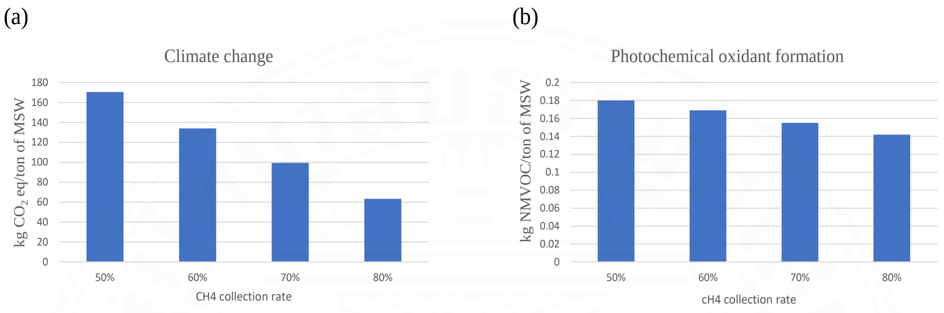

Figure 4.8 Sensitivity analysis results;(a) climate change, and (b) photochemical oxidant formation on CH_4 collection rate

4.3 Cost-Benefit Analysis Results

4.3.1 Composting Results

The amount of organic mixed waste is proposed as 50% of MSW (1276.235 tons/day) in scenarios B and F, and 25% of MSW (638.115 tons/day) in scenario D to degrade to waste in composting process. The amount of compost can be at 540 kg/ton of MSW (Rajcoomar et al., 2017). The main revenue from this process is compost fertilizer with a price of 51.52 USD/ ton (YCDC,2017).Composting proposes 1000 tons/day for scenarios B and F. Therefore, it is supposed that around 11 % of MSW is separated for recyclable waste and others discharged as wastewater in scenarios B and F.

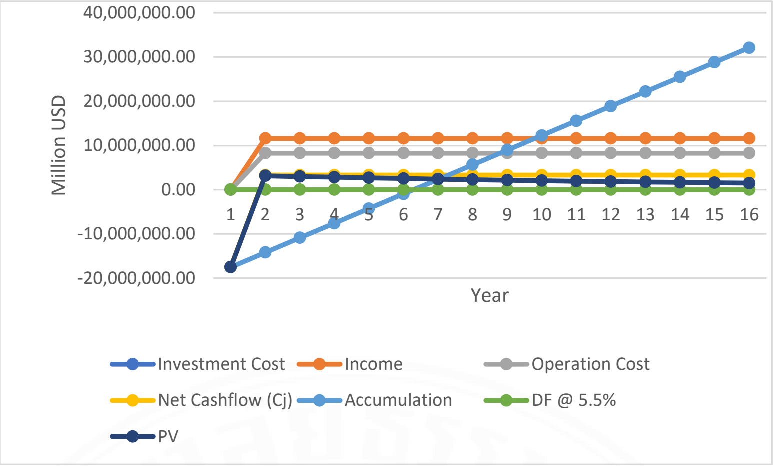

Figure 4.9 Feasibility study cash flow of composting plant of scenarios B and F (1000 tons/day)

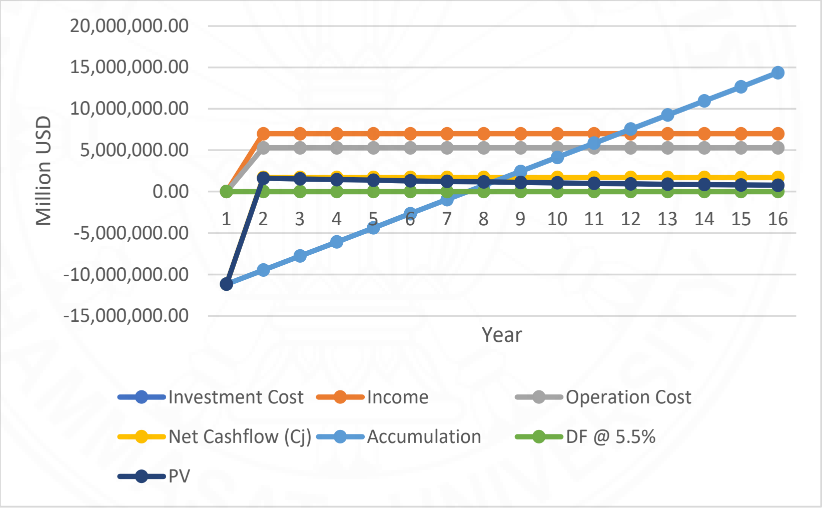

Figure 4.10 Feasibility study cash flow of composting plant for scenario D (638.115 tons/day)

Net present value (NPV) for this project is 15,699,760.14 USD/year in scenarios B, and F with IRR of 17 %, and 5.3 year of payout time (see Figure 4.9). In scenario D, the NPV is 5,904,580.28 USD/year, with IRR of 13 % and a payout time of 6.6 years (see Figure 4.10). As a result, this project is profitable due to the positive value of NPV and IRR with a short period of recovery cost.

4.3.2 Incineration Results

The amount of mixed MSW is proposed to be incinerated by 15% of MSW in scenarios B to E, and by 10% of MSW in scenario F. The incineration plant has a capacity of 1000 tons/ day with a capital investment cost of USD 16 million in 2017 (Thien et al., 2020). The average interest rate is 5.5%. At the current operation, the electricity of 20 MW is produced, in which 4 MW is used for 60 tons of daily treated. The main revenue from this process is electricity with a selling price of 135 MMK/kWh (USD 0.0824/kWh) (Van Seventer, 2021). The tipping fee is also considered for revenue from households and businesses, which are 2.4 USD/ton and 5.1 USD/ton, respectively in Yangon city (World Bank Group, 2019).

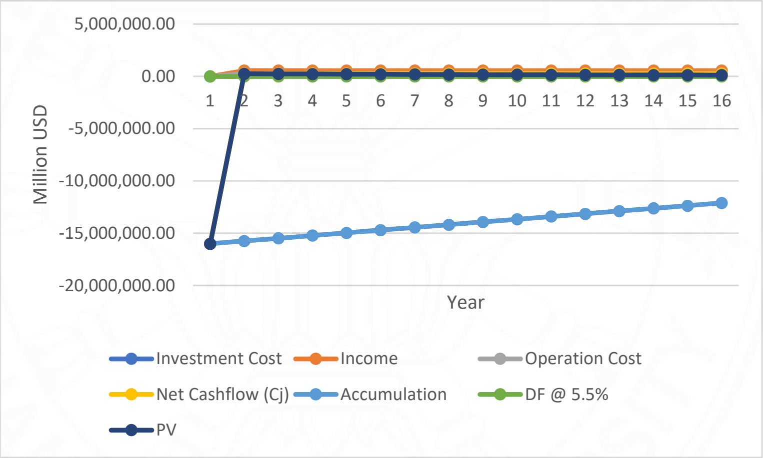

Figure 4.11 Feasibility study cash flow of incineration plant for scenario BAU (60 tons/day)

NPV for incineration plant is -13,390,670.61 USD/year in BAU due to a very low amount of operating rate which is 2.4% of MSW at 1000 tons/day plant capacity. This gives the IRR value of -14 % and POT of 61.5 years, as shown in Figures 4.11. As a result, this project is not feasible due to the negative NPV, low IRR, and a long period to recover the initial investment cost.

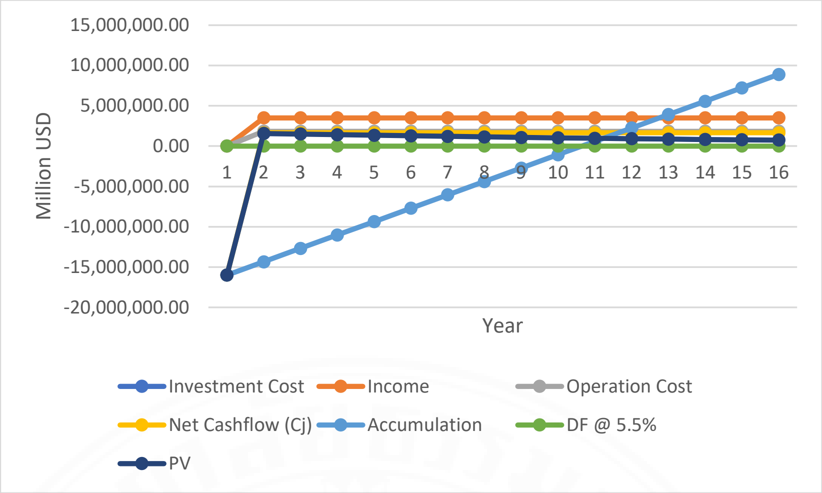

Figure 4.12 Feasibility study cash flow of incineration plant from scenarios B to E (382.871 tons/day)

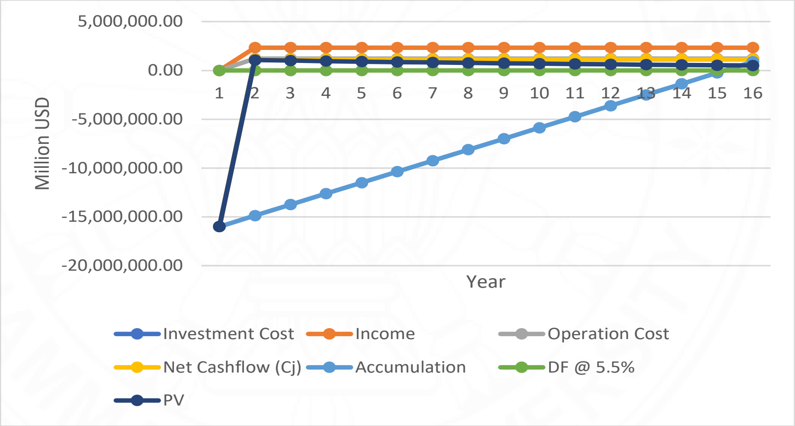

Figure 4.13 Feasibility study cash flow on incineration plant for scenario F (255.25 tons/day)

The NPV of scenarios B to E is 650,626.31 USD/ year and IRR of 6 % with the POT of 9.6 years. The results show that the process is feasible with positive NPV, IRR, and POT is within the lifetime to recover the initial investment cost (see Figure 4.12). In scenario F, the NPV is - 4,705,595.78 USD/year, and IRR is 1 %, and POT is 14.2 years. This scenario is not economic feasible (see Figure 4.13).

4.3.3 Anaerobic digestion Results

The mixed organic waste is proposed as 50 % of MSW (1276.235 tons/day) in scenario C and 25% of MSW in scenario D to be sent to an anaerobic digestion plant. Data, including investment cost, operation, and maintenance cost, produced biogas, digestate, and prices are collected from an anaerobic digestion plant in Thailand and converted to the proposed capacity in this study. An interest rate of 5.5% is assumed in the financial calculation. The main income from this process is biogas and digestate with the same selling price of electricity as incineration process is used. The tipping fees are also considered for revenue from households and businesses, which are 2.4 USD/ton and 5.1 USD/ton respectively in Yangon city (World Bank Group, 2019). Anaerobic digestion process 1000 tons/day is assumed in scenario C. Therefore, it is supposed that around 11 % of MSW is separated for recyclable waste and others discharged as wastewater in scenario C.

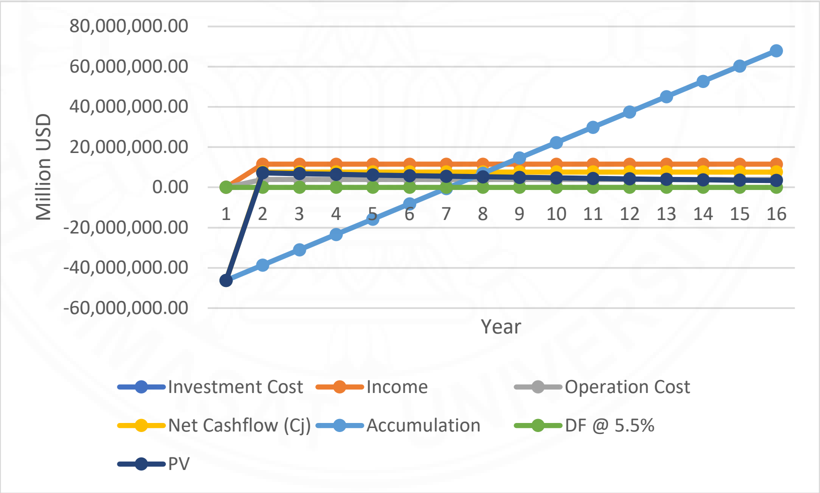

Figure 4.14 Feasibility study cash flow of an anaerobic digestion plant for scenario C (1000 tons/day)

The calculated NPV for scenarios C is 30,123,040.52 USD/year with IRR of 14 % and POT of 6.1 years (see Figure 4.14). NPV for scenario D is 15,108,291.82 USD/year with the IRR of 12%, and payout time of 6.6 years (see Figure 4.15). This result shows that the project is economic feasible.

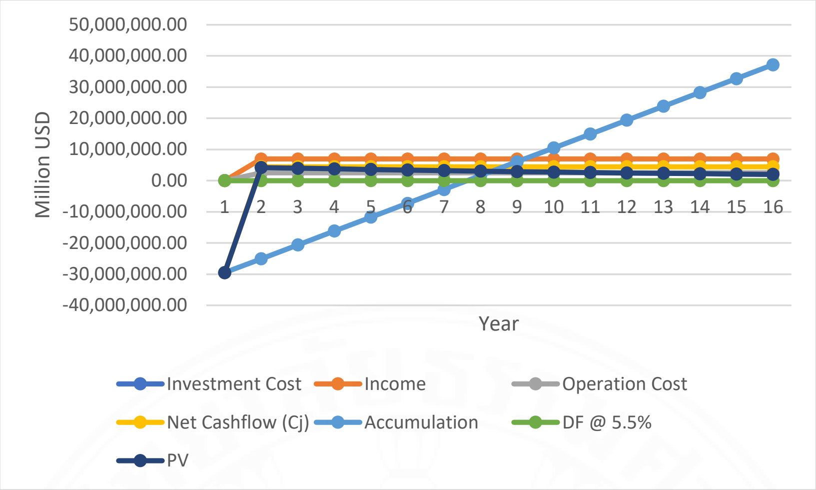

Figure 4.15 Feasibility study cash flow of an anaerobic digestion plant for scenario D (638.115 tons/day)

4.3.4 Landfill with Energy Recovery

75% of MSW is assumed to be sent to landfills for energy recovery in scenario E. The relevant data, such as investment cost including installation cost 13800 USD/ton, power engine (ICE 469 kW_e) 312,584 USD, Gas cleaning system 116,667 USD, exhaust gas 98,195 USD, and operation and maintenance costs includes specification land of 1.64 USD/ton, maintenance operation for engine power of 21,160 USD and landfill of 66,667 USD are collected from landfills with energy recovery in Thailand (Pawananont & Leephakpreeda, 2017). The collection rate of 50% of CH_4 emissions is taken from the IPCC calculation and converted into electricity in this study. The interest rate is 5.5% and the main income from this process is landfill gas which can be produced electricity 106 kWh/ton with the selling price of 0.082 USD/kWh (Wanichpongpan & Gheewala, 2007).

To calculated NPV is 30,376,925.30 USD/year with an IRR of 20 % and POT of 4.7 years (see in Figure 4.16). Therefore, energy recovery from landfills is feasible based on the consideration of the active life of landfill of 15 years.

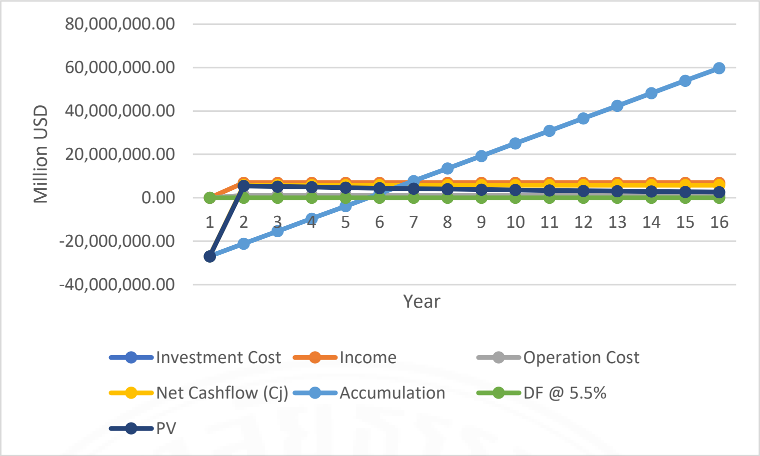

Figure 4.16 Feasibility study cash flow of 50% CH_4 collection from landfill in scenario E

The summary of the six economic feasibility results of all six scenarios is as shown in Table 4.3. In this study, the highest NPV, IRR, and the shortest POT values are assumed the highest positive value level 6 and the second positive value is 5. The middle positive values for NPV, IRR, and POT are level 4, and the low positive values are level 3. The moderate positive values for NPV, IRR, and POT are level 2, with the negative values are level 1, which is not economic feasible for this study. It is found that scenario E is the most economic feasible.

Table 4.3 Economic feasibility Ranking of Six Scenarios

CBA	SA	SB	SC	SD	SE	SF
NPV						
INC	1	2	2	2	2	1
COM		5		3		5
AD			4	3		
LF					6	
IRR						
INC	1	1	1	1	1	4
COM		6		6		6
AD			3	2		
LF					5	
POT						
INC	1	3	3	3	3	2
COM		5		3		5
AD			4	3		
LF					6	
Economic score	1	3.5	3.3	2.7	3.8	3
Economic Ranking	1	4	3	3	4	3

Legend

6	Best
5	
4	
3	
2	
1	worst

Note: high positive value =6, 2nd high positive value=5, Middle high positive value= 4, lower positive value= 3,moderate value= 2, and negative value= 1

4.3.5 Sensitivity Analysis of Economic Feasibility

Sensitivity analysis is performed in the CBA method by changing the selling price of compost on composting projects and the gas collection rate to examine the robustness of the results composted plant to observe on IRR and POT. The results reveal that the selling price of 54.02 USD gives the result IRR of around 20 % and POT of 4.7 years, while the selling price of 49.02 USD gives the IRR of 14 % and POT of 6.1 years (see Figure 4.17and 4.18). With high values of IRR and short POT, this project can be firmed with its feasibility.

Figure 4.17 Sensitivity curve of IRR with the change of compost prices

Sensitivity analysis is also performed by changing the landfill gas collection rate on scenario E at 50% landfill gas collection rate. In this study, the two-gas collection rates are changed to observe on IRR and POT results. Figures 4.19 and 4.20 illustrate the 25% increase and decrease in gas collection rate (i.e., 25%,50%, and 75%). The results reveal that a higher gas collection rate gives higher IRR value and shorter POT and the 25% gas collection rate gives the negative NPV, IRR and longer POT.

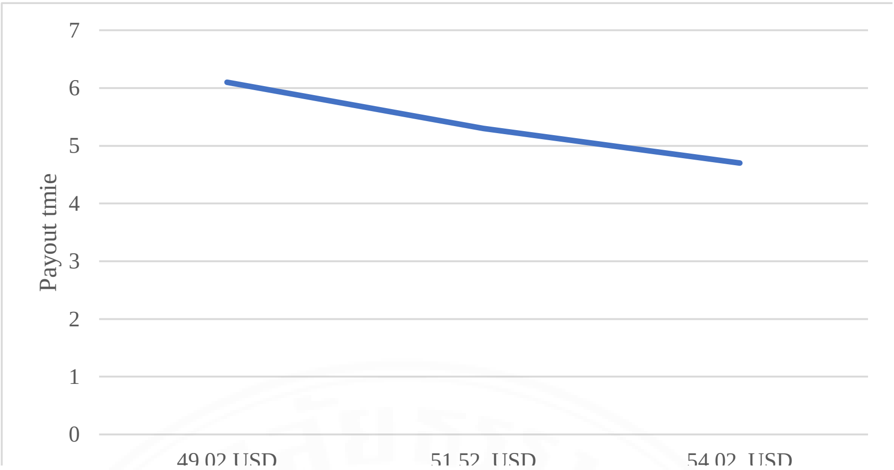

Figure 4.18 Sensitivity curve of POT with the change of compost prices

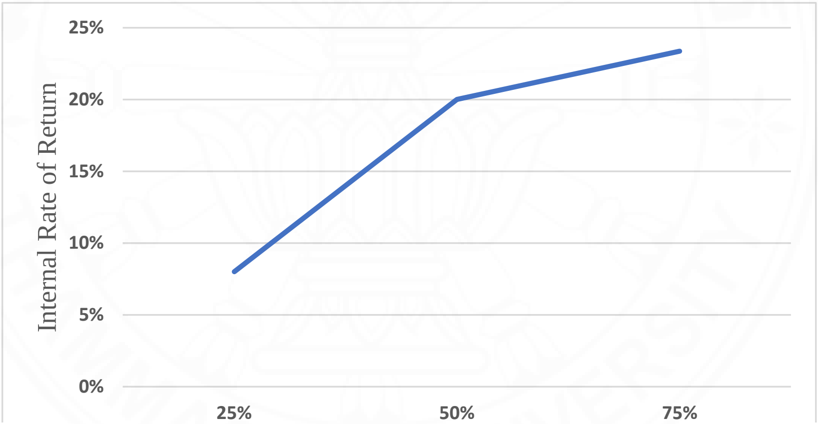

Figure 4.19 Sensitivity curve of IRR with the change in gas collection efficiencies

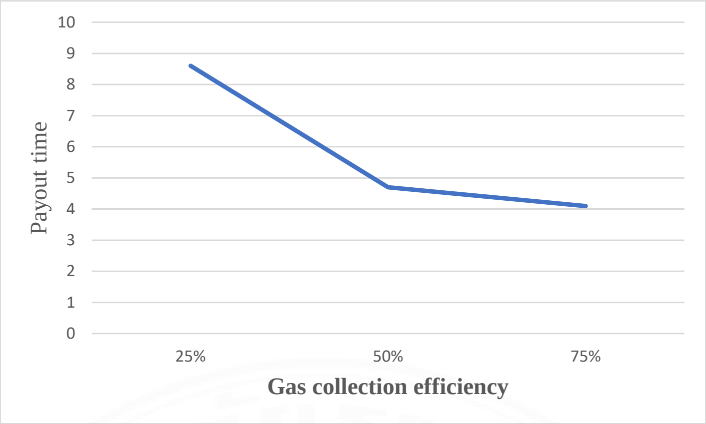

Figure 4.20 Sensitivity curves of POT with the change in gas collection efficiencies

CHAPTER 5
CONCLUSIONS AND FURTHER STUDIES

5.1 Conclusions

This study evaluates the severe impact of the current WMS in Yangon city, and propose proper waste management option using the LCA and CBA approaches. LCA is the most useful tool that can support the local authority of the municipality to decide on the waste management plan. Proposed scenarios are compared with BAU to pinpoint environmentally friendly options for WMS. The input inventory data are calculated using the IPCC and EEA default methods.

The LCA results reveal that BAU is the highest impacts scenario, and scenario F is the most proper option in this study based on the combination of high rates of the recycling process, composting process, and incineration. Scenario C and D are also scenarios with a reduction of environmental impacts from biological treatment.

CBA method is used to estimate economic feasibility and provide optimal waste management projects in the next 15 years. The results show that the BAU is the lowest economically feasible option due to the low rate of incinerated process on 1000 tons plant capacity. Scenario E is, on the other hand, the most economically feasible with the highest NPV and IRR values, and short-term POT. Apart from scenario E, scenarios B and C provide acceptable NPV and IRR from the increase of composting process.

To reduce the environmental impacts and recover the initial investment cost, the incineration project is required to operate increased amount of MSW as it can reduce GWP than landfilling (Istrate et al., 2020). To minimize the potential impact and achieve great revenue, it is required to increase the recycling rate and operate the sanitary landfill with energy recovery.

Scenario B is found the best as it considers incineration rate together with the composting projects which achieved the lower environmental impacts from the life cycle perspective and higher economic feasible from the CBA in this study. Although scenarios C and D are proper scenarios for in this study, they have high initial investment costs and operational costs from anaerobic digestion. This is a major obstacle for the local authority with insufficient budget. In addition, POT is long.

Scenario E is found that the best as its revenue and lower investment and operation cost from the view of CBA. Although scenario E can reduce the environmental impact from CH_4 collection, the impacts are higher than scenario B and the cost of landfill gas employment is quite low (Intharathirat et al., 2016).

Therefore, performing waste treatment projects requires collaboration stream public and private stakeholders to consider from their perspectives. If the local authority and stakeholders can install the anaerobic digestion, scenarios C, and D could be possible for apart from scenarios F and E. Therefore, a community-based WMS should be implemented for final decisions.

5.2 Further Studies

The main goal of this study is to achieve sustainable MSW management in Yangon city, Myanmar. This current study is only focused on the LCA (environmental sustainability) and CBA (economic sustainability). It is recommended that future study could be performed to examine the sustainability of MSW management system using, for examine the analytic hierarchy process (AHP). The responsibility of stakeholders is to consider the best option for future projects with reduction of environmental effects and promoting income of the study area. To implement sound waste management, the stakeholder plays an important role to obtain the benefit of the three pillars (environment, economic and social) of sustainability. In Future works, could be carried out through analysis and evaluation of different MSW management systems, through the interviews of the stakeholders. Phyu (2019) confirmed that although the national waste management strategy has 100 % collection efficiency, it cannot be implemented effectively without the participation of a community-based organization. Therefore, to achieve an efficient WMS, stakeholders and local participation is needed.

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