MUNICIPAL SOLID WASTE FORECASTING AND MANAGEMENT FOR SUSTAINABLE DEVELOPMENT IN BANGKOK

BY

NAYSEANG SUN

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (ENGINEERING AND TECHNOLOGY)
SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
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A Thesis Presented

By

NAYSEANG SUN

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Abstract

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Municipal solid waste (MSW) is a result of human activities. The tremendous growth of population, economic, and uncontrolled urbanization have accelerated the generation of MSW, causing its management to be a challenging issue, especially in developing Asian countries. Accurate forecasting of MSW generation is considered a crucial part of sustainable management systems and planning since it can illustrate the future trend of waste generation. With this information, policymakers would be able to set the strategy to solve the upcoming problem. This study aims at provision of the selection methodology to evaluate the sustainable MSW management system in Bangkok. Firstly, the study reviews the current management and finds existing problems. The second step is the prediction of future MSW generation. The third step is the evaluation of suitable solutions. Along with these processes, various statistical models are used, such as multivariate model and artificial neural networks (ANNs) in the forecasting part. Meanwhile, analytical hierarchy process (AHP) is applied to evaluate the sustainable MSW management system. The results show that the existing problem in MSW management is weak regulation related to MSW consumption, and the lack of community participation. Whereas, the result of forecasting shows that the trend of future MSW generation given by ANNs is slowly increased. Furthermore, the integrated system of anaerobic digestion and gasification (AD+GF) is recommended for Bangkok MSW management system for many reasons.

Keywords: Sustainable municipal solid waste management, Forecasting technique, Decision-making tool, Bangkok.

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List of Abbreviations

AD	Anaerobic Digestion
AHP	Analytical Hierarchy Process
ANNs	Artificial Neural Networks
BMA	Bangkok Metropolitan Administration
CBA	Cost-benefit analysis
CP	Composting
GF	Gasification
IC	Incineration
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
LF	Landfill
LFG	Landfill gas
MCDA	Multi-criteria decision analysis
MRA	Multiple Regression Analysis
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
OECD	Organization for Economic Co-operation and Development
PAHO	Pan American Health Organization
PCA	Principal Component Analysis
PY	Pyrolysis
Re	Recycling

Chapter 1
Introduction

1.1 Background of the study

Environmental pollution is one of the greatest global issues causing various health problems and other negative effects, which undoubtedly affect the quality of life. Municipal solid waste (MSW) is considered one of the environmental pollutions, which cause air pollution, disease, soil and water contamination.

MSW is a product of human activities. The changes in consumption patterns and uncontrolled urbanization results in increasing MSW generation, which is a serious problem for all countries in the world, particularly in many developing countries [1]. MSW generation rate is affected by a variety of factors including the geographical location, season, use of kitchen food waste grinders, collection frequency, characteristics of service area, onsite processing, people's food habits, economic conditions, recovery and reuse boundaries, existence of solid waste management laws, local culture and beliefs, population growth, weather conditions and household size [2].

MSW management has been a serious consideration for many megacity authorities in the world. Dealing with the MSW problem is not an easy task as it involves socio-economic as well as environmental factors. Although MSW management is complicated, especially disposal treatment, the 3Rs strategy (reduce, reuse, and recycle) is reviewed as the most effective and possible solution. However, these activities require the participation and cooperation from community residents. Further MSW processes rely on the social service which is the responsibility of local authorities. In other words, local authorities have a duty to set up policies and planning for the community to obtain the proper waste management to improve the quality of life as well as to reduce the negative environmental impacts, such as greenhouse gas (GHG) emission which causes global warming.

There are two sides to every coin, not only impacts have been caused by waste, but many benefits also come from wastes. MSW contains substances which can be used as renewable energy sources. Thus, appropriate waste treatment can prevent the community from the problem as well as provide back the sustainable system for local development.

1.2 Statement of problem

The tremendous increase in population, economic growth, and uncontrolled urbanization have resulted in the increasing of MSW generation. MSW management is becoming a challenging issue in many countries in the world, especially in developing and underdeveloped countries, not only due to the increase of the waste amount, but also its improper management and disposal.

Bangkok is the capital city of the Kingdom of Thailand, located on the low flat plain of Chao Phraya River at latitude of 13° 45' north and longitude of 100° 28' east. The city is divided into 50 districts and 154 sub-districts with the total area of 1,569 sq.km. [3]. Data from the National Statistical Office (NSO) of Thailand shows that there were 8,625,230 people living in Bangkok in 2015 [4]. On top of that, there are 50 million visitors from around the world who visited Bangkok in 2014. The increasing number of the population, inbound tourists and economic growth leads to huge amounts of MSW being generated daily in the municipality. The Pollution Control Department (PCD) revealed that MSW generation was 11,500 tons/day in 2015 which is equivalent to 1.33kg/capita/day[5]. This amount was approximately 15.6 percent of total solid waste generated in Thailand and this number will gradually increase in the future. The Bangkok Metropolitan Administration (BMA) is a local government administration of Bangkok. Recently, the BMA reported that of the MSW collected in Bangkok 10% was composted in On-Nut, 3% was incinerated in Nong khaem, and the other 87% was sent to landfills outside Bangkok for final disposal by two private companies. In this regard, the BMA has concerns about the instability of management if these companies suddenly stop receiving wastes. The BMA is seeking the solution to decrease the MSW amount at the landfill and increase the efficiency of management in any forms of waste to energy. How to solve this problem is the ultimate issue.

1.3 Objectives

The main purpose of this research study is to aid Bangkok to find a sustainable MSW management system by providing a methodology to select waste treatment options that associate with three main pillars of sustainability: environmental, social, and economic. To meet this objective, many other related issues are determined as follows:

- Define municipal solid waste and describe its current management in Bangkok and a city in Japan to find out the differences in waste management as well as to adapt some strategies for practicing in Thailand.
- Determine the influential factors affecting MSW generation and predict the future quantity of Bangkok waste to plan the strategies to solve the problem beforehand.
- Evaluate the sustainable MSW management systems for Bangkok.

1.4 Scope and Limitations

This study focuses on the MSW management system in Bangkok area, which covers 50 districts.

The limitations of this research study can be stated as follows:

- The MSW management in Bangkok and Kitakyushu are taken from the review of their city websites and other related journal papers.
- In forecasting of future MSW generation in Bangkok and the information of variables affecting MSW quantity and forecasting model are extracted from available online sources, such as conference papers, journals, and student theses. Furthermore, data collection and policies related to Bangkok MSW are obtained from Pollution Control Department (PCD), Bangkok Metropolitan Administration (BMA), National Statistical Office (NSO), Tourism Authority of Thailand (TAT), Bureau of Registration Administration (BORA), and other online databases. Any missing data are calculated using scientific techniques.
- In the evaluation of a sustainable MSW management system for Bangkok, the interview is considered an important action to know about the local situation and resident’s viewpoints related to that system. Getting this kind of information is not an easy task, especially when we must question the experts or/and officers. However, a previous study of the JICA team had

interviewed some BMA officials and experts about this issue; thus, their results are modified to apply in this study.

1.5 The significance of the study

According to the results of this research study, the main output can be part of a renewable energy development plan. This can help both government and private sectors obtain sufficient data on MSW generation to act to reduce wastes and improve the current waste management system. In addition, these results can be used as primary information for investors who wish to invest in MSW treatment, especially waste-to-energy technologies. In contrast to the increasing trend of MSW produced by human activities, this study also provides the strategies practiced in Japan to slow down the amount of MSW as well as to minimize the MSW amount in landfills. Furthermore, the last part of this study related to the evaluation of a sustainable MSW management system is expected to help policy makers and decision makers better comprehend MSW management and be able to select the most suitable solution for Bangkok MSW generation.

1.6 Organization of the dissertation

To cover all objectives mentioned above, this study is organized into 6 Chapters. Chapter 1 presents the introduction to this research, including the background of the study, statement of problem, objectives, scope, and limitations, significance of the study, and the organization of the dissertation. Chapter 2 provides the overall research methodology such as the framework of each chapter and some specific information. Chapter 3 reviews current MSW management in Bangkok and another city in a developed country to find the differences in management systems and adapt their good points for Bangkok. Chapter 4 presents the forecasting of MSW generation. In this part, we will discuss both factors affecting MSW quantity and selection of an appropriate model to predict the quantity of future MSW generation in Bangkok. Chapter 5 presents evaluation of an appropriate MSW management system for sustainable development by applying decision-making tool. Moreover, sensitivity analysis is utilized to search for the uncertainty of the system. Chapter 6 provides conclusions and recommendations for the future study to improve MSW management in Bangkok.

Chapter 2
Overall research Methodology

This chapter describes the overall methodology to conduct this study. This research is divided into three main stages: an overview of current MSW management system, development of a model for MSW forecasting, and evaluation of the most appropriate MSW management systems for sustainable development in Bangkok. Results from the overview of MSW management system are used as basic information for identifying the problem in the AHP method. Similarly, results from MSW quantity forecasting are also used as one of the input data in the AHP method to discuss the feasibility and the flexibility of the selected system.

2.1 Research Framework

The framework of this research is to propose an appropriate MSW management system for sustainable development in Bangkok. The structure of research can be divided into three stages as follows.

Stage 1: Identification of issues of MSW management in Bangkok

In this part, the background of Bangkok, such as geographical and demographical condition, and its current MSW management system, are presented step by step. Along with this review the MSW management system in a city of Japan, Kitakyushu, is also assessed to find out its strong points to improve Bangkok waste management system.

Stage 2: Development of an appropriate model for forecasting MSW generation in Bangkok

Accurate prediction of future MSW quantity is important in the planning of MSW management. This part is conducted to find the root causes of MSW generation and select the appropriate scientific forecasting model to aid policymakers in determining those quantities. The details of this investigation can be found in Chapter 3.

Stage 3: Evaluation of sustainable MSW management system in Bangkok

After getting the information associated with the Bangkok MSW management situation and its current problems, as well as the trend of MSW generation, it is the time to aid Bangkok to find the solution. MSW management typically involves generation, storage, collection and transportation, constructing and operation of treatment facilities for waste recycling, and waste final disposal. However, this study focuses only on generation and treatment or final disposal. This means that the initial point of waste generation and the final point of waste lifetime are investigated. In this section, various decision-making tools and a variety of MSW treatment options are presented. According to the summation of existing information and interview of stakeholders, the output can describe the status of Bangkok MSW management and provides the sustainable MSW management system for Bangkok.

2.2 Summary

The information in Figure 2.1 shows the whole structure of this research and the relationship between each chapter. The main purpose is to propose an appropriate MSW management system for sustainable development in Bangkok.

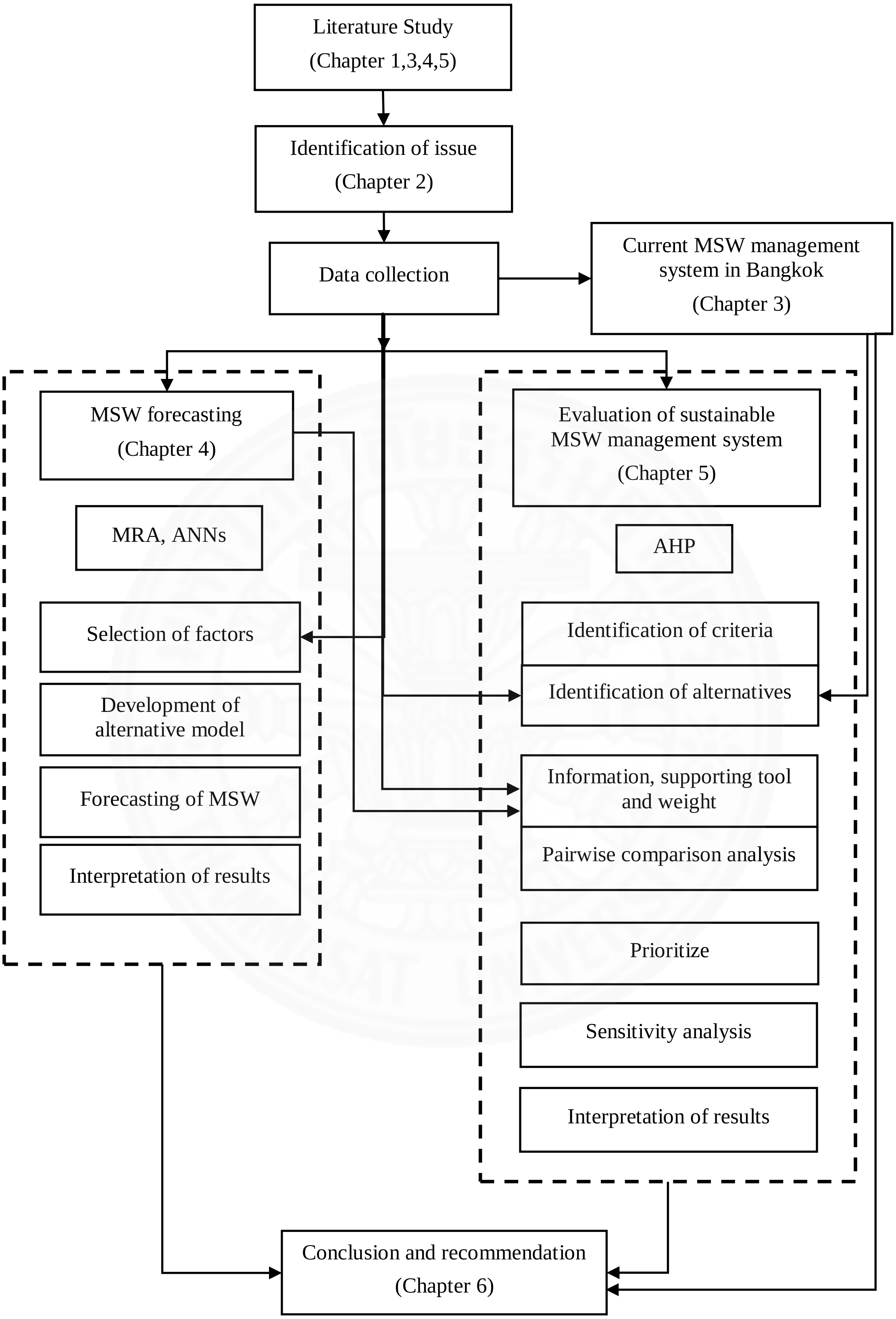

Figure 2.1 Overall framework of the study

Chapter 3
Municipal Solid Waste management situation

3.1 Definition

Municipal solid waste is a by-product of people's lifestyle. There are many definitions of MSW given by various organizations such as [6]:

By OECD: "Municipal solid waste is collected and treated by municipalities. It includes waste from households, bulky waste, wastes from commerce and trades, office buildings, institutions and small businesses, yard and garden, street sweepings, contents of litter containers, and market cleaning. However, wastes from municipal sewage networks and treatment as well as municipal construction and demolition are excluded".

By PAHO: "Solid or semi-solid waste generated in population centers including domestic and commercial wastes, as well as those originated by the small-scale industries and institutions (including hospital and clinics); market street sweeping, and from public cleaning".

By IPCC: "Municipal Solid Waste comprises food waste; garden (yard) and park waste; paper and cardboard; wood; textiles; nappies (disposable diapers); rubber and leather; plastics; metal; glass; and other (e.g., ash, dirt, dust, soil, electronic waste)".

Municipal solid waste (MSW) refers to any non-liquid waste that is created by an individual person, household, small business, or institution, such as a school. This type of waste is commonly called trash or garbage and includes everyday items, things that are broken, food that has spoiled, or simply any item a person no longer needs or wants. In the municipal solid waste stream, waste is broadly classified into organic and inorganic [7]. The most common waste composition is categorized as organic, paper, plastic, glass, metals, and other as shown in Table 3.1 [6].

Table 3.1 Types of wastes and their sources

Type	Sources
Organic	Food scraps, yard (leaves, grass, brush) waste, wood, process residues
Paper	Paper scraps, cardboard, newspapers, magazines, bags, boxes, wrapping paper, telephone books, shredded paper, paper beverage cup. Strictly speaking, paper is organic but unless it is contaminated by food residue, paper is not classified as organic.
Plastic	Bottles, packaging, containers, bags, lids, cups
Glass	Bottles, broken glassware, light bulbs, colored glass
Metal	Cans, foil, tins, non-hazardous aerosol cans, appliances (white goods), railings, bicycles
Others	Textiles, leather, rubber, multi-laminated, e-waste, appliances, ash, other inert materials

The definition of MSW management in this study is extracted from Henry, et al. [8]: "Municipal Solid Waste Management (MSWM) includes the collection, transfer, resource recovery, recycling, and treatment of waste. The main target is to protect the population health, promote environmental quality, develop sustainability and provide support to economic productivity".

In the following part, the management of MSW in Bangkok of Thailand and Kitakyushu of Japan is described to demonstrate the variety of MSW management.

3.2 MSW management in Bangkok, Thailand

Bangkok is the capital city of Thailand. It is in the central part of Thailand, stretching from 13.45 N to 100.35 E. With an overall area of 1,569 km^2, it comprises 50 districts (see Figure 3.1) and it is also the 68^{th} largest province in Thailand. Bangkok is a huge administrative area with a registered population of 8.6 million from total 67.2 million people in Thailand and around 2 to 3 million unregistered laborers from nearby countries in 2015 [9]. The city is administrated by the Bangkok Metropolitan Administration (BMA) which is the combination of Metropolitan City Municipality and Sanitation Administration, established in 1972 by National Executive Council Order Number 335. BMA administration's work also includes the collection of MSW generated in Bangkok (Figure 3.2 shows the organizational chart of BMA). In 2015, the BMA collected an average of 11,500 tons/day of MSW with the average annual increase in quantity approximately 3% (during 2005-2015). The generation rate of MSW is approximately 1.3 kg/capita/day. A BMA published report also indicates that all collected waste are disposed in controlled treatment facilities, 10% composting, 3% incineration, and the other 87% controlled landfill.

Figure 3.1 Map of Bangkok area (online source)

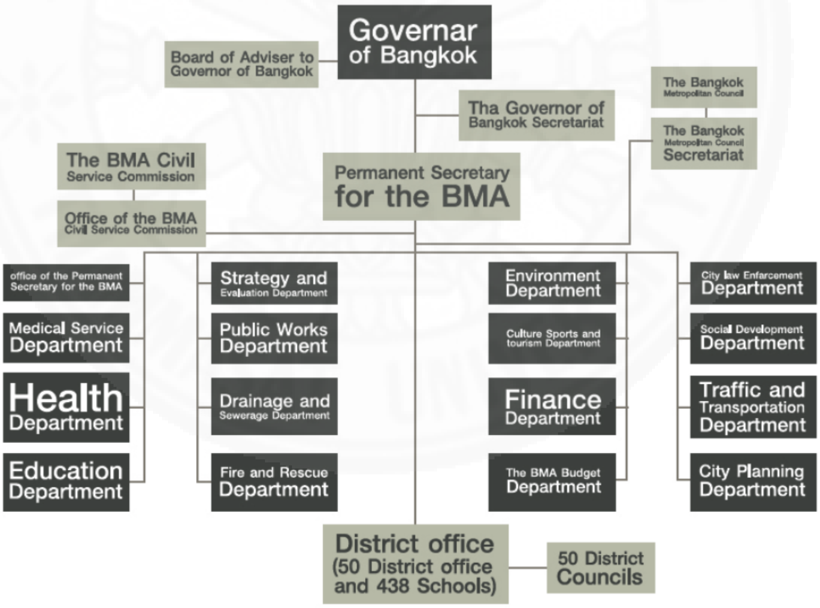

Figure 3.2 BMA's organizational chart

The BMA classifies the process of MSW management into 3 steps: 1) Waste minimization and separation, 2) Waste collection and transportation, and 3) Waste treatment and disposal [10]. Each step is described below.

3.2.1 Waste Minimization and Separation

The BMA classifies MSW into 4 main categories, including organic, recyclable, general, and household hazardous waste. Regarding these 4 types of waste, the BMA has provided the proper waste bins for public use in the colors of green, yellow, blue, and red, respectively, as shown in Figure 3.3. To minimize and separate the amount of MSW in Bangkok, the BMA has introduced many activities to the community, including the 3R strategy (Reduce, Reuse, Recycle), pilot projects at schools for waste separation and many other campaigns. The meanings of the 3Rs strategy are:

- Reduce: It is an activity to minimize resource consumption to the level that is adequate for a basic need.
- Reuse: It is an act of using goods and materials until they cannot be repaired or fixed to perform their function.
- Recycle: It is an activity of reprocessing the materials that are discarded into new products.

The effective minimizing of waste is source reduction, which is possible only before the moment of discharge. From a survey in Bangkok, less than 65% of people separate dry recyclable waste at home. Although there is no food waste segregation at the household level in Bangkok, it is done in some commercial enterprises, i.e. schools, shopping malls, restaurants, canteens, etc. [11]. Overall, minimization and separation of MSW in Bangkok are still limited due to lack of community participation and no enforcement or strong regulation on MSW consumption.

3.2.2 Waste Collection and Transportation

The action of waste collection and transportation in Bangkok is organized as shown in Figure 3.4, and it is divided into two stages. First is the primary collection in which MSW is collected from every household and public place by trucks and sent to a transfer station for sorting of recoverable items and materials. After sorting and separating, the remaining wastes are sent to landfills outside Bangkok for disposal. More details of these two collections are presented below.

Figure 3.3 Proper waste bin in Bangkok

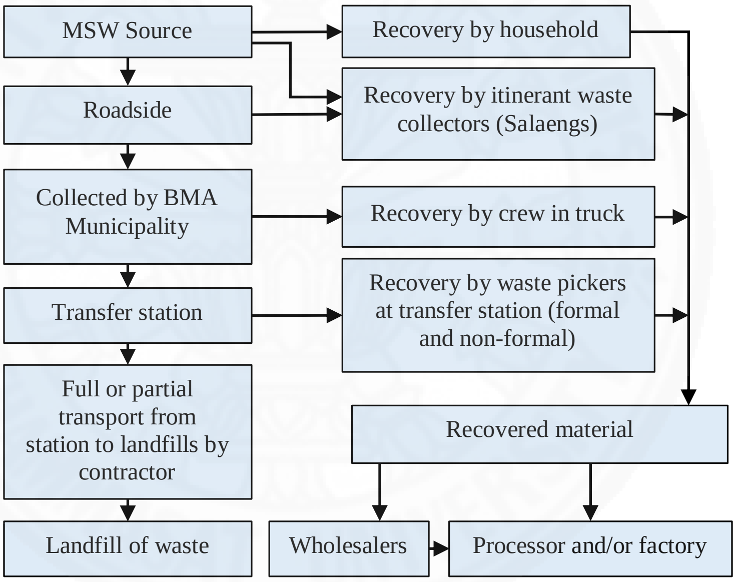

Figure 3.4 Waste collection and transportation

Primary collection and transportation

As Bangkok comprises 50 districts, thus each district is responsible for its own waste collection from each household, community, building and commercial area, but under the control of the BMA. For this action, the BMA also provides trucks for ground base collection and boats for picking up wastes from canals [10]. The BMA is able to collect close to 100% of its total waste generation in the area [12]. The effective waste collection mainly needs the cooperation of the public by specifying the proper time and dropping point. According to the BMA set plan, the collecting schedule was assigned:

- Main streets, minor streets, and marketplace: collecting time 08:00 pm to 03:00 am and collection completed by 06:00 am
- Daily collecting for communities, small roads, and lanes
- Waste collection by types; general wastes (daily or every other day), recyclable waste (every Sunday), and hazardous waste (1^{st} and 15^{th} of the month) [13].

However, lack of proper source separation and cost of transportation causes bulk collection to happen. During waste collection, separating and sorting of recoverable materials are done by the collectors for selling to the junk shop. After collection is completed, the trucks deliver the remaining waste to the transfer stations in Bangkok for treatment.

To operate this process, the BMA follows the polluter-pays-principle (PPP) by charging for collection and disposal fee from every household based on the MSW generation rate as shown in Table 3.2. The sub-district officers under the BMA's environmental bureau are responsible for this fee collection. However, the survey study revealed that this collection fee covers only 7% of total expenditure in Bangkok waste management [11].

Table 3.2 Waste collection fees

Amount of MSW	Collection Fee	Frequency
< 20 litres/day	20 THB/month	Every 6 months or year
< 500 litres/day	40 THB/month (every 20 liters by amount of MSW)	Every month or every year
> 500 litres/day (not exceeds 1000 liters/day)	2000 THB/month	Every month or every year
> 1000 litres/day	2000 THB/1000 liters/month	Every month or every year

Secondary collection at the transfer station

All MSW collected in Bangkok are transferred to three operational waste transfer stations which are owned and operated by Department of Public Cleaning (DPC). Those are On-Nut, Nong khaem and Tha raeng transfer stations.

On-Nut station is located approximately 20 kilometers to the east of the city center. It covers 93.28 hectares of residential area which is owned by the Thai government. Apart from being a transfer station, this site also houses two hospital waste incinerators (Krungthep Thanakom Co., Ltd, with a capacity of 30 tons/day), a composting plant (capacity 1000t/d), and a night soil treatment plant. Other wastes that cannot be disposed in this site are transferred to a landfill in Panomsarakham by Pairojsompong, while hazardous waste is transferred to an incinerator in Samut Prakarn by Akkhie Prakarn Public Co., Ltd.

Nong Khaem station is located to the west of the city center, on 58.88 hectares of residential area. The site houses a night soil treatment plant and wastewater treatment plant. General waste is transferred to a landfill in Kamphaeng Saeng by Group 79 Co., Ltd. On May 10, 2016, a new incinerator began operation in this transfer station with the capacity of 300-500 tons/day and the ability to generate approximately 5 MW of electricity. The generated electricity is used for site operation, and the leftover is for grid supplying.

Tha Raeng station is built on 8 hectares of residential area which belongs to the government. General waste from this station is transferred to a landfill in Kamphaeng Saeng by Group 79 Co., Ltd.

The total amount of wastes at these transfer stations is shown in Figure 3.5 [5]. Bangkok waste contains a high proportion of organic waste, followed by plastic, paper, textile, glass, bone and shell, and metal with a small amount of hazardous waste as shown in Table 3.3 [14]. Around 87% of the total amount is then sent to landfills for disposal.

3.2.3 Waste Treatment and Disposal

MSW management in Bangkok is the responsibility of the BMA, but the BMA officials never own the management system themselves. All the above treatments in Bangkok are operated by private companies who sign a contract with the BMA. Key stakeholders for MSW management systems in Bangkok consists of two sectors: the official sector and the private sector as shown in Table 3.4

Composting is an integral part of the waste processing and disposal systems. It is the most hopeful area for the recovery of organic wastes. Around 10% of Bangkok MSW generation is composted to produce fertilizer [15]. However, it is just a small amount if compared with the total compostable which is around 50% of total MSW.

Incineration is one of the methods for MSW disposal in Bangkok. This method is suited to the huge municipality and tourist municipality area because the plant is able to reduce more than 70% of the total amount sent to landfills; moreover, it can have less environmental impact than landfills do [12]. Now only the Nong Khaem transfer station has a waste incinerator, while the On-Nut incinerator is being revamped [16].

Landfills are usually located far from the source of waste, resulting in increasing transfer costs and additional investments in infrastructure. The majority of Bangkok MSW generation is transferred to landfills outside Bangkok for disposal. Private companies charge the BMA 438-535baht/t waste (12-15USD/t) to dispose of these wastes.

Besides formal waste sectors which have been mentioned above, there are also informal waste sectors such as junk shops, second handed/recyclable waste mobile shop, junk collectors, and sorting waste workers. They all play an important role in MSW management. However, there is no recorded data of this informal sector in the BMA report.

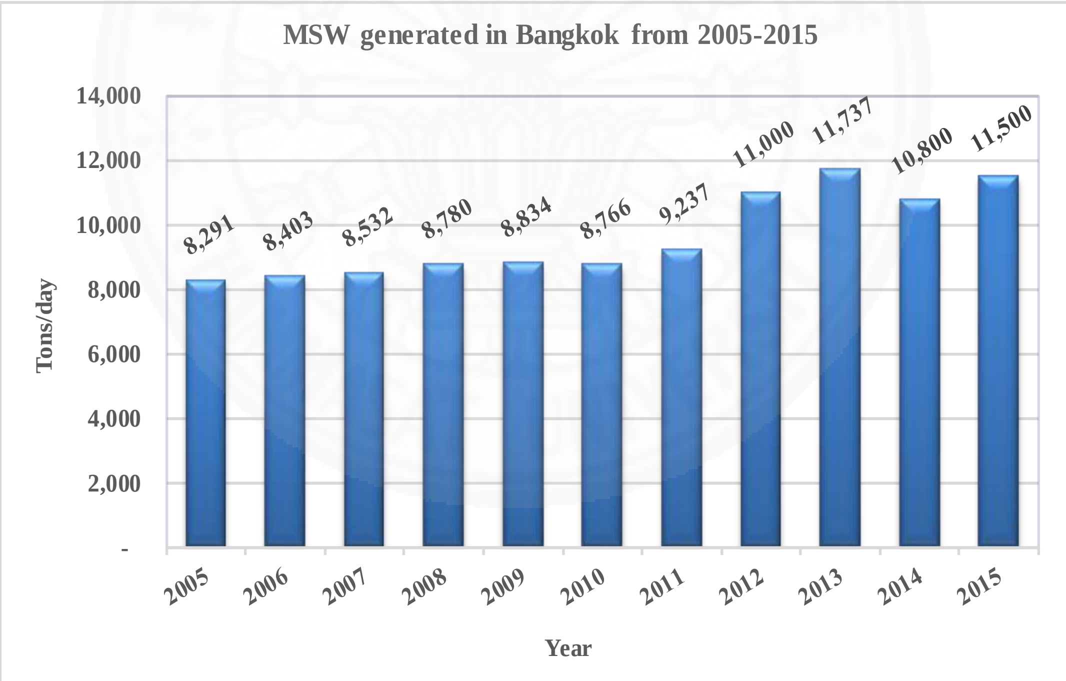

Figure 3.5 Total MSW generated in Bangkok from 2005-2015

Table 3.3 MSW composition in Bangkok

Composition	Percentage (%-wt.)
Food waste	48.41
Wood and leaf waste	6.46
Paper	7.67
Plastic	24.83
Foam	1.55
Glass	2.56
Rubber	1.40
Clothes/textiles	3.99
Stone and ceramic	0.65
Metal	1.72
Bone and shell	0.76
Other	0.00

Source: BMA (2015)

Table 3.4 Key stakeholders of Bangkok MSW management

Sector	Ministry/Company
Official sector	Bangkok Metropolitan Administration
	Pollution Control Department
	Ministry of Public Health, Department of Health
	Ministry of Industrial, Department of Industrial Works
Private sector/subcontractor	Pairoj Sompong
	Group 79 Co., LTD
	Wasaduphan-turakit Co., Ltd.
	Akkhie Prakarn Public Company Limited
	The Krungthep Thanakorn Co., Ltd
	Euro Waste Engineering Co., Ltd.
	C&G Environmental Protection (Thailand) Co., Ltd.

3.3 MSW management in Kitakyushu, Japan

Japan is a country that has a good waste management system, especially Kitakyushu city in Fukuoka Prefecture. Kitakyushu city has dramatically overcome severe environmental pollution from industrial activities in 1980. Based on the official government campaigns and best cooperation of local residents, Kitakyushu is now becoming one of the great places to live. Recently, Kitakyushu has supported the environmentally friendly industries in order to reduce and use waste with high efficiency, and it is now known as an "Eco-town"[17]. The details of waste management consist of 1) waste minimization, 2) waste separation and collection, 3) waste recycling and 4) final waste treatment and disposal.

3.3.1 Waste Minimization

In Kitakyushu, the MSW management crisis is addressed and there is a strong regulation, such as paying as you throw. In this case, sorting at the source and reducing the amount of MSW are well practiced. Besides this, there are a lot of regulations and policies to minimize the amount of MSW [18].

3.3.2 Waste Separation and Collection

The city of Kitakyushu is responsible for proper collection and treatment of the MSW. They apply the separated waste collection system. Household waste is separated into 15 types or 21 categories and disposed of accordingly. Figure 3.6 illustrates the waste separation types in Kitakyushu City. The residents are requested to purchase the designated bags to separate their household or kitchen waste and other waste. The bags for household garbage are blue, the bags for cans and glass are brown, the bags for "PET" bottles are orange and the bags for plastic products are green as shown in Figure 3.7. Properly designated garbage bags are sold in grocery stores and convenience stores [19].

The separated wastes are collected on designated collection days, so residents should place their waste at the designated collection spot by 8:30 am. The household waste is collected twice a week. Cans, glass bottles and plastic bottles (PET bottles) are collected every Wednesday. Plastic containers and packages are collected once a week on a designated day. The city has established waste collection spots at a ratio of one location for 10-20 households to ensure effective operation [20]. Figure 3.8 shows the process flow of municipal solid waste in Kitakyushu city.

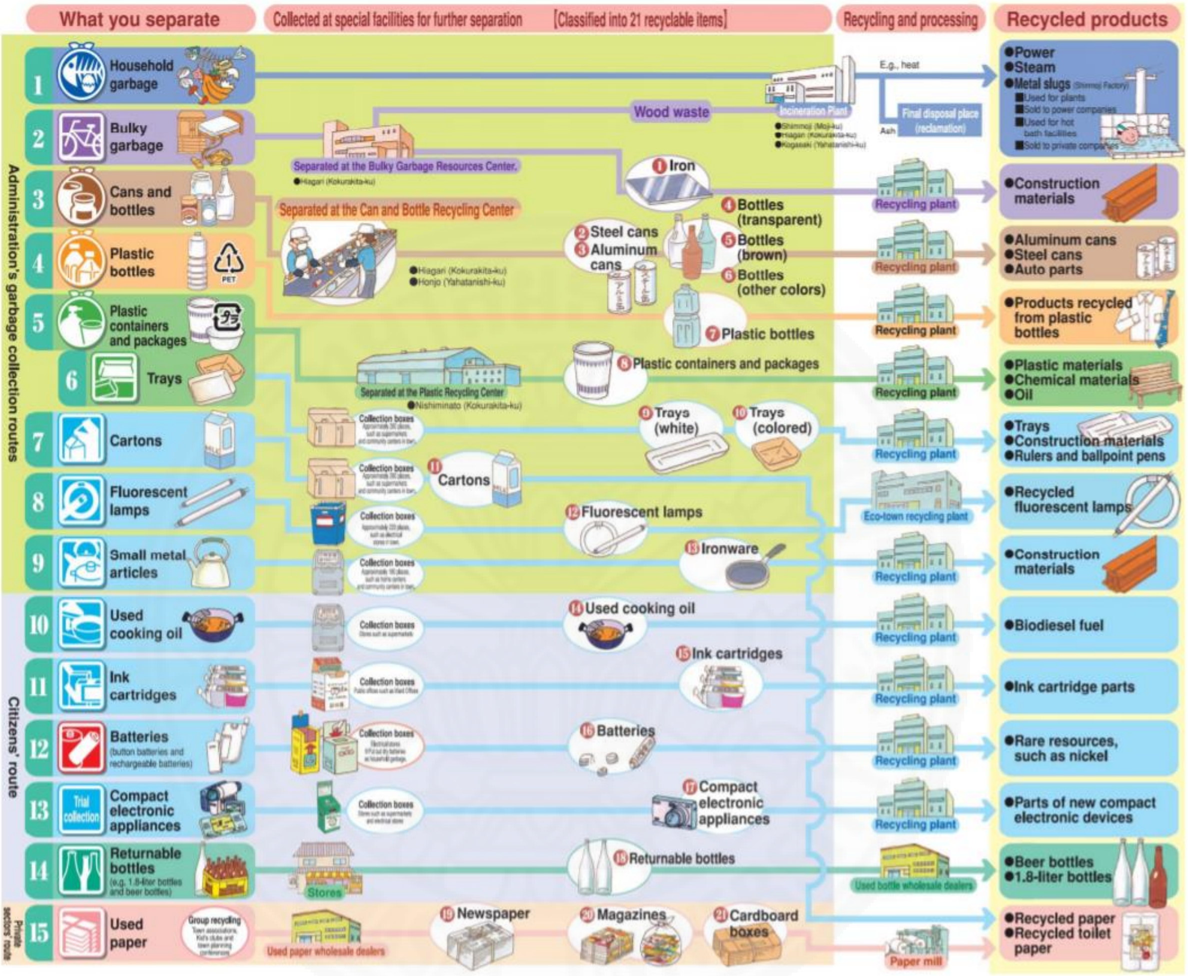

Figure 3.6 Solid waste management and resource circulation

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Household garbage | Cans and glass bottles | PET bottles | Plastic containers and packages

Figure 3.7 Type of garbage bag

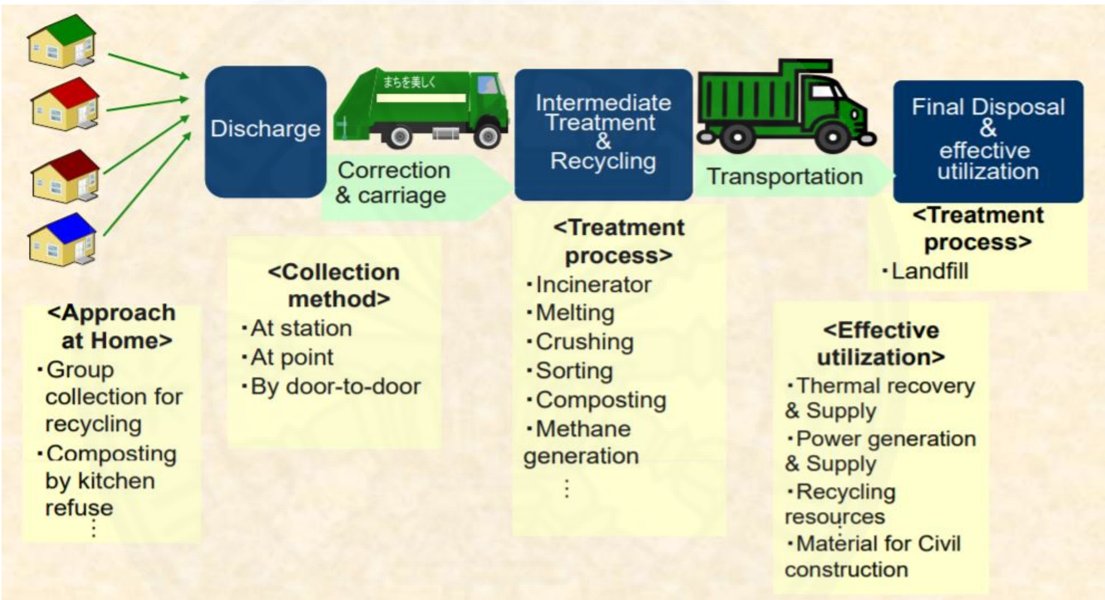


Figure 3.8 Process flow of MSW collection

3.3.3 Waste Recycling

The collected recyclable materials from the collection spots are transported to the two recycling facilities that are established close to the incineration facilities in Hiagari and Honjo areas. Both recycling centers are highly mechanized and have introduced proper measures to improve the working condition such as a bag tearing machine, steel and aluminum can separators, and soundproofing and fresh air supply (See Figure 3.9). The recycling centers employ handicapped people in the city as part of their social welfare program integrating them into the productive society. After that, separated recyclable materials will be brought to the recycling businesses located in the Eco-Town and other areas.

Figure 3.9 Separation of cans and bins at Hiagari Recycling Center

3.3.4 Final Treatment and Disposal

Since the transportation of MSW from one city to another is prohibited in Japan, the city of Kitakyushu has set up three incineration facilities along with other waste recycling and treatment facilities to treat the household waste aiming to sanitize and reduce the volume of landfilled waste. The three facilities are named Shinmoji, Kogasaki, and Hiagari and their locations are shown in Figure 3.10 [21]. All facilities are highly automated with computer control, including the automatic weighing of waste, and the automatic functioning of the crane and the incinerator. The details of these 3 incinerators are shown in Table 3.5

Table 3.5 Waste Incineration Facility in Kitakyushu City

Description	Shinmoji Plant	Kogasaki Plant	Hiagari Plant
Year of operation	April 2007	July 1998	April 1991
Total construct costs	224 million USD	310 million USD	120 million USD
Capacity of the plant	720 tons/day (240 tons/day x 3units)	810 tons/day (270 tons/day x 3 units)	600 tons/day (200 tons/day x 3 units)
Type of treatment	Gasification-type (waste-gas-burning)	Stoker type (waste-burning)	Stoker type (waste-burning)
Ash	Melting and recycling	Landfill	Landfill
Electricity generation	550 kWh/ton	410 kWh/ton	230 kWh/ton
Steam condition	40 kg/cm^3 and 400^{0}C	24 kg/cm^3 and 285^{0}C	21 kg/cm^3 and 260^{0}C
Low calorific value (kcal/kg)	1500-3000	1500-3000	1200-2500

Source: Resource Circulation Division, Environmental Bureau (2012)

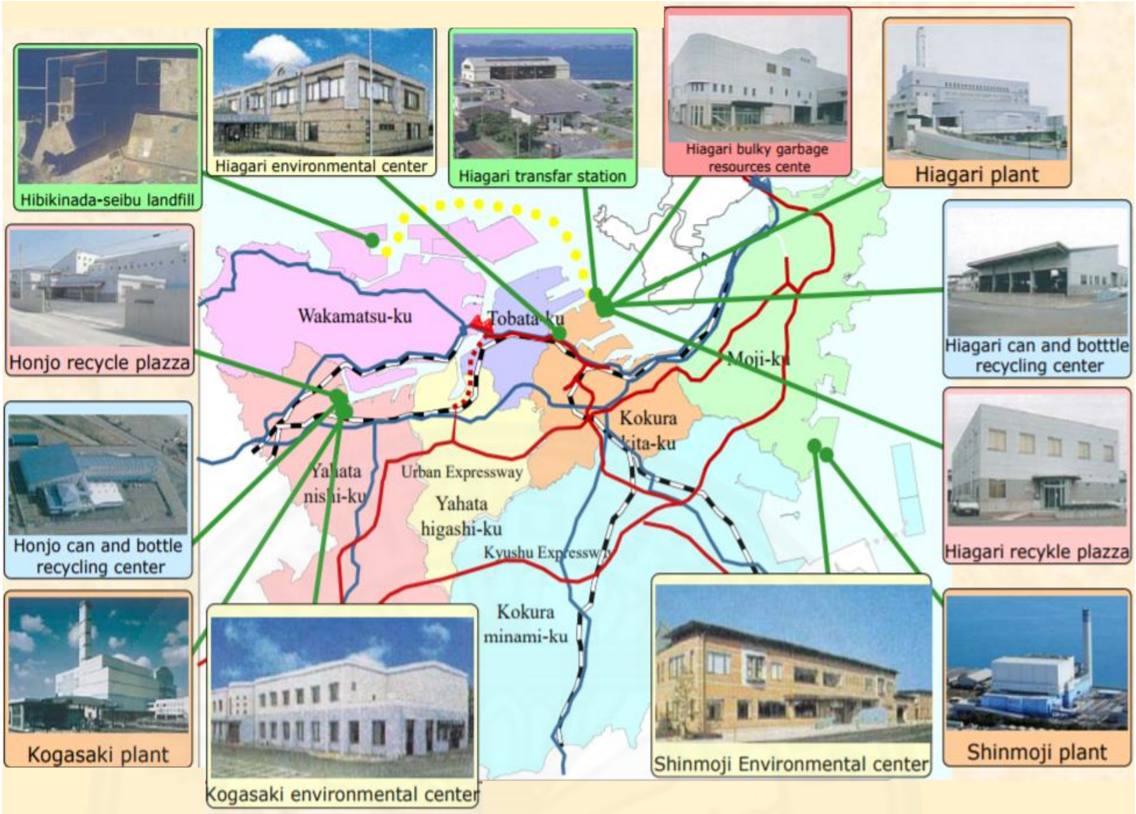


Figure 3.10 Location of waste treatment facilities in Kitakyushu City

3.4 Conclusion

Base on the above literature review, we can see that MSW management systems in Bangkok and Kitakyushu are quite different as shown in Table 3.6. The ineffective MSW management systems in Bangkok are influenced by many factors such as inadequate financial and human resources as well as weak legislation related to MSW consumption.

Table 3.6 The difference between MSW management systems in Bangkok and Kitakyushu

Waste Treatment	Bangkok, Thailand	Kitakyushu, Japan
Minimization and separation	Promote the implementation of the 3Rs strategy, no enforcement or legislation.	Strong regulation, such as paying as you throw.
Collection and transportation	Household by household collection. Waste is collected every day and put all waste together in one truck. Wastes are sent to transfer station for recovery of valuable material then transferred to landfills outside Bangkok.	Point by point collection and each type of waste is collected on designated collection days; thus, wastes are separated from each other. Transportation of MSW from one city to another is prohibited.
Recycling	Salaeng separate recyclable waste and sell it to junk shops. And the rest is done by the workers of contract company.	Mixed recyclable waste collected from households is again carefully separated at recycling centers then transferred to the nearest recycling business center.
Treatment and disposal	Only 10% of total MSW is composted and 3% is incinerated, while nearly 87% of total MSW is sent to landfills outside Bangkok for final disposal.	All waste in the city is sent to local incinerators and gasifiers to combust to generate electricity for local households, and the residues (small amount) are sent to landfills or used to mix with construction material.

Therefore, in comparison to the case of Kitakyushu, we can see many weak points in the Bangkok MSW management are related to policies and regulations. In this regard, BMA officers should strengthen the regulation and strongly enforce the MSW management strategies to gain an effective system and increase participation from residents. The development of policies and technology will contribute to an improved quality of life for the people of Bangkok.

Chapter 4
Appropriate forecasting model for MSW generation

The objective of this chapter is to determine the influential variables affecting the quantity of Bangkok MSW generation and to find the appropriate modeling tool for forecasting of future MSW generation in Bangkok. The reason for MSW forecasting is introduced in section 4.1. The details in section 4.2 are an overview of MSW forecasting techniques including a review of factors affecting MSW characteristics and a review of modelling tools for MSW forecasting. Section 4.3 describes the systematic methodology for identifying the factors affecting MSW amounts and formulating alternative models for Bangkok MSW forecasting, followed by section 4.4 which illustrates the results and discussion, and section 4.5 which is the conclusion.

4.1 Introduction

Nowadays, a large amount of MSW is created by human activities. Waste management organizations must collect, transport, process and finally dispose of the residues in an economical and environmentally efficient way. Therefore, it is important for MSW managers to estimate the future waste generation so that they can set plans or strategies to deal with the upcoming problems. This shows that the accurate prediction of MSW quantities is needed [22]. A number of researchers have developed various prediction methods for implementation of different locations and situations; however, they have the same purpose which is ensuring the accurate waste generation for sustainable planning and management systems [23]. In this chapter, factors affecting the amount of MSW generation and prediction methods are presented.

4.2 Literature review

4.2.1 A review of factors affecting MSW characteristics

MSW characteristics are different in each region as they depend on human lifestyle. MSW characteristics in this study are focused only on the amount of MSW. According to the literature review, many different variables have been studied, such as population, income, household size, resident type, age groups, employment, electricity consumption, tipping fees, Consumer Price Index (CPI), Gross domestic product (GDP), education, culture, geography, and climate. Population and income have been considered as the most important variables affecting waste generation [24]. Moreover, population age between 15 and 59 is also a significant variable influent on waste generation [23].

For Bangkok, average income per household, GDP per capita, and CPI have been determined as the most crucial influencing factors on MSW generation, while the population, the number of households, and household size are of secondary importance [25]. In addition, the study on waste generation variables and people's attitudes toward waste management in Bangkok showed that income level per capita, economic growth (GDP, CPI), population size, size and number of households, consumption/lifestyle, industrialization, perception on impact of MSW, MSW-related legislation, number of tourists, technology applied, MSWM knowledge, public involvement, MSWM fee, and seasons all influence MSW generation [26].

4.2.2 A review of modeling tools for MSW forecasting

Knowing the nature of solid waste generation, such as its amount and characteristics/composition, including calorific value, is a fundamental management activity. This leads to getting primary information for the planning, operation, and optimization of waste management systems [27]. To get this kind of information, several researchers collected the previous years' data and did the prediction to determine the future MSW generation. The prediction of MSW quantities cannot be done directly and depends on many factors. As a result of uncertainties and unavailability of sufficient data, modeling methods are required for this prediction [1].

In developing the relationship between variables and waste generation, most researchers developed regression analysis and time series model. Ghinea et al. (2016) used a waste prognostic tool and Minitab (regression analysis and time series) to forecast MSW generation and composition in Iasi, Romania. The result revealed that the waste prognostic tool, which is based on log-linear regression model, requires a certain variable but cannot show the relationship between variables. Minitab contains several techniques that can be applied to forecast the dynamic of waste generation and determine the changes of response variables when a predictor variable is changed. The output showed that population age between 15 and 59 years and total MSW are significant factors for the analysis and strongly influence the waste generation [23].

Besides regression analysis and time series, Artificial Neural Networks (ANN) have become a popular and useful tool for predicting solid waste in developing countries where MSW generation data is missing or incomplete. Noori et al. (2009) applied ANN and multivariate linear regression (MRL), which is based on the principal component analysis (PCA), to predict the solid waste generation in Tehran for short-term prediction. The results revealed that ANN, which is a nonlinear and dynamic modeling technique, gave a better result compared with the PCA-MLR model [28]. ANN was also successfully used by Antanasijevic et al. (2012) to model and forecast MSW generation in Bulgaria and Serbia based on a comparison of actual MSW generation data with predictions given by the model. The result demonstrated that ANN can be applied to model and forecast MSW generation on a national scale with the broad scope of possible application of the model [29]. Azadi and Karimi-Jashni (2015) have verified the performance of an artificial neural network (ANN) and multiple linear regression (MLR) in predicting the mean seasonal municipal solid waste generation rate. The accuracy of the proposed models is illustrated through a case study of 20 cities located in Fars Province, Iran. Four performance measures, MAE, MAPE, RMSE, and R^2 were used to evaluate the performance of these models. The MLR, as a conventional model, showed poor prediction performance. On the other hand, the results indicated that the ANN model, a nonlinear model, provided a higher predictive accuracy when it comes to prediction of the mean seasonal MSW generation rate [30]. Table 4.1 shows the summary of the waste prediction model.

Kolekar et al. [1] reviewed 20 MSW generation prediction models from 2006 to 2014, which can be classified into five broad categories based on modeling method, study area, time series, independent variables considered, and waste stream. Figure 4.1 presents the percentage of models used from 2006 to 2014.

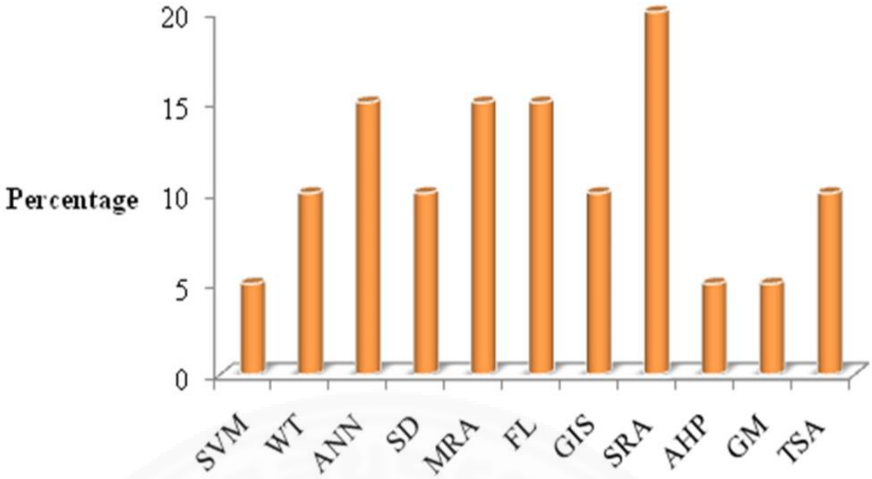


Figure 4.1 Proportional use of modeling methods (2006-2014)

SVM	:	Support vector machine
WT	:	Wavelet transform
ANN	:	Artificial neural network
SD	:	System dynamic
MRA	:	Multiple regression analysis
FL	:	Fuzzy logic
GIS	:	Geographical information system
SRA	:	Single regression analysis
AHP	:	Analytic hierarchy process
GM	:	Gray model
TSA	:	Time series analysis

Table 4.1 Summary of waste prediction models

No.	Modeling Tools	Inputs	Outputs	Author-year
1	1. Waste prognostic tool 2. Minitab (Regression analysis and Time series)	1. Number of inhabitants 2. Population aged 15-59 years 3. Urban life expectancy 4. Total municipal solid waste (t/year)	1. Paper 2. Glass 3. Plastic 4. Metals 5. Organic 6. Other	Ghinea et al. (2016)
2	1. Artificial Neural Networks (ANNs)	1. GDP per capita 2. Domestic material consumption (kg per capita 3. Resource productivity (€ per capita)	1. MSW generation (kg per capita)	Antanasijevic et al. (2012)
3	1. Artificial Neural Networks (ANNs) 2. Principal Component Regression Analysis	1. Seasonal pattern of waste generation 2. Number of trucks	1. MSW generation	Noori et al. (2008)
4	1. Artificial neural network (ANN) 2. Multiple linear regression (MLR)	1. Population 2. Solid waste collection frequency (Times per week) 3. Maximum seasonal temperature (^{o}C) 4. Altitude (m)	1. The mean SMSWG rate(g/cap.day)	Azadi and Karimi-Jashni (2015)

4.3 Methodology

In general, to conduct the study which is related to a forecasting technique, the process in Figure 4.2 is used. In this study, two modeling tools are chosen for the modeling process to predict future MSW generation in Bangkok. Those two models are multiple regression analysis and artificial neural networks. Multiple regression analysis in Minitab software is used to determine the influential variables affecting the amount of total MSW and to find the relationship between input variables and output. After finding the significant influential variables, an Artificial Neural Networks (ANNs) tool (in Matlab software) is used to find the relationship between input variables and outputs. The results from the selected models, both multiple regression analysis and artificial neural networks, are compared by using statistical indicators. This leads to reaching an appropriate model for Bangkok MSW generation forecasting.

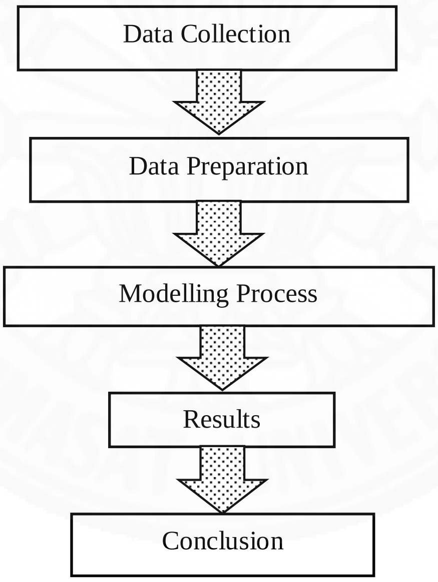


Figure 4.2 Forecasting process

Mean absolute error (MAE), root mean square error (RMSE), and correlation coefficient (R^2) are used to evaluate the performance models. A smaller MAE or RMSE and a bigger R^2 indicates better performance [31]. The following formula is used to calculate these indicators:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|W_o - W_p\right| \tag{4.1}$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{\mathrm{n}}\sum_{\mathrm{i=1}}^{\mathrm{n}}(\mathrm{W_0} - \mathrm{W_p})^2} \tag{4.2}$$

$$\mathrm{R}^2 = 1 - \frac{\sum_{\mathrm{i=1}}^{\mathrm{n}}(\mathrm{W_0} - \mathrm{W_p})^2}{\sum_{\mathrm{i=1}}^{\mathrm{n}}(\mathrm{W_0} - \mathrm{W_0'})^2} \tag{4.3}$$

where W_0 is the actual values of W_{t+1} with i = 1, 2, ..., n year observations,

W_0' is the average of W_{t+1}

n is the total observation number

W_p is the predicted W_{t+1} value.

The process of conducting this study is shown in Figure 4.3. Data collection is the first step of the process. After all necessary data are collected, data preparation is a very important action because there may be missing data that is needed.

4.3.1 Data Collection

Based on the literature review, influential variables affecting the amount of MSW generation consist of number of residents, people aged between 15 and 59 years, number of households, household size, income per household, GDP, CPI, number of tourists, etc. In this study, possible indicators are collected, such as a waste-related indicator (total municipal solid waste), population indicators (total number of residents, native residents, total native people aged 15-59 years and total people aged 15-59 years), a dwelling indicator (number of households), an economic indicator (income per household), and an external indicator (number of tourists), from 2005 to 2015. Definitions and source of variables are presented in Table 4.3 and Table 4.4.

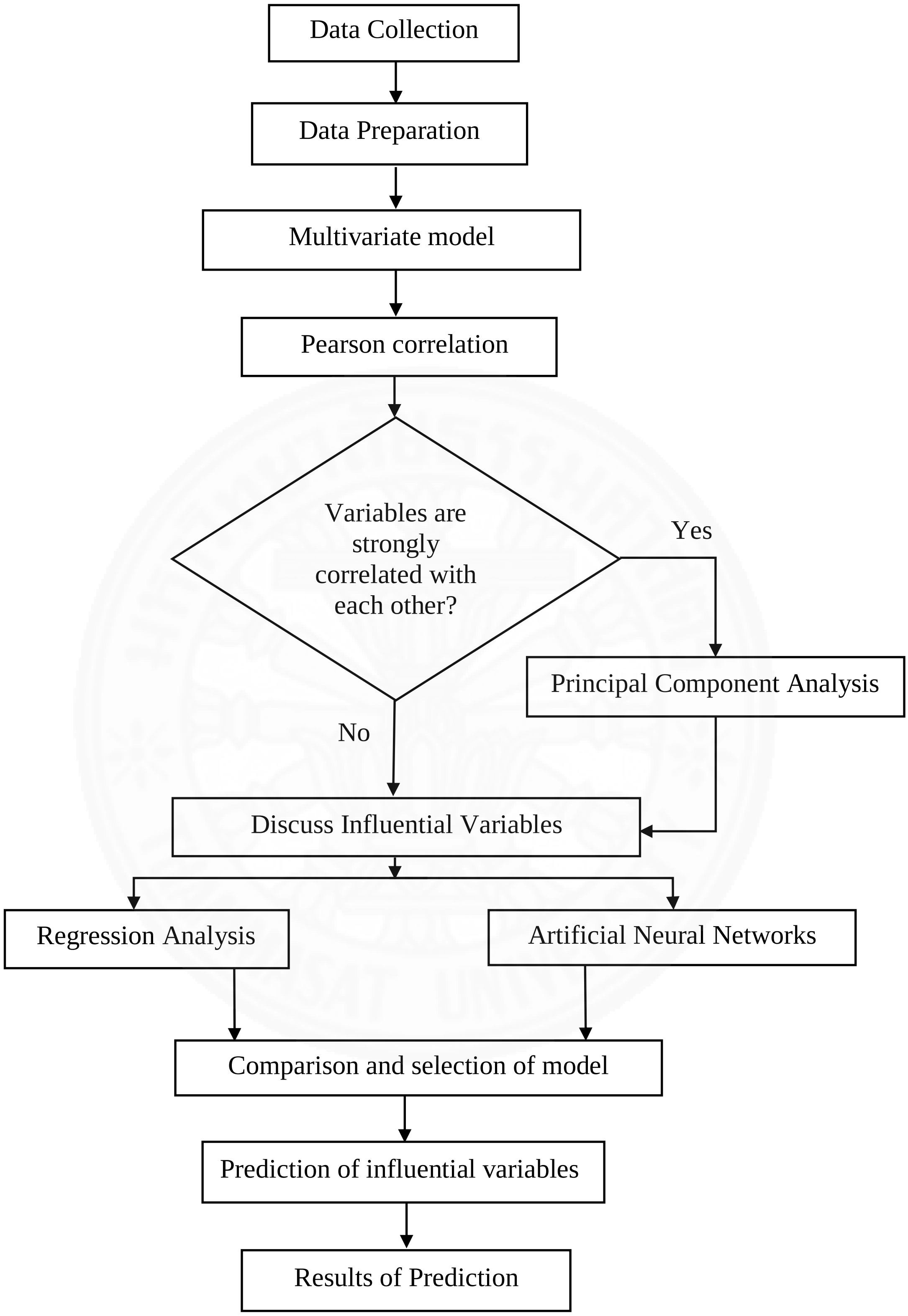


Figure 4.3 Flowchart of conducting this part

4.3.2 Data Preparation

Missing data are dealt with by imputation, which means missing values are substituted by others. We use trend analysis of each missing variable by using Microsoft Excel software which provides us 6 trends, such as Exponential, Linear, Logarithm, Polynomial, and Power. For polynomial, we choose 2^{nd} and 3^{rd} degree in this study. To select the appropriate trend, we use two statistical indicators, R^2 and RMSE which are discussed above.

4.3.3 Multivariate Model

Generally, to determine the key factors of multiple input variables and output variables, searching for correlation is very important. In Minitab, Pearson's Correlation Coefficient (PCC) is usually used to search for this coefficient. PCC does not only show the relationship between inputs and output but also provides the correlation between each input variable. In case there is a strong relationship between each input variable, the equation provided by the modeling method must be carefully discussed. Thus, to avoid the critical problem, Principal Component Analysis should be considered. The following details describe the ways that these tools work.

4.3.3.1 Pearson's Correlation Coefficient

Pearson's Correlation Coefficient is one kind of correlation coefficient that is commonly used in statistics to evaluate the linear relationship between two continuous variables. If a change in one variable is related to a proportional change in the other, it means that these two variables have a linear relationship. Pearson's Correlation Coefficient can be calculated by using equation (4.4) and it returns a value of between -1 and +1. Table 4.2 shows the way to interpret strengths of correlation using Pearson's Correlation coefficient.

Pearson's Correlation Coefficient

$$r = \frac{\sum_i (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_i (X_i - \bar{X})^2}\sqrt{\sum_i (Y_i - \bar{Y})^2}} \qquad (4.4)$$

where X and Y are variables of MSW quantity, and influencing factor, respectively.

r is a value of the correlation coefficient which is described in Table 4.2.

Table 4.2 Interpreting strengths of correlations using Pearson's Correlation Coefficient

r values	Relationship
+.70 or higher	Very strong positive relationship
+.40 to +.69	Strong positive relationship
+.30 to +.39	Moderate positive relationship
+.20 to +.29	Weak positive relationship
+.01 to +.19	No or negligible relationship
0	No relationship [zero order correlation]
-.01 to -.19	No or negligible relationship
-.20 to -.29	Weak negative relationship
-.30 to -.39	Moderate negative relationship
-.40 to -.69	Strong negative relationship
-.70 or higher	Very strong negative relationship

In our study, Pearson's Correlation Coefficient is used to search for multicollinearity between variables are shown in Table 4.8.

Pearson's Correlation Coefficient table shows that waste generation is very strongly positively correlated with number of households, income per household, and number of tourists, but very strongly negatively correlated with native people aged between 15 and 59 years. At the same time, waste generation has a strong positive relationship with total number of residents, total people aged between 15 and 59 years, and negligibly related to native residents. Moreover, some variables also have a strong correlation with each other. So instead of using these variables directly, we change them into principal components.

4.3.3.2 Principal Component Analysis (PCA)

Principal Component Analysis, one of the multivariate statistical methods, is used to reduce input variables complexity and avoid multicollinearity when there are many variables involved in the number of observations. It is used to explain the maximum amount of variance with the minimum number of principal components. This method changes the input variables into principal components that are the linear combinations of the original variables, and the maximum number of components extracted always equals the number of original variables. One way to determine the number of principal components is based on the size of eigenvalues. The eigenvalues of the correlation matrix are equal to the variance of the principal components. Based on the Kaiser criterion, retain principal components with eigenvalues greater than 1 or components that cumulatively explain 90% of the variance. However, we can use any one or combination of these techniques to determine the number of principal components.

In our case study, we have 7 independent variables, so we can create 7 principal components as shown in Table 4.9. After the principal components are created, we will then generate the regression equation to find the relationship between those principal components and amount of total MSW.

4.3.3.3 Regression Analysis (RA)

Regression Analysis is one simple way to investigate and model the relationship between a response and a predictor. It determines how the response variable changes when the predictor variable changes. We can model both linear and polynomial relationships. The regression equation takes the form of

Response = constant + coefficient * predictor + ... + coefficient * predictor

or $Y = b_o + b_1X_1 + b_2X_2 + ... + b_kX_k$

where Response (Y) is the value of the response

Constant (b_o) is the value of the response variable when the predictor variable(s) is zero.

Predictor(s) (X) is the value of the predictor variable(s).

Coefficient(s) (b_1, b_2, ..., b_k) represents the estimated change in mean response for each unit change in the predictor value.

Fit Regression Model is one tool in Regression Analysis that consists of stepwise model selection [32]. Stepwise regression is a procedure that generates a model by including variables or excluding variables from the model based on the specified Alpha-to-Enter and Alpha-to-Remove values.

4.3.4 Artificial Neural Networks

Artificial Neural Networks (ANNs) are the simplified computational model whose functions are like the human brain. They are capable of curve fitting, classifying, clustering, and dynamic time series forecasting [24]. A neural fitting tool solves an input-output fitting problem by using a two-layer feedforward neural network with sigmoid hidden neurons and linear output neurons. The network is trained with the Levenberg-Marquardt backpropagation algorithm, and it maps between a data set of numeric inputs and a set of numeric targets. The neural fitting app selects data, creates and trains a network, and evaluates its performance using root mean square error and regression analysis (MATLAB, R2015a). More information on use can be found in [33].

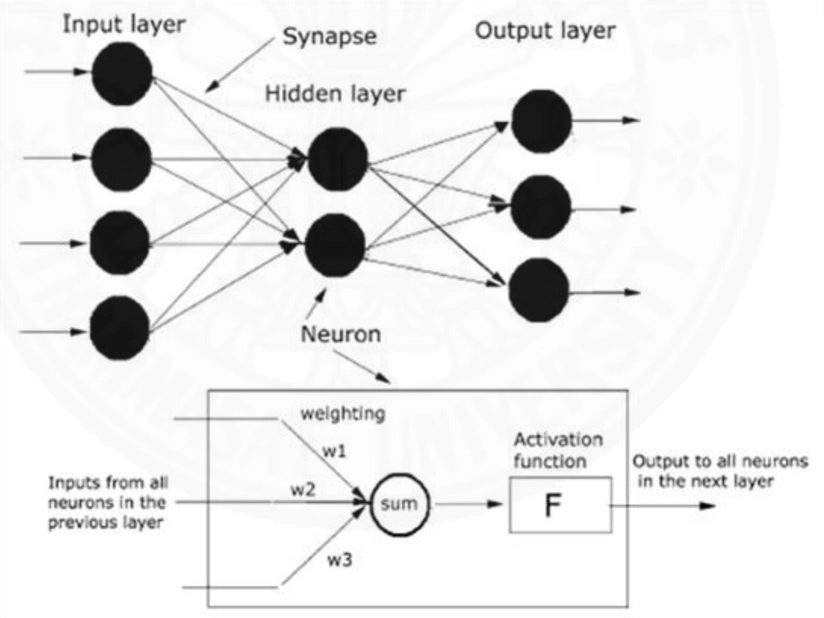


Figure 4.4 Elements of an artificial neural network (ANN) architecture

Table 4.3 Definitions and source of variables

Variables	Symbol	Description	Unit	Accessed Sources
Total MSW	x_0	Waste collected by the municipality typically comprises household and commercial materials, excluding hazardous and industrial waste.	Tonnes/day	PCD (1998-2015)
Total number of residents	x_1	Total number of people who live in Bangkok, including immigrants.	Capita	NSO (2016)
Native residents	x_2	Number of registered Thai people who live in Bangkok.	Capita	BORA (2017)
Native people aged 15-59 years	x_3	Number of registered Thai people who live in Bangkok aged 15 to 59 years.	Capita	BORA (2017)
Total people aged 15-59 years	x_4	This variable equals to the summation of Native people aged 15-59 years and the difference between Total number of residents and Native residents (assumes that immigrants are people aged 15 to 59 years.)	Capita	
Number of households	x_5	Total number of registered households in Bangkok.	None	BORA (2017)
Income per household	x_6	Income per month in a household.	Baht/month	BMA (2017)
Number of tourists	x_7	Total number of national and international Tourists in Bangkok per year collected by Tourism Authority of Thailand.	Capita	TAT (2017)

Table 4.4 Data collection

Year	Total number of residents	Native residents	Native people age 15-59 years	Total people age 15-59 years	Number of households	Income per household (Baht/month)	Number of tourists (Capita/year)	Total MSW (tons/day)
2005	6,796,000	5,658,954	3,819,582		2,091,558		34,838,704	8,291
2006	6,825,956	5,695,958	3,843,438		2,150,706	36,658	36,172,138	8,403
2007	6,905,699	5,716,248	3,853,428		2,207,453	39,020	35,953,546	8,532
2008		5,710,883	3,853,994		2,263,680		35,110,693	8,780
2009		5,702,595	3,846,880		2,334,126	42,380	30,037,911	8,834
2010	8,305,218	5,701,394	3,842,849		2,400,540		38,222,903	8766
2011		5,674,843	3,834,031		2,459,680	48,951	43,763,002	9,237
2012		5,673,560	3,819,740		2,522,855		47,185,031	11,000
2013		5,686,252	3,795,076		2,593,827	49,191	50,568,902	11,737
2014	8,563,548	5,692,284	3,771,113		2,672,423		50,972,772	10,800
2015	8,625,230	5,696,409	3,750,817		2,753,972	45,572	56,515,597	11,500

From Table 4.4, we can see that there are three variables which contain missing values. In this case, two variables (Total number of residents and Income per household) are processed as described above in data preparation. Total people aged 15-59 years can be calculated by the following equation

Total people age 15-59 years = (Total number of residents – Native residents) + Native people age 15-59 years (4.5)

Assume that extra people (Total number of residents – Native residents) are people aged 15-59 years who come to Bangkok to work or earn a living.

The selected trend is noted by a highlight mark. The results of preparation data are shown in Table 4.5, Table 4.6, and Table 4.7.

Table 4.5 Total number of resident trends

Trend	Equations
Exponential	$y = 3.2930202975E\text{-}17e^{2.6772365901E\text{-}02x}$
Linear	$y = 2.0547761453E+05x - 4.0523699122E+08$
Logarithmic	$y = 4.1307442470E+08\ln(x) - 3.1340248311E+09$
Polynomial Order 2	$y = -1.7172355433E+04x^2 + 6.9241896049E+07x - 6.9790142636E+10$
Polynomial Order 3	$y = -7.4586705552E+03x^3 + 4.4955171646E+07x^2 - 9.0318103082E+10x + 6.0484893929E+13$
Power	$y = 1.2764708236E\text{-}171x^{5.3821231829E+01}$

Year	Total number of residents	Trends					
		Exponential	Linear	Logarithm	Polynomial 2	Polynomial 3	Power
2005	6796000	6759451	6745626	6744977	6560793	6737972	6758873
2006	6825956	6942862	6951104	6950948	6924371	6830704	6942716
2007	6905699	7131249	7156581	7156816	7253605	7061221	7131463
2008		7324748	7362059	7362581	7548494	7384770	7325244
2009		7523498	7567536	7568245	7809038	7756599	7524191
2010	8305218	7727640	7773014	7773805	8035238	8131957	7728437
2011		7937321	7978492	7979264	8227092	8466091	7938122
2012		8152692	8183969	8184620	8384603	8714250	8153388
2013		8373907	8389447	8389875	8507768	8831681	8374379
2014	8563548	8601125	8594924	8595027	8596589	8773632	8601247
2015	8625230	8834507	8800402	8800078	8651065	8495352	8834143
R^2		0.900	0.905	0.905	0.938	0.972	0.900
RMSE		272238.0	256921.6	256660.6	208444.6	140593.9	271944.4

Table 4.6 Income per household (Baht/month) trends

Trend	Equations
Exponential	$y = 2.4581791663E\text{-}21e^{2.8919154622E\text{-}02x}$
Linear	$y = 1.2276380822E+03x - 2.4241285682E+06$
Logarithmic	$y = 2.4689870198E+06\ln(x) - 1.8735416723E+07$
Polynomial Order 2	$y = -2.9475088851E+02x^2 + 1.1863725086E+06x - 1.1937392980E+09$
Polynomial Order 3	$y = -6.0376151410E+01x^3 + 3.6387072922E+05x^2 - 7.3098084385E+08x + 4.8948804436E+11$
Power	$y = 3.2915521183E\text{-}188x^{5.8161154490E+01}$

Year	Income per household (Baht/month)	Trends					
		Exponential	Linear	Logarithm	Polynomial 2	Polynomial 3	Power
2005		37348.16	37285.79	37277.55	31641.16	36339.05	37340.93
2006	36658	38444.01	38513.42	38508.66	35767.86	36852.96	38439.71
2007	39020	39572.01	39741.06	39739.16	39305.05	38420.97	39570.24
2008		40733.10	40968.70	40969.04	42252.74	40680.82	40733.43
2009	42380	41928.27	42196.34	42198.31	44610.93	43270.26	41930.22
2010		43158.50	43423.98	43426.96	46379.62	45827.02	43161.54
2011	48951	44424.83	44651.62	44655.01	47558.80	47988.86	44428.38
2012		45728.32	45879.25	45882.45	48148.49	49393.52	45731.75
2013	49190.8	47070.05	47106.89	47109.27	48148.67	49678.73	47072.68
2014		48451.15	48334.53	48335.49	47559.35	48482.25	48452.23
2015	45571.7	49872.77	49562.17	49561.10	46380.53	45441.81	49871.50
R^2		0.698	0.682	0.683	0.929	0.982	0.698
RMSE		2804.21	2669.19	2667.04	1260.23	628.50	2802.03

Table 4.7 Final Prepared Data

Year	Total number of residents	Native residents	Native people aged 15-59 years	Total people aged 15-59 years	Number of households	Income per household (Baht/month)	Number of tourists	Total MSW (tons/day)
2005	6796000	5,658,954	3,819,582	4,956,628	2,091,558	36339.05	34,838,704	8,291
2006	6825956	5,695,958	3,843,438	4,973,436	2,150,706	36658	36,172,138	8,403
2007	6905699	5,716,248	3,853,428	5,042,879	2,207,453	39020	35,953,546	8,532
2008	7384770	5,710,883	3,853,994	5,527,881	2,263,680	40680.82	35,110,693	8,780
2009	7756599	5,702,595	3,846,880	5,900,884	2,334,126	42380	30,037,911	8,834
2010	8305218	5,701,394	3,842,849	6,446,673	2,400,540	45827.02	38,222,903	8,766
2011	8466091	5,674,843	3,834,031	6,625,279	2,459,680	48951	43,763,002	9,237
2012	8714250	5,673,560	3,819,740	6,860,430	2,522,855	49393.52	47,185,031	11,000
2013	8831681	5,686,252	3,795,076	6,940,505	2,593,827	49190.80	50,568,902	11,737
2014	8563548	5,692,284	3,771,113	6,642,377	2,672,423	48482.25	50,972,772	10,800
2015	8625230	5,696,409	3,750,817	6,679,638	2,753,972	45571.7	56,515,597	11,500

4.4 Results and Discussion

4.4.1 Multiple Regression Analysis

After changing variables into PCs, multicollinearities between variables are removed. The correlation matrix (see Table 4.9) shows that the first three principal components (PCs) cumulatively explain 98.5% (more than 90%) of the total variability, suggesting that these 3 PCs adequately explain the variation in the data.

Table 4.8 Pearson correlation between variables

	x_1	x_2	x_3	x_4	x_5	x_6	x_7
x_2	-0.186						
x_3	-0.596	0.277					
x_4	0.999	-0.199	-0.571				
x_5	0.921	-0.04	-0.801	0.907			
x_6	0.973	-0.191	-0.476	0.977	0.858		
x_7	0.777	-0.23	-0.885	0.76	0.897	0.713	
x_0	0.833	-0.182	-0.817	0.819	0.904	0.763	0.916

Table 4.9 Eigen-analysis of the Correlation Matrix

Eigenvalue	5.1111	1.0185	0.7621	0.0841	0.0184	0.0059	0
Proportion	0.73	0.146	0.109	0.012	0.003	0.001	0
Cumulative	0.73	0.876	0.985	0.997	0.999	1	1

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7
x_1	0.426	-0.126	0.262	-0.18	0.409	0.156	-0.714
x_2	-0.108	-0.915	-0.337	0.021	0.01	0.191	0.015
x_3	-0.345	-0.265	0.629	0.456	0.181	-0.417	-0.03
x_4	0.422	-0.12	0.302	-0.165	0.426	0.137	0.699
x_5	0.429	-0.166	-0.172	-0.222	-0.169	-0.825	0
x_6	0.405	-0.147	0.405	0.19	-0.74	0.257	0
x_7	0.402	0.111	-0.37	0.804	0.204	0.006	0

The continuous predictor standardization, subtracted by the mean then divided by the standard deviation, is applied to the PCs values. A stepwise algorithm, with candidate terms PC1, PC2, and PC3, is processed to select the significant terms and construct the regression equation. Significant terms are chosen based on the significance level. Alpha-to-Enter is selected to be 0.15, greater than the usual 0.05 so that it is not too difficult to enter predictors into the model. While Alpha-to-Remove is

0.15, greater than the usual 0.05 so that it is not easy to remove predictors from the model. A stepwise regression procedure provides the final model in equation (4.6). The model has R^2 or R-sq = 0.8687, which means that 86.87% of the variation in the response data can be explained by this model. Adjusted R^2 or R-sq (adj) = 85.41% is a modified R-sq that has been adjusted for the number of terms in the model. This indicator increases only if the new term improves the model more than would be expected by chance, and it is always lower than R-sq. While R^2 predicted or R-sq (pred) = 80.76% it indicates that the regression model is able to predict the response for new observations.

Figure 4.5 presents the analysis of variance for total MSW generation, which illustrates the variation amount in data response explained by predictors. In this regression, the p-value is 0.000 showing that at least one of the regression coefficients is significantly different than zero. P-value of PC1 = 0.000, and only one predictor exists in the model, so PC1 is the significant predictor in this regression model. Looking back to Table 4.9, PC1 changes -0.108 when x_2 changes one unit, while it changes more than 0.3 when the other PCs change one unit. So, we can say that x_2 (native residents) does not significantly affect the amount of total municipal solid waste in Bangkok.

The regression equation in uncoded units of total MSW is therefore expressed as

$$x_0 = 2913 + 0.000307 \text{ PC1} \qquad (4.6)$$

where $\text{PC1} = 0.426x_1 - 0.108x_2 - 0.345x_3 + 0.422x_4 + 0.429x_5 + 0.405x_6 + 0.402x_7$

The result from this model provides the value of RMSE = 462.9 and R-sq = 0.8687

Regression Analysis: X0 versus PC1, PC2, PC3

```
Method

Continuous predictor standardization
Subtract the mean, then divide by the standard deviation

Predictor        Mean     StDev
PC1          21834166   4060731
PC2          -3716029    781973
PC3         -11456385   2856574


Stepwise Selection of Terms

α to enter = 0.15, α to remove = 0.15


Analysis of Variance

Source       DF    Adj SS    Adj MS  F-Value  P-Value
Regression    1  15586893  15586893    59.54    0.000
  PC1         1  15586893  15586893    59.54    0.000
Error         9   2356144    261794
Total        10  17943037


Model Summary

      S    R-sq  R-sq(adj)  R-sq(pred)
511.658  86.87%     85.41%      80.76%


Coded Coefficients

Term      Coef  SE Coef  T-Value  P-Value   VIF
Constant  9625      154    62.39    0.000
PC1       1248      162     7.72    0.000  1.00
```

Figure 4.5 Analysis of variance for total MSW generation

Table 4.10 Regression result by PC1, PC2, and PC3

Year	x_0 observation	x_0 predicted
2005	8,291	8431.3
2006	8,403	8606.1
2007	8,532	8604.6
2008	8,780	8633.8
2009	8,834	8115.2
2010	8,766	9277.4
2011	9,237	10015.3
2012	11,000	10510.5
2013	11,737	10965.3
2014	10,800	10954.1
2015	11,500	11663.4
R^2		0.8687
RMSE		462.9

Since the above result can conclude that native residents (x_2) are not significantly influential in the total amount of MSW in Bangkok, we can generate the regression equation again by ignoring this variable. By using the same condition as in the first step, we get the new solution as below.

Table 4.11 Eigen-analysis of the Correlation Matrix

Eigenvalue	5.0623	0.7929	0.0849	0.0415	0.0183	0
Proportion	0.844	0.132	0.014	0.007	0.003	0
Cumulative	0.844	0.976	0.99	0.997	1	1

Variable	PC1	PC2	PC3	PC4	PC5	PC6
x_1	0.428	-0.286	0.168	-0.157	0.398	-0.723
x_3	-0.344	-0.69	-0.42	0.427	0.215	-0.002
x_4	0.424	-0.32	0.144	-0.236	0.41	0.688
x_5	0.435	0.086	0.301	0.836	-0.101	0.056
x_6	0.408	-0.425	-0.209	-0.183	-0.759	-0.017
x_7	0.404	0.389	-0.8	0.063	0.205	-0.001

The regression equation in uncoded units of total MSW is therefore expressed as

$$x_0 = 2718 + 0.000306\ PC1 \tag{4.7}$$

where $PC1 = 0.428x_1 - 0.344x_3 + 0.424x_4 + 0.435x_5 + 0.408x_6 + 0.404x_7$

The result from this model provides the value of RMSE = 462.8 and R-sq = 0.8687.

Regression Analysis: X0 versus PC1, PC2

```
Method

Continuous predictor standardization
Subtract the mean, then divide by the standard deviation

Predictor       Mean    StDev
PC1         22578731  4081069
PC2          9591737  2980384


Stepwise Selection of Terms

α to enter = 0.15, α to remove = 0.15


Analysis of Variance

Source      DF    Adj SS    Adj MS  F-Value  P-Value
Regression   1  15587507  15587507    59.56    0.000
  PC1        1  15587507  15587507    59.56    0.000
Error        9   2355530    261726
Total       10  17943037


Model Summary

      S    R-sq  R-sq(adj)  R-sq(pred)
511.591  86.87%     85.41%      80.76%


Coded Coefficients

Term      Coef  SE Coef  T-Value  P-Value   VIF
Constant  9625      154    62.40    0.000
PC1       1248      162     7.72    0.000  1.00
```

Figure 4.6 Analysis of variance for total MSW generation

Table 4.12 Regression result by PC1 and PC2

Year	x_0 observation	x_0 predicted
2005	8291	8438.9
2006	8403	8615.3
2007	8532	8614.5
2008	8780	8643.6
2009	8834	8123.9
2010	8766	9288.1
2011	9237	10026.5
2012	11000	10522.5
2013	11737	10978.6
2014	10800	10967.6
2015	11500	11678.4
	R^2	0.8687
	RMSE	462.8

4.4.2 Artificial Neural Networks

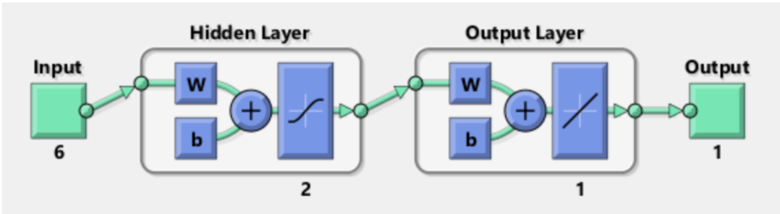


Figure 4.7 Architecture of Artificial Neural Network

From above results, the number of native residents is not a significant variable affecting the amount of MSW, so this variable is not mentioned again in other parts or models. A neural network architecture with 6 inputs and 1 output is designed by choosing 2 neurons in the hidden layer and 1 neuron in the output layer. Each time a neural network is trained, the results can be different because of the different initial weight and bias values and divisions of data in training, validation, and test sets. To make sure that a neural network has good accuracy, retraining several times is required. In this model, 70% of data is used in training, 15% in validating and the other 15% in testing. The result provides a network with RMSE = 85.74 and R^2 = 0.9952 which is considered as satisfactory output, so this network can be used on new inputs to predict future MSW generation. Figure 4.8 shows the observed and predicted MSW from Multiple regression analysis and ANN architecture.

Table 4.13 Observation and MSW prediction from Multiple regression analysis and ANN model

Year	Observation	Multiple Regression Analysis	ANN architecture
2005	8,291	8,438.9	8,291.13
2006	8,403	8,615.3	8,403.08
2007	8,532	8,614.5	8,719.45
2008	8,780	8,643.6	8,771.66
2009	8,834	8,123.9	8,772.37
2010	8,766	9,288.1	8,774.41
2011	9,237	10,026.5	9,236.93
2012	11,000	10,522.5	10,967.54
2013	11,737	10,978.6	11,535.15
2014	10,800	10,967.6	10,799.93
2015	11,500	11,678.4	11,499.52
R^2		0.8687	0.9952
RMSE		462.8	85.74

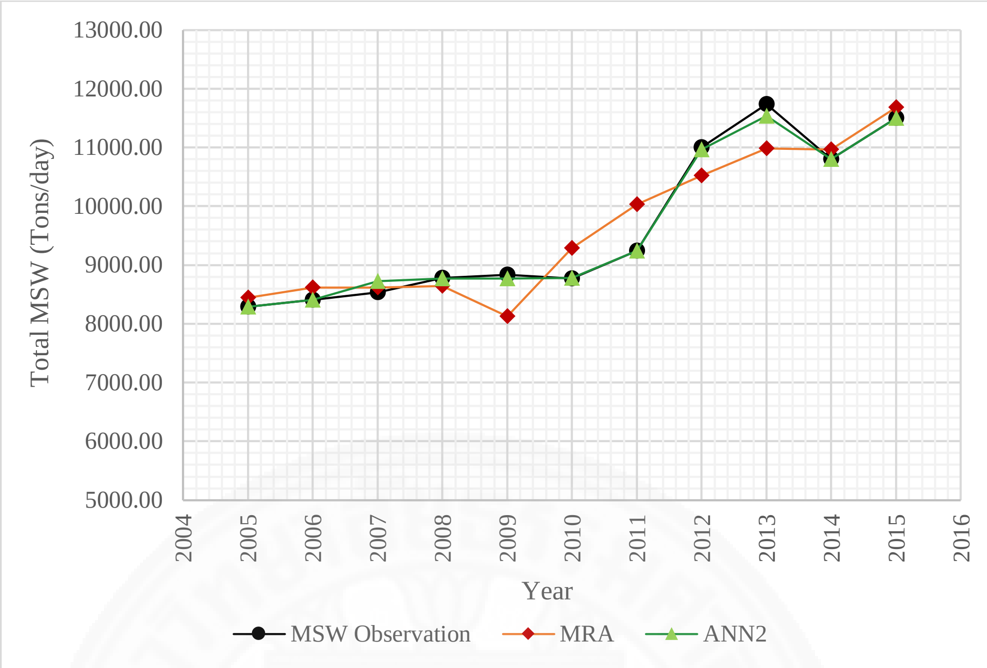


Figure 4.8 Observed and predicted MSW from Multiple regression analysis and ANNs

Since we already know the relationship between all influential variables and the significant principal component, and the relationship between the component and total amount of MSW, we can calculate the total amount of MSW if we know the value of each variable. To predict future MSW generation in Bangkok, the appropriate predicted value of those variables is needed. Time series of each variable is used to generate the trend and perform the suitable equation to predict their values in the next 5 years. The following part gives the time series forecasting of each variable. After getting the future value of each variable, we determine the value of MSW amount by using those values. The forecasting of future variable values is done by using Microsoft Excel software trend fit. Data from 2005-2012 are used to build the trend, while data from 2013-2015 are used to validate to select a highly accurate trend using R^2 and mean absolute percentage error (MAPE). The trends of all influential variables are shown in Tables 4.14-4.21. The result of MSW forecasting is shown in Figure 4.9.

The formula to calculate MAPE:

$$MAPE(\%) = \left(\frac{1}{n}\sum_{i=1}^{n}\frac{AbsoluteError}{ActualValue}\right)\times 100 \tag{4.8}$$

Table 4.14 Total number of residents

Trend	Equation
Exponential	$y = 2.3399694654E\text{-}29e^{4.0711850436E\text{-}02x}$
Linear	$y = 3.1189060417E+05x - 6.1878795564E+08$
Logarithmic	$y = 6.2640155464E+08\ln(x) - 4.7562289523E+09$
Polynomial Order 2	$y = 1.5025007626E+04x^2 - 6.0043565031E+07x + 5.9993099485E+10$
Polynomial Order 3	$y = -1.4356183475E+04x^3 + 8.6518208539E+07x^2 - 1.7380155489E+11x + 1.1637975712E+14$
Power	$y = 6.5469412852E\text{-}264x^{8.1766826000E+01}$

Year	Total number of residents (Capita)	Exponential		Linear		Logarithmic		Polynomial 2		Polynomial 3		Power	
		Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)
2005	6,796,000	6,599,011		6,552,706		6,552,215		6,657,880		6,816,999		6,598,575	
2006	6,825,956	6,873,212		6,864,596		6,864,557		6,879,620		6,780,337		6,873,167	
2007	6,905,699	7,158,808		7,176,487		7,176,743		7,131,411		6,989,068		7,159,040	
2008	7,384,770	7,456,270		7,488,378		7,488,773		7,413,251		7,357,054		7,456,653	
2009	7,756,599	7,766,093		7,800,268		7,800,649		7,725,142		7,798,159		7,766,480	
2010	8,305,218	8,088,789		8,112,159		8,112,369		8,067,082		8,226,245		8,089,016	
2011	8,466,091	8,424,894		8,424,049		8,423,934		8,439,073		8,555,176		8,424,777	
2012	8,714,250	8,774,964		8,735,940		8,735,344		8,841,114		8,698,814		8,774,298	
2013	8,831,681	9139,581	3.49	9,047,831	2.45	9,046,599	2.43	9,273,204	5.00	8,571,022	2.95	9,138,134	3.47
2014	8,563,548	9,519,348	11.16	9,359,721	9.30	9,357,700	9.27	9,735,345	13.68	8,085,664	5.58	9,516,865	11.13
2015	8,625,230	9,914,896	14.95	9,671,612	12.13	9,668,647	12.10	10,227,536	18.58	7,156,601	17.03	9,911,093	14.91
Avg.			9.87		7.96		7.93		12.42		8.52		9.84

Table 4.15 Native people aged between 15 and 59 years

Trend	Equation
Exponential	$y = 6.5058092051E+06e^{-2.6259690432E-04x}$
Linear	$y = -1.0092857143E+03x + 5.8663931071E+06$
Logarithmic	$y = -2.0219036471E+06\ln(x) + 1.9216108714E+07$
Polynomial Order 2	$y = -2.6218928571E+03x^2 + 1.0531134321E+07x - 1.0571025059E+10$
Polynomial Order 3	$y = 3.6246464647E+02x^3 - 2.1866526201E+06x^2 + 4.3971534973E+09x - 2.9474102076E+12$
Power	$y = 2.0977066600E+08x^{-5.2605789038E-01}$

Year	Native people aged 15-59 years	Exponential		Linear		Logarithmic		Polynomial 2		Polynomial 3		Power	
		Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)
2005	3,819,582	3,842,752		3,842,775		3,842,768		3,824,422		3,820,922		3,842,744	
2006	3,843,438	3,841,743		3,841,766		3,841,760		3,839,144		3,842,169		3,841,736	
2007	3,853,428	3,840,734		3,840,757		3,840,752		3,848,622		3,852,735		3,840,729	
2008	3,853,994	3,839,726		3,839,747		3,839,745		3,852,857		3,854,795		3,839,723	
2009	3,846,880	3,838,717		3,838,738		3,838,738		3,851,847		3,850,524		3,838,717	
2010	3,842,849	3,837,710		3,837,729		3,837,732		3,845,594		3,842,096		3,837,712	
2011	3,834,031	3,836,702		3,836,720		3,836,726		3,834,097		3,831,687		3,836,708	
2012	3,819,740	3,835,695		3,835,710		3,835,721		3,817,357		3,821,471		3,835,705	
2013	3,795,076	3,834,687	1.04	3,834,701	1.04	3,834,716	1.04	3,795,372	0.01	3,813,623	0.49	3,834,702	1.04
2014	3,771,113	3,833,681	1.66	3,833,692	1.66	3,833,712	1.66	3,768,144	0.08	3,810,317	1.04	3,833,701	1.66
2015	3,750,817	3,832,674	2.18	3,832,682	2.18	3,832,709	2.18	3,735,672	0.40	3,813,729	1.68	3,832,700	2.18
Avg.			1.63		1.63		1.63		0.16		1.07		1.63

Table 4.16 Total people aged between 15 and 59 years

Trend	Equation
Exponential	$y = 8.1835390876E\text{-}41e^{5.3705684873E\text{-}02x}$
Linear	$y = 3.1155016369E+05x - 6.1995674257E+08$
Logarithmic	$y = 6.2571561951E+08\ln(x) - 4.7528648793E+09$
Polynomial Order 2	$y = 1.6105001674E+04x^2 - 6.4382241561E+07x + 6.4348699046E+10$
Polynomial Order 3	$y = -1.4843867819E+04x^3 + 8.9457830544E+07x^2 - 1.7970795069E+11x + 1.2033553392E+14$
Power	$y = 0.0000000000E+00x^{1.0786404533E+02}$

Year	Total people aged 15-59 years	Exponential		Linear		Logarithmic		Polynomial 2		Polynomial 3		Power	
		Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)
2005	4,956,628	4,761,313		4,701,336		4700,849		4,814,071		4,962,397			
2006	4,973,436	5,024,014		5,012,886		5,012,849		5,028,991		4,910,123			
2007	5,042,879	5,301,209		5,324,436		5,324,693		5,276,121		5,112,717			
2008	5,527,881	5,593,698		5,635,986		5,636,382		5,555,461		5,481,116			
2009	5,900,884	5,902,324		5,947,536		5,947,916		5,867,011		5,926,256			
2010	6,446,673	6,227,979		6,259,086		6,259,295		6,210,772		6,359,075			
2011	6,625,279	6,571,602		6,570,637		6,570,519		6,586,742		6,690,509			
2012	6,860,430	6,934,183		6,882,187		6,881,588		6,994,922		6,831,495			
2013	6,940,505	7,316,770	5.42	7,193,737	3.65	7,192,502	3.63	7,435,312	7.13	6,692,970	3.57		
2014	6,642,377	7,720,466	16.23	7,505,287	12.99	7,503,262	12.96	7,907,912	19.05	6,185,870	6.87		
2015	6,679,638	8,146,435	21.96	7,816,837	17.02	7,813,868	16.98	8,412,722	25.95	5,221,133	21.84		
Avg.			14.54		11.22		11.19		17.38		10.76		

Table 4.17 Number of households

Trend	Equation
Exponential	$y = 6.8128659492E\text{-}18e^{2.6973308757E\text{-}02x}$
Linear	$y = 6.2067333333E+04x - 1.2235841425E+08$
Logarithmic	$y = 1.2466094123E+08\ln(x) - 9.4576043528E+08$
Polynomial Order 2	$y = 5.8492857143E+02x^2 - 2.2875907381E+06x + 2.2372826331E+09$
Polynomial Order 3	$y = -2.2408585859E+02x^3 + 1.3508142695E+06x^2 - 2.7142211492E+09x + 1.8178740245E+12$
Power	$y = 2.6615495199E\text{-}173x^{5.4176035232E+01}$

		Exponential		Linear		Logarithmic		Polynomial 2		Polynomial 3		Power	
Year	Number of households	Estimated	MAPE (%)	Estimated	MAPE (%)	Estimated	MAPE (%)	Estimated	MAPE (%)	Estimated	MAPE (%)	Estimated	MAPE (%)
2005	2,091,558	2,092,281		2,086,589		2,086,483		2,090,684		2,092,976		2,092,182	
2006	2,150,706	2,149,484		2,148,656		2,148,642		2,149,241		2,147,500		2,149,470	
2007	2,207,453	2,208,252		2,210,724		2,210,771		2,208,969		2,206,555		2,208,296	
2008	2,263,680	2,268,627		2,272,791		2,272,869		2,269,866		2,268,797		2,268,703	
2009	2,334,126	2,330,652		2,334,858		2,334,935		2,331,934		2,332,881		2,330,730	
2010	2,400,540	2,394,373		2,396,926		2,396,971		2,395,171		2,397,463		2,394,421	
2011	2,459,680	2,459,836		2,458,993		2,458,976		2,459,578		2,461,198		2,459,820	
2012	2,522,855	2,527,089		2,521,060		2,520,950		2,525,155		2,522,741		2,526,971	
2013	2,593,827	2,596,180	0.09	2,583,128	0.41	2,582,894	0.42	2,591,902	0.07	2,580,749	0.50	2,595,920	0.08
2014	2,672,423	2,667,161	0.20	2,645,195	1.02	2,644,806	1.03	2,659,818	0.47	2,633,876	1.44	2,666,715	0.21
2015	2,753,972	2,740,082	0.50	2,707,262	1.70	2,706,688	1.72	2,728,905	0.91	2,680,778	2.6	2,739,404	0.53
Avg.			0.20		1.04		1.06		0.49		1.53		0.22

Table 4.18 Income per household

Trend	Equation
Exponential	$y = 7.3243360007E\text{-}39e^{4.9020756562E\text{-}02x}$
Linear	$y = 2.0829350426E+03x - 4.1411688564E+0$
Logarithmic	$y = 4.1833814345E+06\ln(x) - 3.1772807033E+07$
Polynomial Order 2	$y = 9.4594163441E+01x^2 - 3.7790181950E+05x + 3.7745802427E+08$
Polynomial Order 3	$y = -5.7652590665E+01x^3 + 3.4748027922E+05x^2 - 6.9810151696E+08x + 4.6750270429E+11$
Power	$y = 0.0000000000E+00x^{9.8455556843E+01}$

		Exponential		Linear		Logarithmic		Polynomial 2		Polynomial 3		Power	
Year	Income per household	Estimated Baht/month	MAPE (%)	Estimated Baht/month	MAPE (%)	Estimated Baht/month	MAPE (%)	Estimated Baht/month	MAPE (%)	Estimated Baht/month	MAPE (%)	Estimated Baht/month	MAPE (%)
2005	36,339.05	35,489.81		35,115.90		35,112.60		35,778.06		36,401.51			
2006	36,658.00	37,272.89		37,198.84		37,198.56		37,293.43		36,879.15			
2007	39,020.00	39,145.56		39,281.77		39,283.47		38,997.99		38,410.77			
2008	40,680.82	41,112.32		41,364.71		41,367.35		40,891.73		40,650.45			
2009	42,380.00	43,177.89		43,447.64		43,450.19		42,974.67		43,252.27			
2010	45,827.02	45,347.24		45,530.58		45,531.99		45,246.79		45,870.33			
2011	48,951.00	47,625.58		47,613.51		47,612.76		47,708.10		48,158.70			
2012	49,393.52	50,018.39		49,696.45		49,692.49		50,358.60		49,771.48			
2013	49,190.80	52,531.42	6.79	51,779.38	5.26	51,771.19	5.25	53,198.29	8.15	50,362.73	2.38		
2014	48,482.25	55,170.72	13.80	53,862.32	11.10	53,848.85	11.07	56,227.17	15.97	49,586.56	2.28		
2015	45,571.70	57,942.61	27.15	55,945.25	22.76	55,925.49	22.72	59,445.23	30.44	47,097.03	3.35		
Avg.			15.91		13.04		13.01		18.19		2.67		

Table 4.19 Number of tourists

Trend	Equation
Exponential	$y = 2.2096863836E\text{-}25e^{3.6946527912E\text{-}02x}$
Linear	$y = 1.5013559286E+06x - 2.9778128915E+09$
Logarithmic	$y = 3.0142107170E+09\ln(x) - 2.2885842450E+10$
Polynomial Order 2	$y = 6.2993403571E+05x^2 - 2.5289436655E+09x + 2.5382182928E+12$
Polynomial Order 3	$y = 1.2071418182E+05x^3 - 7.2673336851E+08x^2 + 1.4583791329E+12x - 9.7553824383E+14$
Power	$y = 3.8253819091E\text{-}238x^{7.4174664820E+01}$

		Exponential		Linear		Logarithmic		Polynomial 2		Polynomial 3		Power	
Year	Number of tourists	Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)	Estimated Capita	MAPE (%)
2005	34,838,704	32,802,383		32,405,745		32,405,325		36,815,378		35,575,833		32,802,120	
2006	36,172,138	34,036,984		33,907,101		33,908,298		34,537,129		35,470,470		34,038,041	
2007	35,953,546	35,318,052		35,408,457		35,410,521		33,518,749		34,814,263		35,319,879	
2008	35,110,693	36,647,337		36,909,813		36,911,996		33,760,237		34,331,496		36,649,314	
2009	30,037,911	38,026,652		38,411,169		38,412,723		35,261,593		34,746,454		38,028,090	
2010	38,222,903	39,457,882		39,912,525		39,912,703		38,022,817		36,783,423		39,458,011	
2011	43,763,002	40,942,979		41,413,881		41,411,938		42,043,909		41,166,688		40,940,948	
2012	47,185,031	42,483,972		42,915,237		42,910,427		47,324,869		48,620,533		42,478,839	
2013	50,568,902	44,082,964	12.83	44,416,593	12.17	44,408,171	12.18	53,865,697	6.52	59,869,245	18.39	44,073,691	12.84
2014	50,972,772	45,742,138	10.26	45,917,949	9.92	45,905,172	9.94	61,666,394	20.98	75,637,107	48.39	45,727,584	10.29
2015	56,515,597	47,463,759	16.02	47,419,305	16.10	47,401,430	16.13	70,726,958	25.15	96,648,406	71.01	47,442,672	16.05
Avg.			13.03		12.73		12.75		17.55		45.93		13.06

Table 4.20 Variables Time-series based on small value of MAPE

Year	Total number of residents		Native people aged 15-59 years		Total people aged 15-59 years		Number of households		Income per household (Baht/month)		Number of tourists	
	Actual	Estimated	Actual	Estimated	Actual	Estimated	Actual	Estimated	Actual	Estimated	Actual	Estimated
2005	6,796,000	6,552,215	3,819,582	3,824,422	4,956,628	4,962,397	2,091,558	2,092,281	36,339.05	36,401.51	34,838,704	32,405,745
2006	6,825,956	6,864,557	3,843,438	3,839,144	4,973,436	4,910,123	2,150,706	2,149,484	36,658.00	36,879.15	36,172,138	33,907,101
2007	6,905,699	7,176,743	3,853,428	3,848,622	5,042,879	5,112,717	2,207,453	2,208,252	39,020.00	38,410.77	35,953,546	35,408,457
2008	7,384,770	7,488,773	3,853,994	3,852,857	5,527,881	5,481,116	2,263,680	2,268,627	40,680.82	40,650.45	35,110,693	36,909,813
2009	7,756,599	7,800,649	3,846,880	3,851,847	5,900,884	5,926,256	2,334,126	2,330,652	42,380.00	43,252.27	30,037,911	38,411,169
2010	8,305,218	8,112,369	3,842,849	3,845,594	6,446,673	6,359,075	2,400,540	2,394,373	45,827.02	45,870.33	38,222,903	39,912,525
2011	8,466,091	8,423,934	3,834,031	3,834,097	6,625,279	6,690,509	2,459,680	2,459,836	48,951.00	48,158.70	43,763,002	41,413,881
2012	8,714,250	8,735,344	3,819,740	3,817,357	6,860,430	6,831,495	2,522,855	2,527,089	49,393.52	49,771.48	47,185,031	42,915,237
2013	8,831,681	9,046,599	3,795,076	3,795,372	6,940,505	6,692,970	2,593,827	2,596,180	49,190.80	50,362.73	50,568,902	44,416,593
2014	8,563,548	9,357,700	3,771,113	3,768,144	6,642,377	6,185,870	2,672,423	2,667,161	48,482.25	49,586.56	50,972,772	45,917,949
2015	8,625,230	9,668,647	3,750,817	3,735,672	6,679,638	5,221,133	2,753,972	2,740,082	45,571.70	47,097.03	56,515,597	47,419,305
2016		9,979,439		3,697,956		3,709,695		2,814,997		42,548.25		48,920,661
2017		10,290,077		3,654,997		1,562,492		2,891,960		35,594.28		50,422,016
2018		10,600,561		3,606,793		-1,309,537		2,971,027		25,889.23		51,923,372
2019		10,910,891		3,553,346		-4,995,457		3,052,256		13,087.16		53,424,728
2020		11,221,068		3,494,655		-9,584,331		3,135,706		-3157.83		54,926,084

Since it is not possible for these variables to be negative numbers, we must select the second equation which gives the small MAPE.

Table 4.21 Final Predicted Variables

Year	Total number of residents		Native people aged 15-59 years		Total people aged 15-59 years		Number of households		Income per household (Baht/month)		Number of tourists	
	Actual	Estimated	Actual	Estimated	Actual	Estimated	Actual	Estimated	Actual	Estimated	Actual	Estimated
2005	6,796,000	6,552,215	3,819,582	3,824,422	4,956,628	4,700,849	2,091,558	2,092,281	36,339.05	35,112.60	34,838,704	32,405,745
2006	6,825,956	6,864,557	3,843,438	3,839,144	4,973,436	5,012,849	2,150,706	2,149,484	36,658.00	37,198.56	36,172,138	33,907,101
2007	6,905,699	7,176,743	3,853,428	3,848,622	5,042,879	5,324,693	2,207,453	2,208,252	39,020.00	39,283.47	35,953,546	35,408,457
2008	7,384,770	7,488,773	3,853,994	3,852,857	5,527,881	5,636,382	2,263,680	2,268,627	40,680.82	41,367.35	35,110,693	36,909,813
2009	7,756,599	7,800,649	3,846,880	3,851,847	5,900,884	5,947,916	2,334,126	2,330,652	42,380.00	43,450.19	30,037,911	38,411,169
2010	8,305,218	8,112,369	3,842,849	3,845,594	6,446,673	6,259,295	2,400,540	2,394,373	45,827.02	45,531.99	38,222,903	39,912,525
2011	8,466,091	8,423,934	3,834,031	3,834,097	6,625,279	6,570,519	2,459,680	2,459,836	48,951.00	47,612.76	43,763,002	41,413,881
2012	8,714,250	8,735,344	3,819,740	3,817,357	6,860,430	6,881,588	2,522,855	2,527,089	49,393.52	49,692.49	47,185,031	42,915,237
2013	8,831,681	9,046,599	3,795,076	3,795,372	6,940,505	7,192,502	2,593,827	2,596,180	49,190.80	51,771.19	50,568,902	44,416,593
2014	8,563,548	9,357,700	3,771,113	3,768,144	6,642,377	7,503,262	2,672,423	2,667,161	48,482.25	53,848.85	50,972,772	45,917,949
2015	8,625,230	9,668,647	3,750,817	3,735,672	6,679,638	7,813,868	2,753,972	2,740,082	45,571.70	55,925.49	56,515,597	47,419,305
2016		9,979,439		3,697,956		8,124,320		2,814,997		58,001.09		48,920,661
2017		10,290,077		3,654,997		8,434,618		2,891,960		60,075.67		50,422,016
2018		10,600,561		3,606,793		8,744,762		2,971,027		62,149.22		51,923,372
2019		10,910,891		3,553,346		9,054,753		3,052,256		64,221.74		53,424,728
2020		11,221,068		3,494,655		9,364,589		3,135,706		66,293.23		54,926,084

Table 4.22 Trend of MSW generation

Year	Total number of residents	Native people aged 15-59 years	Total people aged 15-59 years	Number of households	Income per household (Baht/month)	Number of tourists	Total MSW (tons/day)	
							MRA	ANN
2005	6,796,000	3,819,582	4,956,628	2,091,558	36,339.05	34,838,704	8,439	8,291.13
2006	6,825,956	3,843,438	4,973,436	2,150,706	36,658.00	36,172,138	8,615.3	8,403.08
2007	6,905,699	3,853,428	5,042,879	2,207,453	39,020.00	35,953,546	8,614.5	8,719.45
2008	7,384,770	3,853,994	5,527,881	2,263,680	40,680.82	35,110,693	8,643.6	8,771.66
2009	7,756,599	3,846,880	5,900,884	2,334,126	42,380.00	30,037,911	8,123.9	8,772.37
2010	8,305,218	3,842,849	6,446,673	2,400,540	45,827.02	38,222,903	9,288.1	8,774.41
2011	8,466,091	3,834,031	6,625,279	2,459,680	48,951.00	43,763,002	10,026.5	9,236.93
2012	8,714,250	3,819,740	6,860,430	2,522,855	49,393.52	47,185,031	10,522.5	10,967.54
2013	8,831,681	3,795,076	6,940,505	2,593,827	49,190.80	50,568,902	10,978.6	11,535.15
2014	8,563,548	3,771,113	6,642,377	2,672,423	48,482.25	50,972,772	10,967.6	10,799.93
2015	8,625,230	3,750,817	6,679,638	2,753,972	45,571.70	56,515,597	11,678.4	11,499.52
2016	9,979,439	3,697,956	8,124,320	2,814,997	58,001.09	48,920,661	11,119.5	11,708.37
2017	10,290,077	3,654,997	8,434,618	2,891,960	60,075.67	50,422,016	11,401.1	11,714.25
2018	10,600,561	3,606,793	8,744,762	2,971,027	62,149.22	51,923,372	11,683.5	11,715.39
2019	10,910,891	3,553,346	9,054,753	3,052,256	64,221.74	53,424,728	11,966.6	11,715.64
2020	11,221,068	3,494,655	9,364,589	3,135,706	66,293.23	54,926,084	12,250.6	11,715.71

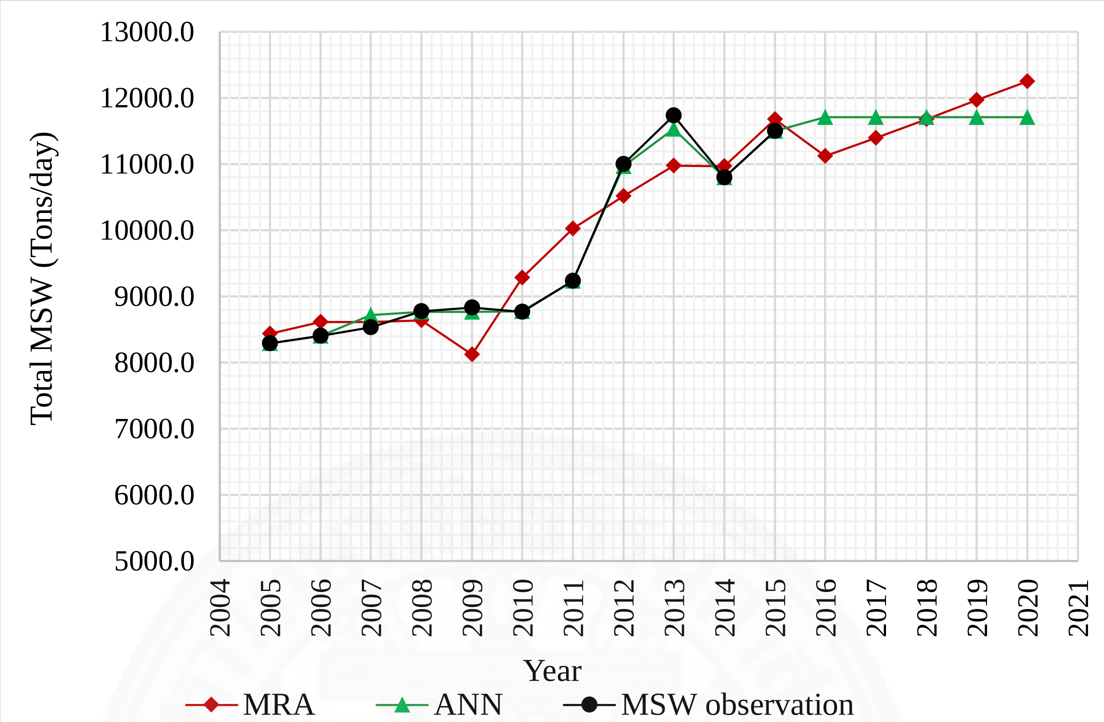


Figure 4.9 Bangkok MSW generation forecast

4.5 Conclusion

An appropriate forecasting model of MSW generation is an important tool in MSW management systems and planning. Total number of residents, native people aged between 15 and 59 years, total people aged between 15 and 59 years, number of households, income per household, and number of tourists are considered as the influential variables since they exist with high coefficient in PC1 which is the significant term in the regression equation. The ANN, which is a nonlinear model, gives a highly accurate result between 2005 and 2015 when compared with linear regression analysis (see Table 4.13 and Figure 4.8). Furthermore, two neurons in the hidden layer of the ANN architecture are enough to give a better result of MSW prediction. The ANN model is possibly stored for further analysis under the same condition for high percentage of accuracy. In case higher accuracy of the result is needed, increasing the number of neurons in the hidden layer is recommended. This study demonstrates the influential variables affecting the amount of MSW generation and offers an appropriate model to forecast MSW in Bangkok. The developed model can be used for further studies on the investigation of sustainable solutions for MSW management, and suitable technologies for Bangkok MSW disposal and power generation. However, in this study there are many points that should be improved. Those factors will be discussed in recommendation part.

After knowing the nature of solid waste generation, such as its amount and characteristics/composition which are primary information for management activity, planning, operation and optimization of waste management systems will be mentioned in the next step.

Chapter 5
Sustainable MSW management system

The aim of this chapter is to evaluate the most appropriate MSW management system for sustainable development in Bangkok. To achieve this objective, the chapter is structured as follows. Section 5.1 introduces the MSW management problem. Section 5.2 reviews the literature, including an overview of supporting tools for decision making, as well as the existing MSW management system in Thailand. Section 5.3 provides the methodology for conducting this part and section 5.4 implements the selected tool. The subsequent sections are results and discussion, followed by the conclusion of this chapter in sections 5.5 and 5.6, respectively.

5.1 Introduction

The tremendous increase in population, uncontrolled urbanization and industrialization have resulted in a lack of appropriate infrastructure and social service in several cities, such as inadequate energy supply and improper MSW management service, especially in developing and underdeveloped countries. Inappropriate MSW management is exacerbated by inadequate financial and human resources in the collection, transportation, processing and final disposal of waste, and it definitely causes air pollution, disease, soil and water contamination [34, 35]. Bangkok is also facing this kind of problem as already mentioned in section 1.2. This part is conducted to provide a methodology to help Bangkok in selecting the suitable and sustainable MSW management system.

5.2 Literature review

In every region, policymakers or decision makers often set and plan a strategy of local and regional goals. Selection of treatment option for MSW plays an important role in achieving the sustainable management system. In order to obtain a suitable MSW management system, it is important that the selected method should be relevant to the goals which are influenced by many criteria, including environmental protection, human health, economic development, and fulfillment of regulatory and social requisites. In the following sections, some decision-making tools and MSW treatment methods are presented to find out which tool and technology is best suited for Bangkok's MSW management plan.

5.2.1 An overview of supporting tools for decision making

A decision-making tool is a supporting tool which plays an important role in the process of deciding. Numerous decision-making tools have been developed, and they can be classified into three group for different situations and purposes: cost-benefit analysis (CBA), life cycle assessment (LCA), multi-criteria decision analysis (MCDA), etc.

Cost-benefit analysis (CBA), sometimes called benefit-cost analysis (BCA), is one kind of decision-making tool which is used by the business analyst or organization to appraise the desirability of a given policy. It is a systematic approach which is used to determine options that provide the best approach to achieve benefit while preserving saving [36]. There are two main purposes of using this method. The first is to determine if it is a sound investment (justification/feasibility) or to verify whether its benefits outweigh the cost, and by how much. The second is to provide a basis for comparing projects that involved comparing the total expected cost of each option against its total expected benefits [37]. This tool is popularly used since the process is easy to understand, and the cost-benefit is easy to see. However, to effectively use this tool the accurate estimation of cost and benefit is needed. For government decisions, CBA needs to be used because it is too costly to hold an election every time a public decision needs to be made. However, although the use of CBA is perfect in terms of economic efficiency, the social welfare is not guaranteed.

Life cycle assessment (LCA) is a compilation and evaluation of the inputs and outputs, and the potential environmental impacts of a product system throughout its life cycle from cradle to grave [38]. To apply the LCA method in a MSW management system, all main inputs are required to be considered (see Figure 5.1). There are four main stages in LCA, including 1) goal and scope definition: define the purpose of the LCA study, assess the product or system, and consider the environmental emissions and impacts; 2) life cycle inventory (LCI): determine all inputs and outputs flows of mass and energy for each process in the system; 3) life cycle impact assessment (LCIA): characterize the environmental impacts related to the emissions and mass flows determined in the LCI; and 4) interpretation and improvement: analyze the results of the LCA study and make sure that each of the stages is consistent with one other, as well as identify potential areas for improvement in the system.

When using LCA, inventory parameters in the 2nd stage are the most critical issue, and similar data across unit operations are required for meaningful comparisons.

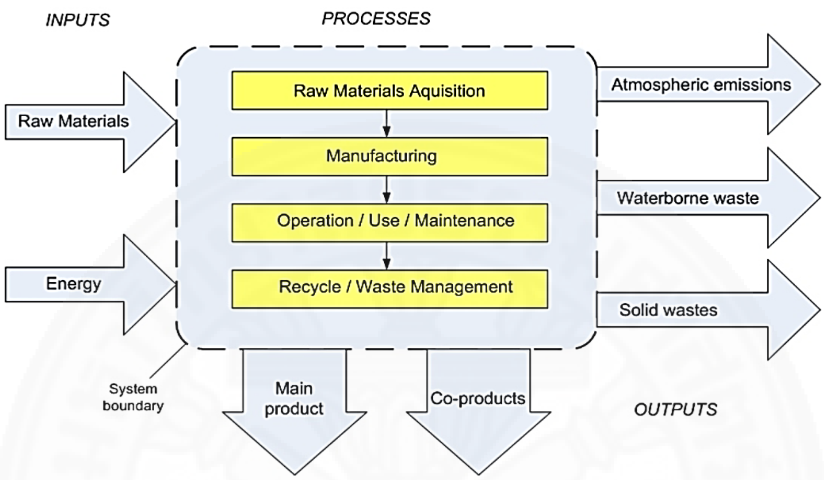


Figure 5.1 The main stages and typical inflows and outflows considered in lifecycle assessment

Multi-criteria decision analysis (MCDA) is a method employed for judging a suitable solution or option due to its particular advantages, for example assisting stakeholders in evaluating conflicting criteria, communicating different opinions, prioritizing the options, and conducting the applicable decisions [39]. The critical point of implementing this framework is the selection of stakeholder groups and the specific criteria associated with the decision problem. Comparing the two methods, MCDA is the most flexible as its approach is designed to use with one or a group of decision makers and problems that involve more than two criteria [40]; moreover, it has been employed extensively in complex MSW management. The analytic hierarchy process (AHP), a member of the MCDA family, is highlighted as a tool suitable for intricate decision making and merging of qualitative and quantitative data. Furthermore, it is the most prevalent method for combining with other approaches, i.e. AHP is combined with a graphical information system (GIS) to study about site selection, and this combination is widely used in MSW management [41].

As already described in the individual framework, each method is used based on the purpose. However, these three methods can be combined and developed to solve the problem associated with the various aspects. Based on the review of these three decision-making tools, AHP has the highest potential to apply in the decision-making process. Thus, in this study, AHP is utilized to evaluate the sustainable MSW management system for Bangkok.

5.2.2 MSW management systems

An MSW management system is a social service responsibility of the local administration organization. MSW management systems generally include generation, storage, collection, transfer and transportation, processing and disposal of MSW [42]. In this study, the author mainly focuses on processing and final disposal of MSW, thus Thailand's MSW management system can be divided into two main options, including general MSW management and Waste-to-Energy technology, as described below.

5.2.2.1 General MSW management

General MSW management involves recycling and disposal of MSW without energy recovery. It consists of 3 methods, including recycling, composting and landfill. These methods are mostly used in the countryside since they are simple and generally require a small budget.

Recycling (Re) refers to the process of converting waste material into new materials and new objects. It can be considered as conventional waste disposal which saves material and helps lower greenhouse gas emission since it reduces the consumption of fresh raw material, thereby reducing energy usage [43]. The recyclable material consists of paper, plastic, glass, and metals. Mechanical treatment (MT), a primary and important process in the sorting of MSW, removes or separates recyclable material from the mixed waste stream. These two processes are always combined with each other and can be called MT-Re.

Composting (CP) is a process of decomposition of organic matter by microorganisms under controlled conditions; thus, this method is excellent for MSW which contains high organic substance. Composting of MSW requires the separation of at least 90% of the organic material for high efficiency which is why it is usually combined with mechanical biological treatment (MBT). An MBT system is designed to process mixed household waste as well as commercial and institutional waste and is also defined as a recycling system. This combined process (MBT-CP) has been successfully used for treating organic waste in Bangkok. The product from composting should be paid much attention in terms of its marketing and quality.

Landfill (LF) is a place where waste is disposed of by burial. The landfill is the big source of methane gas which is reported as having the highest potential of greenhouse gas (GHG) emission. Landfill causes many environmental problems, such as contamination of groundwater or soil, dust, and odor, as well as reducing local property values. In developed countries, the landfill is replaced by a sanitary landfill which has pollution control facilities such as leachate collection and treatment and gas collection are installed to protect public health. Conversely, the landfill is still commonly used to dispose of waste in some developing countries due to the cost efficiency, simplicity and the requirement of less manpower.

5.2.2.2 Waste-to-Energy technology

Waste-to-Energy (WTE) technology is not only the process of disposing of waste but also of providing energy as a byproduct, and it can control the GHG emission by itself as well [44]. WTE can be divided into three types: physical conversion, thermal conversion, and biochemical conversion. Energy from waste is suggested to be account in renewable energy generators for the smart grid, hence it presents the advantage of more steady and predictable generation pattern compared to generation profiles of other renewable energy sources, such as solar or wind energy.

(1) Physical conversion

Physical conversion is the mechanical process to transform waste into a fuel source for further processing in the form of pallets, wood chips, wood briquettes, etc. MSW converted pallets are called Refuse-derived fuel (RDF) [44].

Refuse Derived Fuel (RDF) or solid recovered fuel (SRF) is a kind of fuel pellets produced from fresh MSW or excavated landfill waste. RDF of fresh MSW contains a high content of paper and plastic waste, has a calorific value of more than 15

MJ/kg at moisture content less than 25%, which is lower than that of RDF from excavated landfill waste (29.5MJ/kg) [45]. MSW used in RDF generally consists of cardboard, paper, various plastic stream, glass, metallic and non-metallic material, etc. [46]. More detail related to RDF can be found in Table 5.2. In Thailand, RDF pallets are traded and co-burnt in power generation or in some process where heat is required, such as co-combustion in coal-fired boilers, co-incineration in cement kilns, and co-gasification with coal or biomass [47]. RDF production plants have appeared in many places in Thailand, namely TPI Polene power (RDF 5,000 tons/day) and SCI Ecoservices/ SCG (24,000tons/year) in Saraburi; and SCI Ecoservices/ SCG (20,000 tons/year) in Phitsanulok, Chachoengsao, Klang, Rayong, Chanthaburi, Nakorn Ratchasima, etc.

(2) Thermal conversion

Thermal conversion includes incineration, gasification, and pyrolysis. Electricity generated from these technologies received the adder from Thai financial incentive or feed-in-tariff at the rate of USD 0.105 per kWh (1USD = 33 Baht) in 2007. This means that Thai government supports the use of MSW as a renewable energy source.

Incineration (IC) is a full oxidative combustion which involves the burning of combustible materials contained in waste [47]. The incinerator is designed for specific waste characteristics, including humidity and varied calorific values. Combustion must be well controlled to prevent pollution and environmental interference such as toxic gas, smut, smell, etc. The residue from this process is finally sent to landfills or combined with construction material for further use, while residue containing metal is recycled. Further details of this technology are shown in Figure 5.2 and Table 5.2. There are four incineration sites in Thailand, namely Phuket province, Samui Island, Lamphun province, and Nong-khaem transfer station with an installed capacity of 250t/d, 75t/d, 10t/d, and 300-500 t/d, respectively.

Gasification (GF) is a partial oxidative combustion of solid or liquid carbon-based material in MSW to form a combustible gaseous or syngas, including carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2), methane (CH_4), water (H_2O) and a trace of hydrocarbons. Gasification is an interesting alternative technology in the thermal treatment of solid waste as it releases less emission pollution. Gasification problem occurs due to the heterogeneity of waste which is used as feedstock. A possible solution is the use of refuse-derived fuel (RDF) with homogeneous and controlled characteristics [48, 49]. This technology is used in various places in Thailand, such as Hatyai (ash melting gasification, 7MW, 250t/d), Kampaengpetch (RDF pallet, 0.2 MW, 3-5t/d), and Pichit (0.24 MW, 4-5t/d) [50].

Pyrolysis (PY) is a thermal waste treatment which takes place in an oxygen-free environment. There are three types of pyrolysis such as conventional pyrolysis (550-900 K), fast pyrolysis (850-1250 K), and flash pyrolysis (1050-1300 K) [51]. The difference in operating temperature results in final products that can be classified into three phases, such as solid phase (ash and coke), liquid phase (pyrolysis oil and water), and gas phase (hydrogen, carbon monoxide, H_2O, nitrogen, and hydrocarbons) [49]. The pyrolysis process can recover around 80% of the energy stored in carbonaceous waste to liquid fuel and char. Pyrolysis liquid oil can be used in energy application after purification and blended with gasoline fuel [46, 47]. In Ubon Ratchathani, this technology is operated with a capacity of 6t/d of plastic waste and generates 4500L/d of fuel oil.

(3) Biochemical Conversion

Biochemical conversion is the degradation process of degradable substances in waste to produce biogas that can be consumed as an energy source. Biochemical conversion can be divided into 2 methods: anaerobic digestion, and landfill gas. In Thailand, electricity generated from both technologies has received the adder of USD 0.075 per kWh since 2007 (1 USD = 33Baht).

Anaerobic Digestion (AD) occurs when micro-organisms break down the biodegradable component in waste to produce biogas and soil improver in absence of oxygen. The produced biogas contains methane (CH_4), carbon dioxide (CO_2), and other elements such as hydrocarbon sulfide, ammonia, etc. All these gases can be directly used to burn in a boiler or used as natural gas in power generation [44]. In an AD plant, one ton of organic fraction can be converted to 100-150 kWh of electricity, in which 0.2 kg CO_2 emission are generated per 1kWh. A soil improver, a byproduct of anaerobic digester, is rich in nutrients and is used in agricultural fields. In Thailand, the anaerobic digesters have increased from 15 plants in 1995 to 1829 plants in 2006, and it is utilized for the purpose of producing biogas as a source of fuel for power generation and the sludge for fertilizer[45, 47]. More details related to this technology can be found in [50].

Landfill Gas (LFG) production of methane in a sanitary landfill is like anaerobic digestion, but there is no operational control. The process naturally occurs by chemical reaction of MSW composition. Landfill gas (LFG) consists of 50-60% of methane, 40-50% of carbon dioxide and a trace of other gases [47]. LFG heating value is approximately 45MJ/m^3 which is higher than that of the AD (15-25 MJ/m^3). The Thai LFG collection system functions at low efficiency as it can capture around 50-70% of produced LFG with the yield of 110 m^3/ton of MSW. More details of this technology are presented in [45, 50]. There are no more LFG projects planned in Thailand due to the explosion of several landfill gas sites in 2014. However, some existing landfill gas sites are still operating, such as Panomsarakham landfill, Chareonsompong (180t/d, 2.2MW), Kampangsaen landfill, Bangkok Green Power (2200t/d, 8.15 MW), and Zenith Green Energy (3300t/d, 8.52 MW).

Table 5.1 Selection of MSW management system based on waste type

	Food	Paper	Wood	Garden	Plastic	Cardboard	Textile	Leather
Recycling	×	√	×	×	√	√	×	×
Composting	√	×	×	√	×	×	×	×
Landfill	√	√	√	√	√	√	√	√
RDF	×	√	√	×	√	√	√	√
Incineration	×	√	√	√	√	√	√	√
Gasification	×	√	√	×	√	√	√	√
Pyrolysis	×	√	√	×	√	√	×	×
Anaerobic Digestion	√	√	×	√	×	×	×	×
Landfill gas	√	√	√	√	√	√	√	√

Note: Glass and metal are considered as recyclable material which should be separated at source [46].

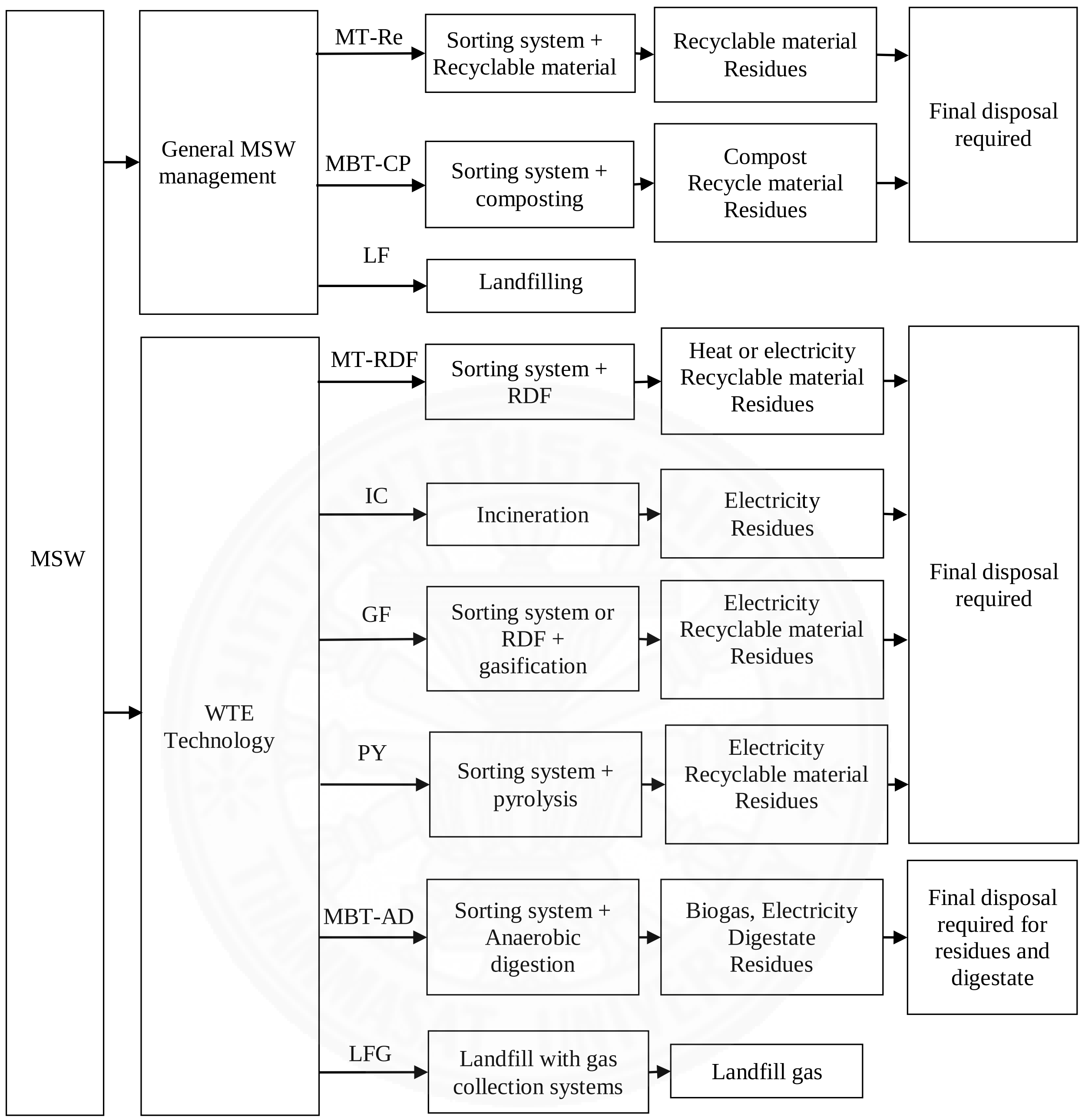


Figure 5.2 General MSW management and WTE treatment

Table 5.2 Advantages and disadvantages of WTE technologies

Technology	Advantages	Disadvantages
Refuse Derived Fuel	• High calorific value, more homogeneous physical and chemical composition, • Lower pollutant emissions, • Can apply in incineration, pyrolysis, and gasification, which gives lower ash content • Reduced excess air requirement during combustion • Easier storage, handling, and transportation • Small disposal facility and small area is needed, which can be located near waste resource • Clean technology	• High net cost per ton • Final disposal of ash is needed • Air pollution occurs in power plant where RDF is used
Incineration	• Volume reduction up to 90% • Mass reduction up to 70% • Quick treatment • Suitable for high calorific value waste • The residue (bottom ash) can be used in construction work • Small site area required • Can be in city, reducing the cost of waste transportation • Can treat large amount of waste • Direct heating or power generation • Relatively noiseless and odorless • Hygienic	• High investment, capital and O&M cost • Social opposition • Solid waste (slag) production • Least suitable for high moisture/ low calorific value and chlorinated waste • Concern for toxic metal, ash and other chemical production (dioxins) • Need skilled person for O&M • Low efficiency for small plant
Gasification	• Can be designed for small-medium scale • Lower gas volume and less expensive gas cleaning equipment than that of incineration	• Syngas is toxic and potentially explosive, the reliable control equipment is required • Feedstock material must be finely granulated, pretreatment is needed for MSW
Pyrolysis	• Recovers up to 80% energy from waste • Reduces site area requirement	• Corrosion of metal tube • High O&M cost

	• Produces fuel gas/oil for various purposes • Separates liquid products in vapor phase • Reduces MSW volume up to 50-90% • Controls superior pollution as compared to incineration [46, 51]	• High capital and operating cost due to high energy requirement (Excessive moisture) • Cleaning of byproducts • Low yield of liquid products • High viscosity of pyrolysis oil can cause problem in burning and transportation
Anaerobic digestion	• Compact design needs less area • Can be done in small scale • Enclosed system able to control GHG emission • No power requirement for sieving and turning of waste pile • Energy recovery with high-grade soil conditioner products	• Unsuitable for waste containing less organic matter • Waste segregation is required for improving the digestion efficiency
Landfill gas	• Low cost and easy to implement • Costs incurred incrementally as landfill expands • Skilled person is not required • Can transform marshy land to useful areas • Can return the nutrients back to the soil • Gas produced can be used for power generation or thermal application	• The product yield is only 30-40% of total gas in landfill • Large area required • Can result in groundwater, air and soil pollution • Site is located far away from city, increasing the cost of waste transportation • The main cost may be up to pipeline quality and leachate treatment • Unplanned explosion because of methane gas build up

5.3 Methodology

In this study, AHP is selected to implement as a decision-making tool for evaluating the sustainable MSW management system for Bangkok. Furthermore, sensitivity analysis is performed to find out whether there is an uncertainty of AHP results. The following sections provide the details of methods used in this study.

5.3.1 Analytic Hierarchy Process (AHP)

The analytic hierarchy process (AHP), one type of multi-criteria decision analysis (MCDA), was pioneered by Saaty in the 1970s. The AHP considers a set of evaluation criteria and a set of alternative options among which the best decision is to be made. It is a theory of measurement which is taken from actual scale or a fundamental scale that reflects the relative strength of one over another. The best option is not generally the one which optimizes each single criteria, rather the one which achieves the most suitable trade-off among the different criteria [52]. The AHP calculation can be performed using Microsoft Excel; thus, non-experts in programming are also able to understand the way of its implementation.

The AHP process consists of 4 main steps and it can be applied by following the flowchart in Figure 5.3 [53].

1) Decomposition: In this step, the goal or decision problem, relative criteria and sub-criteria, as well as decision alternatives are defined. The AHP hierarchical structure can be designed following the standard form as shown in Figure 5.4. The 1st level represents the goal or the decision problem. The 2nd and 3rd levels present the inter-related elements. The 4th level called alternatives are then implemented as options of decision making.

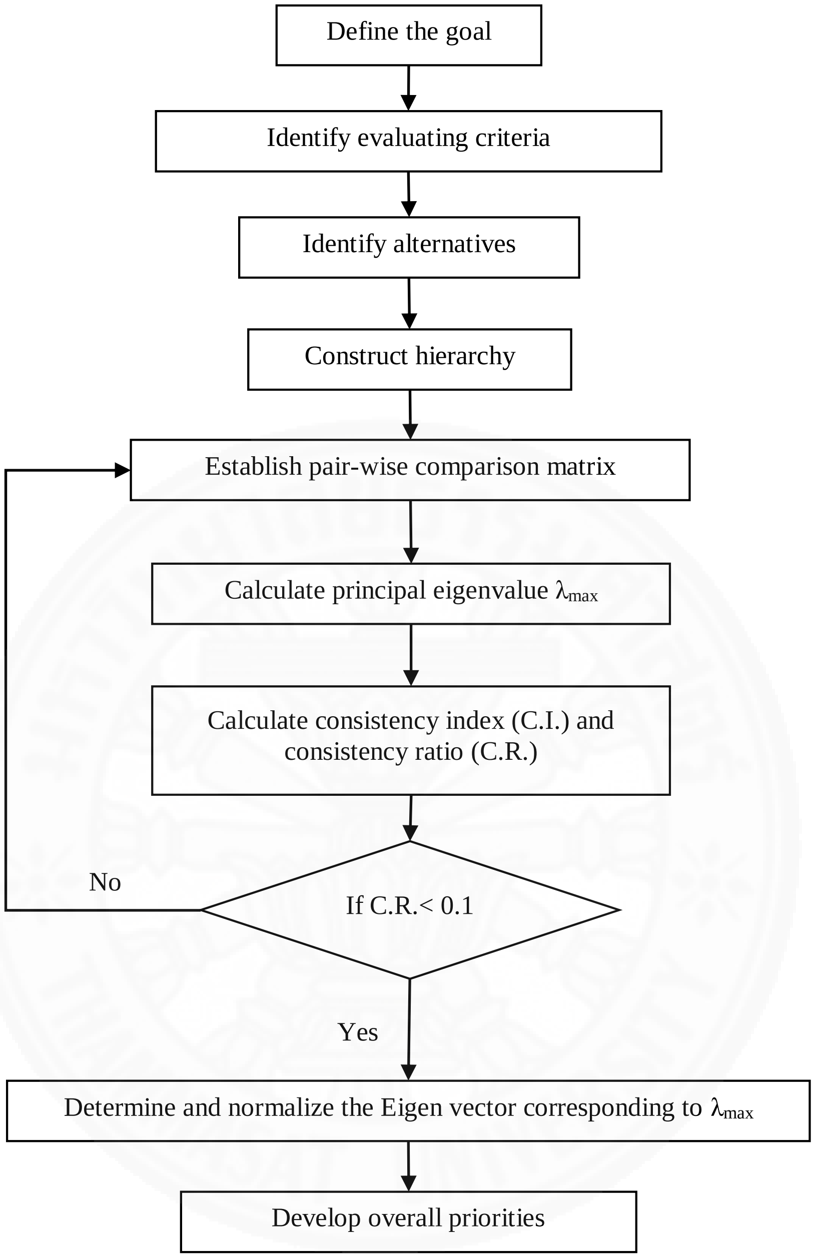


Figure 5.3 Process of AHP

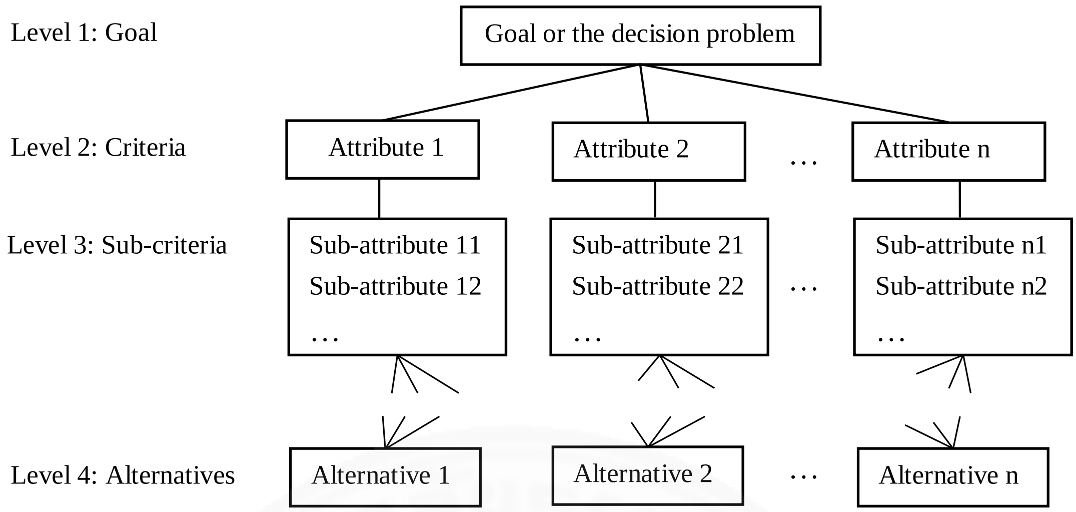


Figure 5.4 The standard form of AHP hierarchy

2) Comparative judgment: Once the hierarchy of the problem is defined, the series of pair-wise comparisons are performed to determine the relative weight of each main criterion, sub-criterion, and alternative with respect to the property in the upper level. The comparison may be taken from actual measurements (such as price, weight, etc.) or relative measurement which is given by stakeholder preferences and feelings. A 9-point weighting scale in Table 5.3 is used for ranking the subjective opinion. The pair-wise comparison matrix can be expressed as equation (5.1). The number of comparisons in each matrix equals $\frac{n(n-1)}{2}$ because it is reciprocal and the diagonal elements are equal to unity, where n is the number of main criteria, sub-criteria or alternatives [54].

$$A=\left[a_{ij}\right]_{n\times n}=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{5.1}$$

where $a_{ij}=w_i/w_j$ is relative importance between indicator i and indicator j.

Table 5.3 Pair-wise comparison scale

Numerical value	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment strongly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored, and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed

3) Consistency Evaluation: Once the comparison judgments have been done, the comparison matrix is used as input to determine the consistency of the judgment matrix by using equations (5.2), (5.3) and (5.4). The consistency ratio value (CR) is acceptable if it does not exceed 0.10 or 10% or else the judgment matrix is inconsistent. To obtain a consistent matrix, pair-wise comparison judgment should be reviewed and improved according to the situation [55].

Calculation of the relative weight

$$Aw = \lambda_{\max} w \tag{5.2}$$

where λ_{max} is the maximum eigenvalue of the judgment matrix *A*.

Calculation of the consistency index (CI)

$$CI = \frac{(\lambda_{\max} - n)}{(n-1)} \tag{5.3}$$

Calculation of the consistency ratio (CR)

$$CR = \frac{CI}{RI} \tag{5.4}$$

where *RI* is the random index value depending on the size of a comparison matrix as presented in Table 5.4.

Table 5.4 Random index (*RI*) value in AHP

n	2	3	4	5	6	7	8	9	10	11	12
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.52	1.54

4) Synthesis of priorities: This is the final step to determine the final weight of each alternative in the decision plans. The rating of a criterion is multiplied by the local weights of the sub-criteria to find the global weight of each sub-criterion. Then, the local weight of each alternative is multiplied by the global weight of each sub-criterion and aggregated to get the global weight of alternatives. By comparing the global weight, it is possible to develop the overall priorities and suggest the most relevant plan.

In the case of several stakeholders, the group preference needs aggregation. The geometric mean method (GMM) is used in the AHP approach to aggregate the group preferences. In the method, individual evaluations provided by the group members are employed to get the aggregated pair-wise matrix by using equation (5.5). The received aggregated pair-wise matrices are then computed through the same AHP process as mentioned above.

$$\text{Geometric mean} = \sqrt[n]{\prod_{k=1}^{n} a_{ij}^{k}} \tag{5.5}$$

where n is the number of members and a_{ij} is the preference of a member for element i over j.

5.3.2 Sensitivity Analysis (SA)

Different weight of criteria assigned by stakeholders group may provide the ranking of different MSW management systems. Thus, in some circumstances, the global weight of alternatives or ranking of alternatives may change. Sensitivity analysis (SA) is an important process in AHP that is used to determine how different input values impact the ranking of alternatives. SA is processed by slightly modifying input data to observe impacts on the results. There are three methods to apply SA: mathematical models, probabilistic simulations and numerical incremental analysis. In this study, the numerical incremental analysis is employed in the SA process. The numerical incremental analysis, also called one-at-a-time (OAT), works by incrementally changing the weight of one criterion at a time associated with calculating new solutions and showing the graph of how the weight/ranking of alternatives change.

5.4 Implementing AHP for MSW management

5.4.1 Identification of main criteria, sub-criteria and alternatives

The interviews conducted in August 2014 by Okumura, et al. [56], with the participation of 2 high-level officials of BMA, 2 experts from academia, and 2 officers from PCD are used in this study. The topic of those interview involved 4 main questions: 1) the status and challenge in MSW management in Bangkok, 2) waste policy in Bangkok, 3) the considered point when developing the policy (the respondent was requested to answer related to pillars of sustainability, environmental, social and economic aspects), and 4) how and why the BMA decided to establish an incinerator (Nong khaem waste transfer station). The details of those responses can be reported as follows:

Environmental aspect: According to BMA consideration and the Thai government, 3 key points were mentioned: amount of waste sent to landfills, GHG emission, and environmental impacts such as odor and water pollution. Reducing the amount of waste at landfills was considered as the most important issue because it related to the expenditure on waste disposal by hiring the private companies. GHG emission was also considered an important factor in selection of waste treatment technology since it was a part of Thai government concerns. Environmental impacts were also important, but less than the other two; however, it was difficult to estimate quantitatively.

Social aspect: In setting the policy or planning, the acceptance of the community was very important. BMA and PCD officers pointed out that the development of social media affected the selection of waste treatment options because people easily knew the effects of each technology from various sources, i.e. the explosion of many landfill gas sites in Thailand made people oppose the development of landfill sites in their neighboring area. Meanwhile, the generation of jobs was also an important factor, but at a lower level compared to community acceptance.

Economic aspect: Construction or capital cost was very important in the viewpoint of BMA officers because it related to the money that they must pay for waste disposal for the lifetime of that plant. However, the operation cost and revenue of the plant were not important for them as both factors were the responsibility of private companies.

According to the interview, waste to energy technology was considered as the very interesting waste treatment option in Bangkok as well as in Thailand. Furthermore, composting was also the interesting process due to Bangkok waste composition. In this study, 6 waste treatment options are selected to be considered: composting (CP), refuse-derived-fuel (RDF), incineration (IC), gasification (GF), anaerobic digestion (AD), and landfill gas (LFG). Based on the summary of the interview report, we can develop the hierarchy of AHP to evaluate the most suitable waste treatment option for Bangkok as shown in Figure 5.5. The characteristics of waste used in each treatment option can be presented in Table 5.5. The description of sub-criteria and highlight of each option are presented in Table 5.6 and Table 5.7. However, all interviewees did not select the importance of one aspect over another.

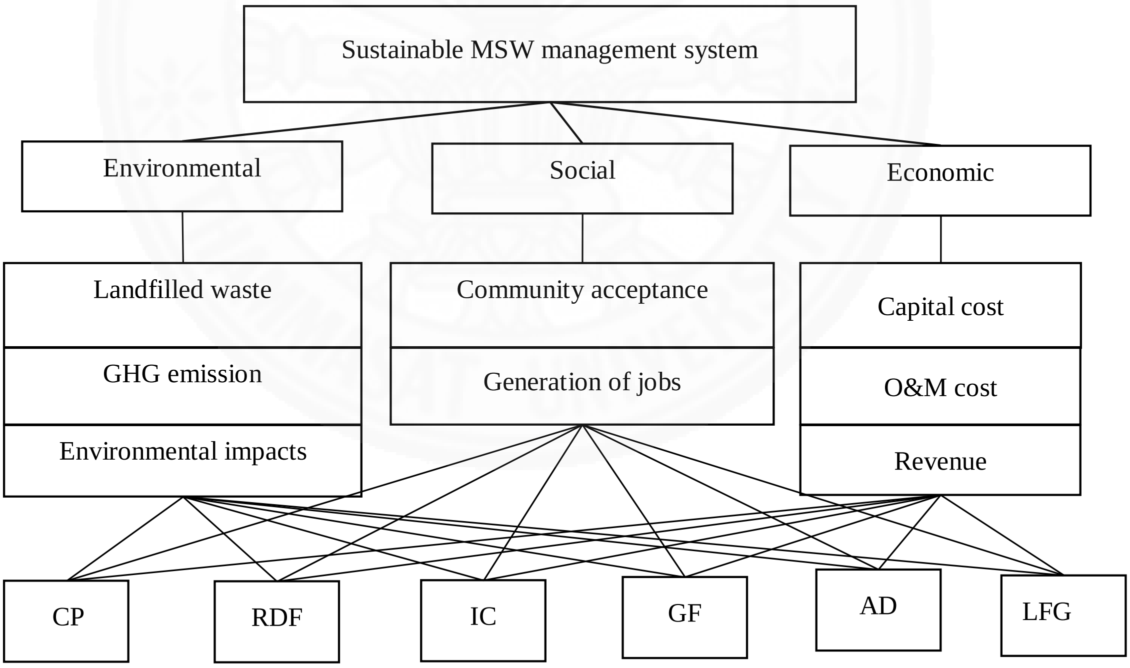


Figure 5.5 Development of hierarchical structure

Table 5.5 Waste treatment options and its waste type

Composition	Percentage (%-wt.)	CP	RDF	IC	GF	AD	LFG
Food waste	48.41	√	×	×	×	√	√
Wood and leaf waste	6.46	√	√	√	√	√	√
Paper	7.67	×	√	√	√	√	√
Plastic	24.83	×	√	√	√	×	√
Foam	1.55	×	√	√	√	×	√
Glass	2.56	×	×	×	×	×	√
Rubber	1.40	×	√	√	√	×	√
Clothes/textiles	3.99	×	√	√	√	×	√
Stone and ceramic	0.65	×	×	×	×	×	√
Metal	1.72	×	×	×	×	×	√
Bone and shell	0.76	×	×	×	×	×	√
Other	0.00	×	×	×	×	×	√
Total	100	54.87	45.9	45.9	45.9	62.54	100
Remaining (exclude BAU) 10% compost, 3% incinerator	87	44.87	42.9	42.9	42.9	52.54	87
Total MSW	11500t/d	5,160.05	4,933.5	4,933.5	4,933.5	6,042.1	10,005

Table 5.6 Description of main criteria and sub-criteria

Main criteria	Sub-criteria	Description
Environment (EV)	EV1: Landfilled waste	The waste remaining from the treatment process.
	EV2: GHG emission	Amount of equivalent CO_2 emission emitted to atmosphere.
	EV3: Environmental impact	Air pollution, wastewater released and other environmental impacts.
Social (SC)	SC1: Community acceptance	Possibly promoting acceptability of local community, the alternative does not present negative impacts to quality of life or human health.
	SC2: Generation of jobs	Number of jobs created for operating the system.
Economic (EC)	EC1: Capital cost	Investment cost of using technology (infrastructure, equipment, installation site).
	EC2: O&M cost	Expenditure during operation (electricity, maintenance, labor).
	EC3: Revenue	Amount of electricity generation multiply by its price or the money from selling the composted product (price in Thailand).

Table 5.7 Highlight of technologies evaluated

Technology	Environment	Social	Economic
CP	Amount of waste landfill is the collected amount minus BAU, then minus composted waste. GHG emission occurs during operation is calculated based on literature review 10.71kg eqCO_2/t waste and other impacts is the odor released from system which is considered as low impact.	The technology is well-known by local people as it is a classical method, so it is not difficult for them to accept its process. Operation requires 21 persons to process 500t waste [56].	The capital and operation cost of this system is adapted from another study, while the revenue is calculated by the amount of composted product multiplied by its price (63 USD/t compost) [57]. Composted product is around 30% of composted waste.
RDF	RDF can reduce 70% as incineration and gasification of combustible material, the residues are sent to landfill. The GHG emission is adapted from another study which states that it releases 1.3 kg eqCO_2/kWh, 1t waste=0.43RDF, and 1t RDF=300kWh. The environmental impact is low level.	RDF is accepted by people as the process is not so difficult, and this technology already exists in Thailand. The number of workers is taken from [58].	Capital cost and operation cost are taken from a review of plants in Thailand [45]. The revenue is calculated by electricity produced multiplied by price of electricity per unit (3.66 baht/kWh [59], 1USD=33baht)
IC	70% of total amount is reduced, and 0.22kg CO_2/kWh released. The problem with this technology is some chemical substances which have medium environmental impacts.	Bad odor and water leachate, however this plant is still acceptable for local people for many reasons, and it create lots of jobs for people (around 85 persons in 600t/d plant).	High capital and operation cost, however it can create more money for revenue as it is able to produce 150-200kWh/t waste.
GF	Not different from incineration in amount reduction, but it releases 0.114kg eqCO_2/kWh, and 1 t waste= 170-190kWh.It is also considered as a medium level of environmental impact.	New technology imported from abroad made this technology more acceptable for communities. It creates fewer jobs than incineration but the same amount of waste disposal in ratio of (66/69)	High capital and operation cost, but still lower than incineration; meanwhile, it generates more electricity, in the range of 170-190kWh/t waste.
AD	This technology is like compost, but the output is electricity, and it can reduce only 30% of total waste. The emission is between incineration and gasification, 0.2 kg CO_2/kWh. The system causes low environmental impacts.	It is judged to be more acceptable from communities as it already is practiced in Thailand. It generates jobs like compost because of the similarity in processing.	The capital and operation cost are low compared to other waste to energy treatments. It makes revenue by electricity an average of 80-120kWh/t waste.
LFG	Like sanitary landfill, but product is landfill gas which is collected and controlled carefully. After operation, it releases 1-1.2kg CO_2/kWh, and generates 7.96kWh/ t waste.	Requires large landfill size, and risk of explosion of gas that makes it not acceptable by local people. However, it creates many jobs as the system needs careful control.	Low capital and operation cost, but can generate more electricity, 7.96 kWh/t waste

Table 5.8 Input and characteristics of MSW management systems

Main criteria	Sub-criteria	Unit	Alternatives					
			CP	RDF	IC	GF	AD	LFG
Environment	Landfilled waste	t/d	4,844.95	6,551.55	6,551.55	6,551.55	3,962.9	10,005
	GHG emission	t $eqCO_2$/d	100.52	827.34	189.94	101.24	120.84	87.60
	Environmental impacts	-	Low (odor) (3)	Low (3)	Medium (1)	Medium (1)	Low (3)	Medium (1)
Social	Community acceptance	-	Acceptable (3)	Acceptable (3)	Acceptable (3)	More acceptable (5)	More acceptable (5)	Unacceptable (1)
	Generation of jobs	Jobs	217	207	699	669	254	800
Economic	Capital cost	10^6 USD	90.35	186.14	597.99	515.80	279.27	331.97
	O&M cost	10^3 USD/d	137.88	65.57	209.28	122.75	76.19	180.09
	Revenue	10^3 USD/d	97.52	70.58	95.75	98.49	67.01	8.83
MSW generation		1.33 kg/capita/day in 2015 or equal to 11500 tons/day with the low increasing rate						

Compost: 1 ton of MSW generate 19.48kg $eqCO_2$, adapted from [56];
RDF: 1 ton MSW=0.43ton RDF, 1ton RDF generates 300kWh$_e$, and release 1.3kg $eqCO_2$/kWh [60]
Incineration: 1-ton MSW= 150-200kWh, and to generate 1kWh releases 0.22kg $eqCO_2$
Gasification: 1-ton MSW= 170-190 kWh, and 1kWh release 0.114 kg $eqCO_2$
AD: 1-ton MSW=80-120kWh, 0.2 kg $eqCO_2$/kWh
LFG: 1-ton MSW=7.96kWh, 1kWh=1.1 kg $eqCO_2$
Data are extracted from [45, 56, 60, 61]

5.4.2 Establish pair-wise comparison matrix

Once the hierarchical structure is constructed, pair-wise comparisons are then performed. This AHP structure contains 3 main criteria, 8 sub-criteria, and 6 alternatives; therefore, a total of 58 pairs are compared to assign weights for elements of the entire matrix. In this comparison part, the author divides the AHP process into 3 stages. The 1st stage is the comparison of main criteria (environmental, social, and economic). The relationships of these three pillars of sustainability are considered in the concept of developing countries (equal weight) and developed countries (environment is the most important followed by social and economic issues) due to no respondents mentioning about this point. The 2nd stage is the comparison of sub-criteria with respect to their main criterion. The report from the interview is transformed from verbal expression to numerical number to compare qualitative items in a quantitative way. The 3rd stage is the comparison of options with respect to sub-criteria; these comparisons mainly are based on the data from the literature review (see Table 5.8**.**).

Developing country: EV=SC=EC= 0.333

Developed country: EV=0.6, SC=0.3, and EC=0.1

Table 5.9 Local weight of sub-criteria

	EV		SC			EC2	
EV1	EV2	EV3	SC1	SC2	EC1	EC2	EC3
0.6	0.3	0.1	0.8	0.2	0.8	0.1	0.1

Table 5.10 Local weight of alternatives

	EV1	EV2	EV3	SC1	SC2	EC1	EC2	EC3
CP	0.2030	0.2163	0.2500	0.1500	0.0762	0.4154	0.1340	0.2225
RDF	0.1501	0.0263	0.2500	0.1500	0.0728	0.2016	0.2819	0.1611
IC	0.1501	0.1145	0.0833	0.1500	0.2456	0.0628	0.0883	0.2185
GF	0.1501	0.2148	0.0833	0.2500	0.2349	0.0728	0.1506	0.2248
AD	0.2482	0.1799	0.2500	0.2500	0.0892	0.1344	0.2426	0.1529
LFG	0.0983	0.2482	0.0833	0.0500	0.2813	0.1131	0.1026	0.0202

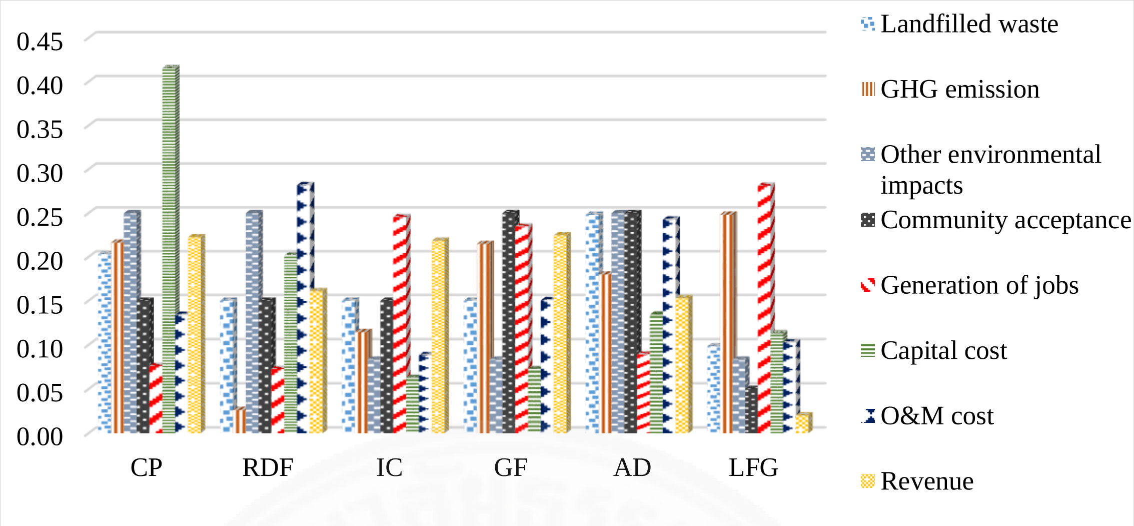


Figure 5.6 Local weight of alternatives with respect to sub-criteria

5.4.3 Examining the consistency of the comparison matrix

In this study the actual measurement is applied in the comparison process, i.e. 100% of environmental criteria is divided among landfill (60%), GHG emission (30%) and environmental impacts (10%). Thus, the importance of the amount at landfills over GHG emission is 60/30 = 2, and over environmental impacts 60/10 = 6. This method is applied to all comparisons in this AHP model. Therefore, the consistency ratio (CR) of the matrix is equal to zero or we can say that the comparison matrix is consistent.

5.4.4 Develop overall priorities

Since the AHP results show the consistency of the model, the pair-wise comparison matrices are not necessary to review or improve. Now the overall priorities of options are calculated following the formula given in section 5.3.1. The results are determined and discussed in 2 cases as mentioned above: 1) concept of developing country and 2) concept of developed country. The details can be found in section 5.5.

5.5 Results and Discussion

5.5.1 Priorities of MSW management system

1st case: The developing country concept gives equal weight to main criteria EV=SC=EC=0.333. From the global weight row (GW) in Table 5.11, the judgment shows that community acceptance (SC1: 26.7%) and capital cost of the plant (EC1:

26.7%) are quoted as the most significant segments, followed by amount of landfilled waste (EV1: 20%), and GHG emission (EV2: 10%). Regarding this weight and local weight of alternative in Table 5.10, we can generate global weights of all alternatives as shown in the same Table 5.11. Results show that CP (23.83%) is the most preferred for Bangkok due to the high proportion of organic fraction in the waste stream that allows this technology to reduce the huge amount of landfilled waste. It has an environmentally friendly process and low capital cost that can attract the investment from private companies. However, this treatment needs high O&M cost because the separation of organic waste from mixed MSW is difficult. Thus, the source separation of waste is very important to gain the effective system. The second ranked is AD (19.67%). It has the similar process to composting, but the output is biogas that can be used to generate electricity. Furthermore, AD gains more acceptance from the community as the system looks more modern and has low operation cost. The third ranked is GF (16.85%), followed by RDF (15.44%), IC (12.76%), and LFG (11.36%). GF is used to dispose the combustible material with low moisture. Table 5.5 shows that GF can dispose types of waste that cannot be done in CP and AD, such as plastic, foam, rubber, and clothes. Moreover, these types of waste are necessary to combust since they are not easy to digest by nature or need a long time to dispose.

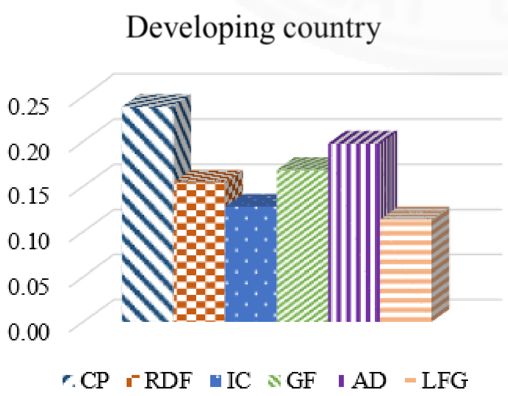
Table 5.11 Matrix of priority weights of waste treatment options in the concept of developing country (EV=SC=EC)

		EV 0.333			SC 0.333		EC 0.333			
	EV1 0.600	EV2 0.300	EV3 0.100	SC1 0.800	SC2 0.200	EC1 0.800	EC2 0.100	EC3 0.100		
GW	0.200	0.100	0.033	0.267	0.067	0.267	0.033	0.033	Priority	Rank
CP	0.2030	0.2163	0.2500	0.1500	0.0762	0.4154	0.1340	0.2225	0.2383	1
RDF	0.1501	0.0263	0.2500	0.1500	0.0728	0.2016	0.2819	0.1611	0.1544	4
IC	0.1501	0.1145	0.0833	0.1500	0.2456	0.0628	0.0883	0.2185	0.1276	5
GF	0.1501	0.2148	0.0833	0.2500	0.2349	0.0728	0.1506	0.2248	0.1685	3
AD	0.2482	0.1799	0.2500	0.2500	0.0892	0.1344	0.2426	0.1529	0.1976	2
LFG	0.0983	0.2482	0.0833	0.0500	0.2813	0.1131	0.1026	0.0202	0.1136	6

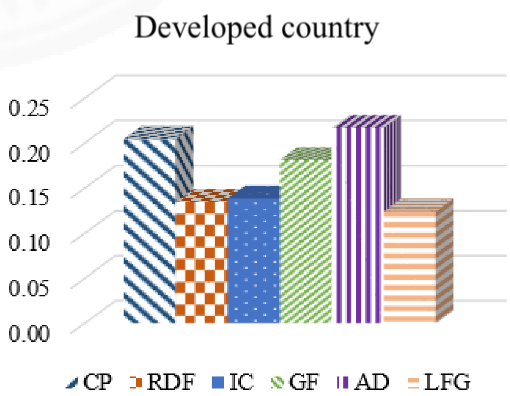
2nd case: The developed country concept gives unequal weight to main criteria EV (0.6)>SC (0.3)>EC (0.1). This means that a developed country gives more importance to the environment than to social and economic aspects. Due to the changing of criteria weight, the ranking of sub-criteria also changes. EV1 (36%) now becomes the first ranked, followed by SC1 (24%), EV2 (18%), EC1 (8%), EV3 = SC2 (6%), and EC2=EC3 (1%). The priorities of alternatives in Table 5.12 shows that AD (21.68%) is first ranked, followed by CP (20.44%), GF (18.14%), IC (13.85%), RDF (13.47%), and LFG (12.42%). There is not much change in the results since AD and CP still are the most preferred, and GF still is third ranked. The reason may not be so different from the previous case, but AD gains more weight in environmental and social aspects than CP. The result from the priority table is just considered point by point. To make sure that the priorities are stable, sensitivity analysis is performed in the following parts.

Table 5.12 Matrix of priority weights of MSW management system in the concept of developed country (EV>SC>EC)

	EV 0.600			SC 0.300		EC 0.100				
	EV1 0.600	EV2 0.300	EV3 0.100	SC1 0.800	SC2 0.200	EC1 0.800	EC2 0.100	EC3 0.100		
GW	0.360	0.180	0.060	0.240	0.060	0.080	0.010	0.010	Priority	Rank
CP	0.2030	0.2163	0.2500	0.1500	0.0762	0.4154	0.1340	0.2225	0.2044	2
RDF	0.1501	0.0263	0.2500	0.1500	0.0728	0.2016	0.2819	0.1611	0.1347	5
IC	0.1501	0.1145	0.0833	0.1500	0.2456	0.0628	0.0883	0.2185	0.1385	4
GF	0.1501	0.2148	0.0833	0.2500	0.2350	0.0728	0.1506	0.2248	0.1814	3
AD	0.2482	0.1799	0.2500	0.2500	0.0892	0.1344	0.2426	0.1529	0.2168	1
LFG	0.0983	0.2482	0.0833	0.0500	0.2812	0.1131	0.1026	0.0202	0.1242	6



(a)



(b)

Figure 5.7 Overall priorities

5.5.2 Sensitivity Analysis

The numerical incremental analysis is applied to investigate the stability of the priorities or ranking of alternatives through increasing and decreasing one of three main criteria while the others are kept at the same proportion.

1) **Developing country concept**: EV=SC=EC=0.333

➢ **Environmental criteria**: First we consider the relationship between environmental criteria and waste treatment alternatives (see Figure 5.8 (a)). By increasing the weight of EV criteria, we can see that the weight of CP goes down, while the weight of AD goes up. This shows that CP has the negative feature and AD has positive feature. The ranking of AD changes from second to first when the weight of EV=0.82 or SC=EC=0.095 which is difficult to happen. In other words, the priorities are not sensitive to change.

➢ **Social criteria**: The ranking of alternatives changes from CP, AD, RDF, GF, LFG, and IC (for 0% social weight) to GF, AD, IC, CP, RDF, and LFG (for 100% social weight) (see Figure 5.8 (b)). Based on this consideration, it can be asserted that weight of the social aspect affects the CP alternative negatively and influences GF positively. Therefore, GF is the most suitable choice in social consideration. However, the first ranked is AD when SC≥0.57 and then GF when SC≥0.67.

➢ **Economic aspect**: As can be seen in Figure 5.8 (c), CP has a strong positive effect on economic consideration, and RDF also has a positive effect while AD, GF, IC, and LFG have negative effects. Thus, CP is the most preferable option in this case.

2) **Developed country concept**: EV (0.6)>SC (0.3)>EC (0.1)

➢ **Environmental criteria**: In this case, the AD option is better than CP, followed by GF. Changing the weight of EV from 0 to 1.00 may not have much effect on the ranking of the first three, AD, CP, and GF (see Figure 5.8 (d)).

➢ In the cases of social and economic criteria considerations, the results and the discussion are the same as in the developing country concept (see Figure 5.8 (e) and (f)).

5.6 Conclusion

This chapter evaluates a sustainable MSW management system in Bangkok by applying the AHP model. Six waste treatment options are proposed: CP, RDF, IC, GF, AD, and LFG. At the same time, 3 pillars of sustainability are considered as the main criteria: environmental, social, and economic aspects, and 8 sub-criteria are also associated: amount of waste sent to landfill, GHG emissions, environmental impacts, community acceptance, generation of jobs, capital cost, operation cost, and revenue. To complete this task, the interviews of people related to MSW management decision making are needed. This study has applied the previous study interview because it is not easy to have meetings or interviews with a decision-making person in the BMA. Without providing the weight of each criterion during the interview, the author has designed the relationship of main criteria into 2 cases: the developing country concept, and the developed country concept.

The results show that the priorities rankings are CP, AD, GF, RDF, IC, and LFG for a developing country, and AD, CP, GF, IC, RDF, LFG for a developed country. It is remarkable that both cases give CP, AD, and GF as the first three ranking priorities. As described in MSW management treatment, each option has been developed to dispose a different type of waste contained in the waste stream; thus, the single treatment may not enough for a sustainable MSW management system. Therefore, an integrated system is needed. Since CP and AD can dispose the similar waste fraction, the integrated system of these two treatments is not recommended. The possible integrated systems are CP+GF and AD+GF. Both integrated systems need the sorting system of waste at the source because the separation at end-pipe treatment is difficult and can increase the operation cost of the system. The first integrated system, CP+GF is preferable in case there are market opportunities of compost product. On the other hand, AD+GF system is preferable if the stakeholders give more importance to biogas production and electricity generation.

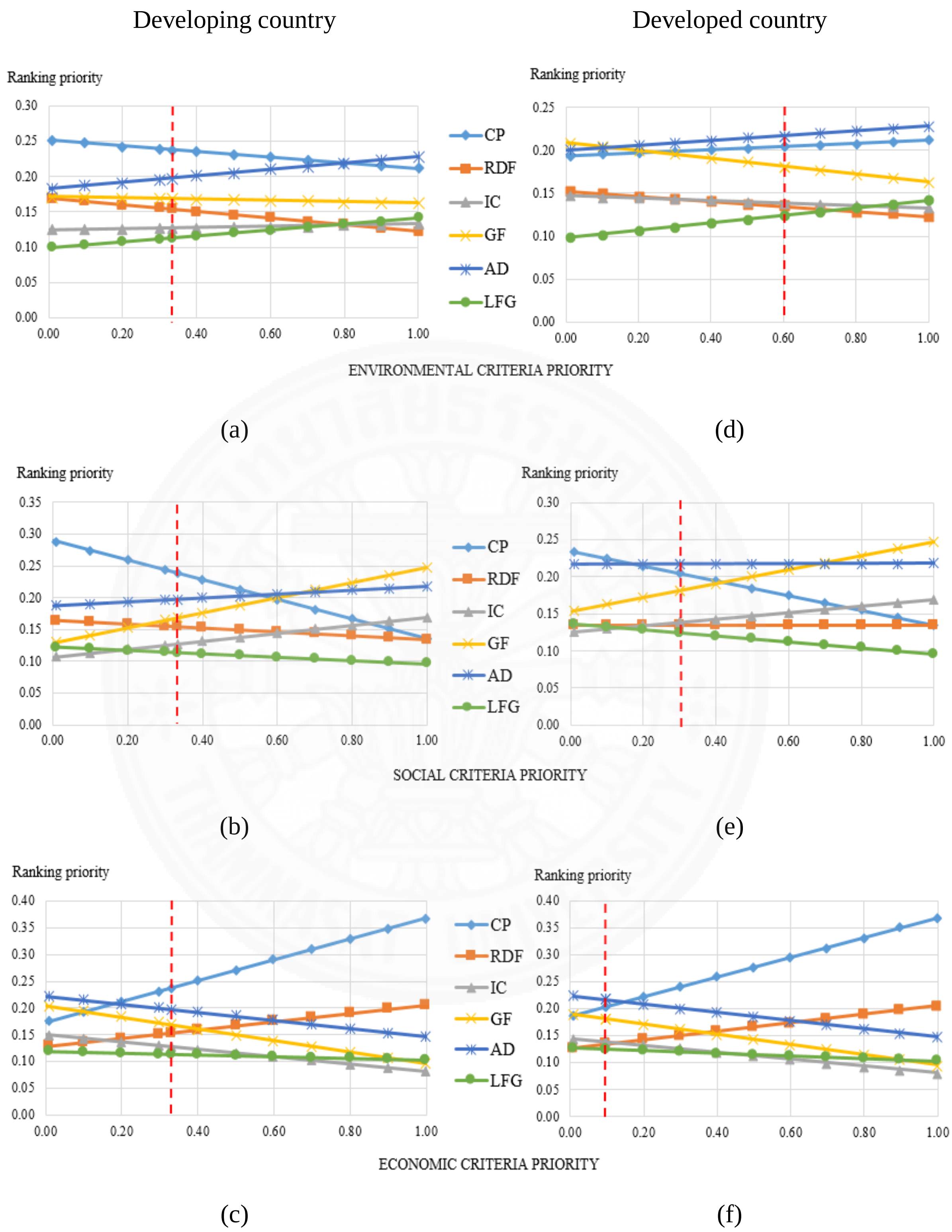


Figure 5.8 Sensitivity analysis

Chapter 6
Conclusions and Recommendations

6.1 Conclusions

The objective of this study was to evaluate the sustainable MSW management system for the municipality of Bangkok that mainly focuses on waste treatment or disposal. To achieve this objective, some related issues are presented. The current MSW management in Bangkok and Kitakyushu are assessed to find out the differences in the system, including policy, regulation, etc. After that, the forecasting of MSW generation is performed to determine the future trend of waste. The results from this forecasting can encourage the policymakers or officers to pay more attention in this field and to start strengthening the laws or enforcement to be more effective as well as prepare beforehand to deal with upcoming issues. The last step is the evaluation of the sustainable MSW management system by applying the AHP model.

Results show that the ineffective MSW management in Bangkok is caused by the weak regulation and the lack of community participation. For example, in some cases, local authorities try to promote the waste source separation to increase the quality of compost and reduce the expenditure in the sorting process; however, there is no residential participation so the project cannot go well. The household waste separated by residents is always collected and put in the same truck by the collectors. The outputs are the same in these two cases. To reach the community goal, it is important to collaborate between local authorities and residents. In short, policymakers should strengthen the regulations related to MSW management to gain the participation from the community.

In the forecasting part, the result shows that the total number of residents, native people aged between 15 and 59 years, total people aged between 15 and 59 years, number of households, income per household, and number of tourists are the influential variables affecting the quantity of MSW generation. Furthermore, ANN, the nonlinear model, gives a highly accurate result compared to regression analysis, which is a linear model. The output also revealed that two neurons in the hidden layer of the ANN architecture are enough to give a better result of MSW prediction. This ANN model can be applied in various fields and provide high accuracy. However, ANN provides the best result if the value of input is in range of the training data. Moreover, ANN should not be used for long-term forecasting as it can provide the result of overfitting which causes the unreasonable output.

The evaluation of a sustainable MSW management system shows that there are two possible integrated systems for Bangkok: CP+GF and AD+GF system. The CP+GF is preferable in case there are market opportunities for compost products. On the other hand, AD+GF system is preferable if the stakeholders give more importance to biogas production and electricity generation. However, in the author's opinion, the AD+GF system is the most suitable for Bangkok due to the huge demand for local electricity. Although the electricity generation is not much, at least this system can substitute a small part of diesel fuel consumption. Furthermore, generation of electricity from an MSW plant can receive feed-in tariff or adder around 3.66 baht/kWh [59]. The outputs of this research study are expected to be part of a renewable energy development plan.

6.2 Recommendations

Implementation of ANN, increasing the number of neurons in the hidden layer makes the calculation more complicated and requires more time for calculation. Moreover, overfitting the model can occur. However, to make ANNs more effective, a huge amount of data is required, especially weekly and monthly data.

The AHP method is not a statistic-based approach; therefore, there is no discussion on the optimal size of the number of stakeholders to be made. Furthermore, one sample size is sufficient for AHP implementation as it was originally pioneered to enable a single decision maker to select the most suitable alternative among several options.

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