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Implementation of Analytic Hierarchy Process for Sustainable Municipal Solid Waste Management: a Case Study of Bangkok

Nayseang Sun*, Supachart Chungpaibulpatana+, and Bundit Limmeechokchai+,1

Abstract – *Municipal solid waste (MSW) is considered as one of the renewable energy sources in Thailand, and MSW management is a challenging issue due to its complicated structure that relevant to environmental and socio-economic condition, especially in developing countries. This study aims to review the current status to highlight issues of MSW management in Bangkok, Thailand, then to analyze the situation in order to propose suitable waste treatment technologies for Bangkok based on data/information analysis. To reach the milestone, the interviewing of local administrators and experts in field of waste treatment technologies as well as reviewing of relevant documents are needed. The Analytic Hierarchy Process (AHP) method is implemented to evaluate a sustainable MSW management for Bangkok by considering a sustainability model that is associated with environmental, social and economic aspects. The result indicates that 90% of total waste generation in Bangkok are collected. Out of MSW collected in Bangkok, 10% was composted in On-Nut transfer station, 3% was incinerated in Nong Khaem transfer station, and the other 87% was sent to landfills outside Bangkok. On the other hand, results of AHP analyses show the preferred technology for Bangkok while sensitivity analysis determines the variation of technologies ranking when the weight of criteria changes. The study also suggests the integrated systems for sustainable development. The first integrated system, composting (CP) and gasification (GF), is preferable in case there are market opportunities for compost products. On the other hand, an anaerobic digestion (AD) and gasification (GF) system is preferable if the stakeholders give more importance to biogas production and electricity generation. The outcomes are thought to provide benefits for the policymakers, investors, researchers, and other stakeholders in Bangkok and elsewhere.*

Keywords – *analytic hierarchy process (AHP), Bangkok, priorities ranking, sustainable municipal solid waste management, waste treatment technology.*

1. INTRODUCTION

The tremendous growth of population, economy, and uncontrolled urbanization have accelerated the generation rate of municipal solid waste (MSW). According to the World Bank, the global MSW generation was about 1.3 billion tons in 2012, and it is estimated to almost double by 2025 to 2.2 billion tons per year [1]. As reported by the United Nations Environment Program (UNEP) and the International Solid Waste Association (ISWA) in 2015, data compiled for Global Waste Management Outlook from 125 countries gives the average waste collection coverage is only about 50% to 90% in Asia, while the World Bank assessment of collection coverage quoted on their website that 30% to 60% of all the urban solid waste in developing countries is uncollected [2]. The increase in MSW generation and improper waste management lead to numerous environmental, social, and economic impacts. The environmental impact of MSW includes air pollution, water, and soil contamination, as well as climate change. For example, improper waste transportation, collection and sorting, open dumping and landfill, and burning of waste are major sources of pollution and greenhouse gases emissions. Furthermore, there are both direct and indirect social impacts such as healthcare and food security impacts. The management of MSW is considered to hugely affect economic development in terms of cost and financing [3]. The improper MSW handling causes problems for human health and ecosystems. It motivates global nations to develop technologies and strategies for appropriate waste treatment. In developed countries, such efforts show the positive outcomes, the amount of waste at landfills is reduced, though treatment of generated waste is still required. In contrast, in developing countries, the landfill is considered as the best-case scenario for waste treatment [4]. In 2014, fire broke out at several dumping sites in Thailand caused more than two hundred residents to move away due to the release of poisonous gases [5]. Praksa landfill, Samut Prakan, was an example of massive garbage dumps fired. The smoke from the fire affected people living in three districts of outer Bangkok – Bang Na, Lat Krabang and Prawes districts. Members of the public complained of thick smoke and the smell of plastic burning [6]. Therefore, solution of waste treatment should be urgently provided in order to avoid poisonous gases from fire broke out at dumping sites.

Selection of appropriate waste treatment options is a challenging issue due to its complicated process which relevant to environmental, social, economic and other conditions. Therefore, the supporting decision-making tool that is reliable, quick and easy to use in analyzing a

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diverse and large quantity of data to facilitate decision-making is greatly needed. The Analytic Hierarchy Process (AHP), a member of the multi-criteria decision analysis family, is highlighted as a tool suitable for intricate decision problems and merging of qualitative and quantitative data [4]. The review study of Soltani *et al.* [7] found that AHP was the most common approach in consideration of multiple stakeholders in the context of MSW management, and experts and governments/municipalities were the most common participants in previous studies. The AHP was used by Taboada-Gonzalez *et al.* [4] to assess the waste treatment technology in Mexico, taking social, political, economic, and environmental issues in considerations. Based on the scientific literature, interviews with experts, decision makers and the community, and waste stream studies, Taboada-Gonzalez revealed that anaerobic digester had the highest rating and should be selected as the waste treatment technology for this study area. Milutinovic *et al.* [8] also used AHP to evaluate the sustainability of a waste management model in the city of Nis in Serbia by considering the pillar of sustainability, including environmental, economic, and social criteria which contained their specific indicators according to stakeholder's perception and condition. Among four examined scenarios, composting of organic and recycling of inorganic waste was found as the best sustainable scenario. In addition to this, the AHP can be used to sensitivity analysis (SA) to determine the variation of alternatives ranking when the weight of criteria or the importance of the element define the decision problem changes. In Thailand, AHP was used for prioritizing and selecting industrial waste management method in Map Ta Phut industrial estate [9]. To reduce bias of the stakeholders in the area, the study divided total score into 2 parts such as the first 50% score taken from stakeholders in the area and the other 50% score taken from external specialist. With the four main criteria (technology, economics, environment, and related regulations), AHP result revealed that experts focus on economics the most up to 30% followed by the technology 25%, environment 25%, and law and regulations 20%. The study also mentioned to increasing the number of specialists and stakeholders in concerning area in order to obtain higher confidence and effectiveness of AHP result. Intharathirat and Salam [10] applied AHP to evaluate the suitable MSW management systems for small and medium cities by considering four main criteria (environmental, social, economic, and technical) which then classified into 12 sub-criteria. Among eight various alternatives of MSW management systems, data compiled for AHP illustrated that the most suitable MSW management system is the mechanical biological treatment combined with composting (MBT-CP) for medium city and mechanical treatment combined with refuse-derived fuel (MT-RDF) for small city. The study indicated that stakeholders prefer the environmental aspect as being the most important followed by social, economic, and technical aspect [10]. Furthermore, AHP had been combined with Geographic Information System (GIS) to investigate the best location for landfill sites in the four southernmost district of Songkhla province, Chana, Na Thawi, Sabayoi and Thepha. Based on the criterion weights assigned by the experts variously drawn from the local administration office, provincial environmental agency, and engineering in related field, the study found as following: eight candidate sites in Thepha, six candidate sites in Chana, and four candidate sites in Sabayoi are suitable for landfill siting. However, Na Thawi district contained no suitable landfill sites based on the suitability criteria employed [11]. As we know that there is no single optimal MSW management system can be applied for both large and small cities due to the difference of their characteristics. Therefore, the evaluation of suitable MSW management system for Bangkok, capital city of Thailand, is a good challenge to conduct. The objectives of the study is to conduct reviewing the current status to highlight issues of MSW management in Bangkok and to propose the suitable MSW treatment technologies for sustainable development by applying the analytic hierarchy process (AHP).

2. LITERATURE REVIEW

2.1 Context of Bangkok MSW Management

Bangkok is the capital city of Thailand; it is located in the central part of the country. Bangkok is a huge administrative area with an overall area of 1,569 km^2 and had a registered population of about 8.6 million and around 2 to 3 million non-registered inhabitants in 2015 [12].

2.1.1 MSW generation in Bangkok

Thailand is a developing country located in Southeast Asia. On the website of World Bank, Thailand has made remarkable progress in social and economic development, moving from a low-income to an upper-income country in less than a generation over the last four decades [13]. As pointed out by many researches, generally waste generation increases as income rises. Generation of waste has become an increasing environmental and public health problems everywhere in the world [14]. According to Thailand National 3R Strategy (reduce, reuse and recycle) and the National Master Plan for Waste Management (2016-2021), Thailand is facing with inefficient waste management that need to be improved.

Based on the information of MSW reported by the Pollution Control Department of Thailand, total waste generation of the whole country was 27.06 million tons in 2016, 4.20 million tons were generated in Bangkok. The examination also found a significant increase in solid waste accumulation which is a major issue and needed to be solved urgently [15]. Bangkok Metropolitan Administration (BMA) classifies MSW into four (4) main categories, including organic, recyclable, general, and household hazardous waste. These wastes can be further classified into various compositions as shown in Figure 1 [16]. Data shows that the major component of waste in Bangkok is organic materials. Therefore, it is important to apply the appropriate organic waste treatment, for example, converting organic waste to fertilizer by composting or to energy by anaerobic digestion. Through appropriate treatment technology, waste components are utilized and eventually reduces the environmental effects that are harmful to humankind.

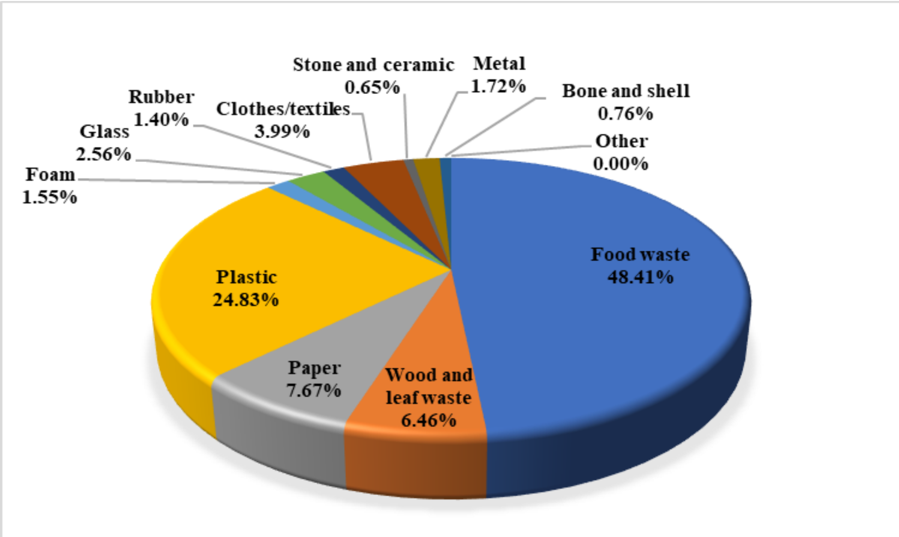

Fig. 1. Composition of MSW in Bangkok in 2012.

2.1.2 Analysis of Bangkok MSW management

BMA waste collection coverage over 90% of total waste generation, all collected waste is disposed in controlled treatment. Out of MSW collected in Bangkok, 10% was composted in On-Nut transfer station, 3% was incinerated in Nong Khaem transfer station, and the other 87% was sent to landfills outside Bangkok [3]. Although the incinerator is operating, the capacity for disposal is still low compared to total MSW generation. BMA revealed that MSW collection and disposal in Bangkok have exhibited noticeable improvement compared to other areas in Thailand, though more effort is required [17]. BMA officials still concerned about two main issues: the increasing of MSW generation and the diminishing landfill volume. They also pointed out that a waste treatment technology that decreases the amount of landfilled waste would be a huge benefit to the BMA. However, the social acceptance and expenditure cost also affect the selection of waste treatment options in Bangkok in a complicated way [16].

2.2 Analytic Hierarchy Process (AHP)

The AHP method is a multi-criteria decision-making technique. It is often used to solve complex decision-making problem in various fields such as manufacturing industry, environmental management, waste management, power and energy industry, transportation industry, *etc*. [18]. The application of AHP is presented in many studies as described in the previous part. It is a well-known method due to its capability to break down the complex problem into several levels that allow decision-makers to easily understand the problem in terms of relevant criteria and sub-criteria. The AHP model consists of four main steps as shown in Figure 2 [18].

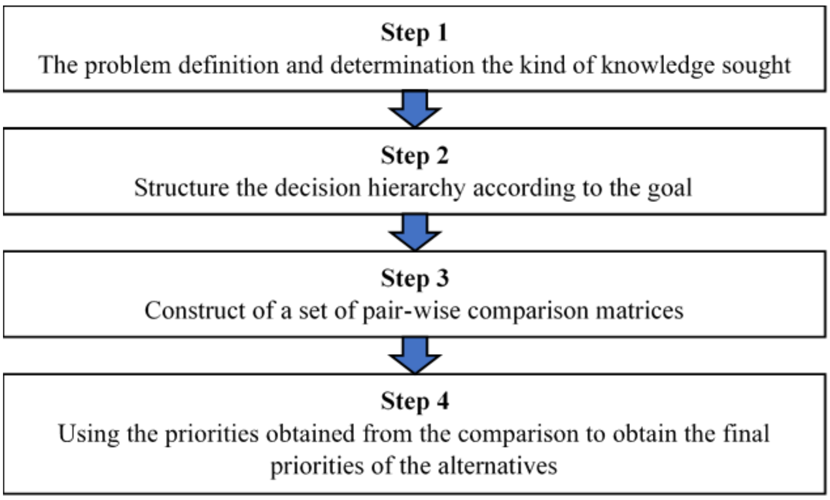

Fig. 2. The decision procedure in the AHP method.

1) The problem definition and determination on the kind of knowledge sought: Find out the goal or decision problem and identify all relevant indicators.
2) Structure the decision hierarchy according to the goal: In this step, all important elements are defined such as goal, criteria, sub-criteria, and alternatives. Then the hierarchical structure is generated.
3) Construction of a set of pair-wise comparison matrices: Each element of the matrix in the upper level is used to compare element in the level immediately below.
4) Use of the priorities obtained from the comparison to obtain the final priorities of the alternatives: This is the final step to determine the weight of each alternative in order to propose the highest-ranking priority.

The most important step of this AHP is a correct pair-wise comparison. Both qualitative and quantitative data are compared using a 9-point weighting scale (see Table 1). The obtained weights are different across stakeholders' preference; thus the consistency of evaluation is discussed to find out whether the comparative judgment needs to be improved. The method calculates a consistency ratio (C.R) to verify the coherence of the judgments, which must be about 0.10 or less to be acceptable. Finally, the synthesis of AHP combines multidimensional scales of measurement into a single one-dimensional scale of priorities. The mathematical foundations of AHP can be found in [19]. The AHP can be completed using a spreadsheet tool so that non-experts in programming are able to understand the ways of its implementation.

Table 1. Pair-wise comparison scale.

Numerical value	Definition	Explanation
1	Equal importance	Two criteria contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one criterion over another
5	Strong importance	Experience and judgment strongly favor one criterion over another
7	Very strong importance	A criterion is highly favored over another
9	Extreme importance	Experience and judgment favor one criterion over another to the greatest extent possible
2, 4, 6, 8	Values between the two adjacent judgments	When compromise is needed

Source: Milutinović B., 2014 [8].

AHP can be used with sensitivity analysis (SA) to determine the variation of alternatives ranking when the weight of criteria or the importance of the element define the decision problem changes. Through this analysis, decision-makers are able to see whether the model is robust or sensitive.

3. MATERIALS AND METHODS

The study is conducted for the purpose of solving the problems related to the selection of suitable technology for waste treatment that is able to bring sustainable development to Bangkok MSW management. The procedure of this study is presented like the detail in Figure 3. To conduct the AHP model, stakeholders' perception and analysis of technology are the most important input data.

Stakeholders' perception is necessary for this evaluation. The interview information is transformed from verbal expression to a numerical value to compare qualitative items in a quantitative way. However, this detail is extracted from the study of Reference [16].

Analysis of technology is presented to propose the possible technologies in the context of Bangkok. Six waste treatment technologies are introduced for this evaluation: composting (CP), refuse-derived fuel (RDF), incineration (IC), gasification (GF), anaerobic digestion (AD), and landfill gas (LFG) because these are the technologies that have been presented to Thailand for solving waste problems and they are familiar to the community. Information of this review is then implemented to generate the weight in comparison matrix.

Furthermore, in this study, the numerical incremental analysis also called one-at-a-time (OAT) is applied to investigate how different input values impact the priorities or ranking of alternatives. This method works by incrementally changing the weight of one criterion at a time while the others are kept at the same proportion, associated with calculating new solution and showing the graph of how the weight/ranking of alternatives change.

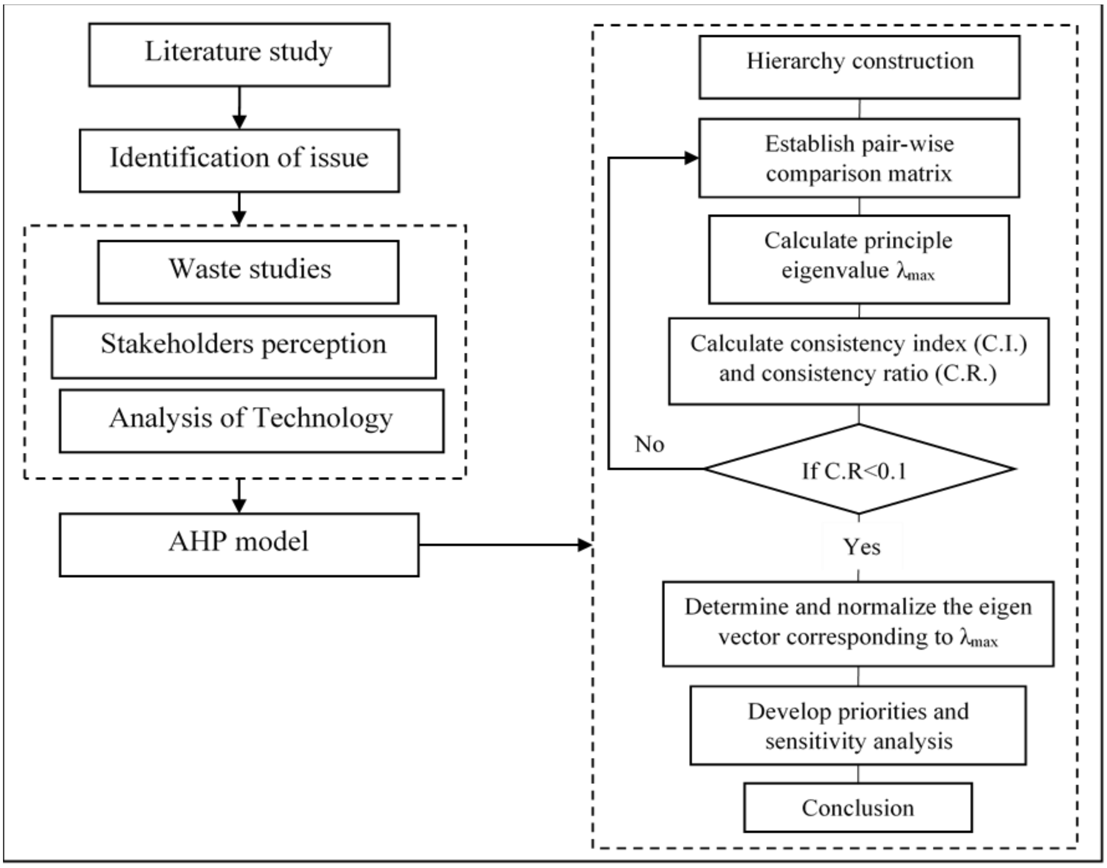

Fig. 3. The overall framework of the study.

3.1. Stakeholders Perception

Based on the interview of two high-level officers in the Bangkok Metropolitan Administration (BMA), two experts from academia, and the other two officers from the Pollution Control Department (PCD) related to waste management in Bangkok [16], the details are summarized into three main aspects as follows:

Environmental aspect
According to BMA consideration and the Thai government, three key points were mentioned in this aspect: the 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 was related to expenditure on waste disposal by hiring private companies. GHG emission was also considered as second important factor in the selection of waste treatment technology as it was a Thai national government concern. Meanwhile, 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 know the effects of technologies 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, BMA officers thought that the operation cost and revenue of the plant were not important since both factors were the responsibility of private companies.

3.2 Analysis of Technologies

Based on stakeholders' perception, eight indicators are used to evaluate the suitable waste treatment options. It is important for decision makers to visualize the advantage and disadvantages of specific technologies related to the impacts of waste treatment on the environment, social benefit, the economic benefit in the long term, and *etc*. Six waste treatment technologies are introduced for this evaluation: composting (CP), refuse-derived fuel (RDF), incineration (IC), gasification (GF), anaerobic digestion (AD), and landfill gas (LFG) because these are the technologies that have been presented to Thailand for solving waste problems and they are familiar to the community.

Environmental indicators

- Volume reduction: The amount of waste reduced before landfill was estimated by waste composition and technology used. In the case of RDF, IC, and GF, only 70% of the total waste amount (mass) is reduced.

- GHG emission: Amount of CO_2 and other GHG emission emitted to atmosphere estimated using the data from the previous papers.
- Environmental impacts: Information related to air pollution, wastewater, odor, *etc*. However, they are difficult to estimate quantitatively.

Social indicators

- Community acceptance: Possibly promoting the acceptability of the local community, the alternative does not present negative impacts on quality of life or human health. Since it is a qualitative criterion which cannot be measured, therefore, the 9-level scale established in the AHP method (1-worst, 9-Best) was used for the assessment of this criterion.
- Generation of jobs: Number of jobs created for operating the system was estimated based on the literature review on waste treatment.

Economic indicators

- Capital cost: Amount of investment cost for using technology (infrastructure, equipment, installation site).
- Operation and Maintenance (O&M) cost: Expenditure during operation (electricity, maintenance, labor).
- Revenue: Determination of revenues was made by the data from the literature. Amount of electricity generation multiply by its price or the money from selling the composted product (price in Thailand).

According to the literature reviews and interviews, this AHP structure contains 3 main criteria, 8 sub-criteria, and 6 alternatives. The structure of AHP can be constructed as Figure 4.

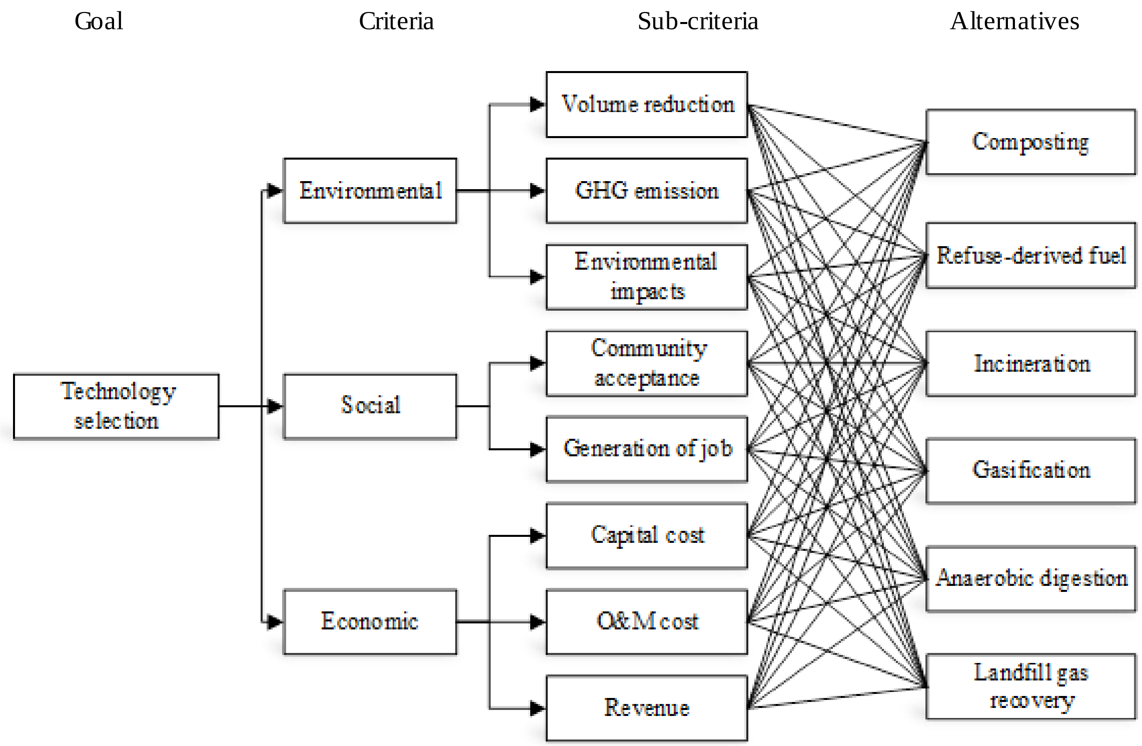

Fig. 4. Level and criterion used in technology selection.

The proposed plant would not affect the existing system's 10% composting, and 3% incineration, whereas 87% being landfilled is our target. Therefore, the amount of possible waste in each process can be found in Table 2 and Table 3. The type of treatment and size of the plant depend on the characteristics and amount of waste generation.

In the comparison part, the author divides the AHP process into 3 stages. The 1st stage is the comparison of main criteria: environmental, social, and economic issues. The 2nd stage is the comparison of sub-criteria with respect to their main criterion. The report from the interview is transformed from a verbal expression to a numerical value 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 previous studies related to each technology in the context of a developing country.

Table 2. Selection of waste treatment technologies based on waste type.

Composition	Percentage (%-wt.)[1]	CP	RDF[2]	IC[2]	GF[2]	AD[2]	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% composting, 3% incineration		44.87	42.9	42.9	42.9	52.54	87
Total treated MSW	11500t/d	5160.05	4933.5	4933.5	4933.5	6042.1	10005

Source: [1] Okumura [16], [2] Ouda [20]

Table 3. Input and characteristic of MSW treatment technologies.

Main criteria	Sub-criteria	Unit	Alternatives					
			CP	RDF	IC	GF	AD	LFG
Environment	Volume reduction[1]	t/d	5,160.05	3,453.45	3,453.45	3,453.45	6042.1	10,005
	GHG emission[2]	t eqCO_2/d	100.52	827.34	189.94	101.24	120.84	87.60
	Environmental impacts[3]	-	Low (odor) (3)	Low (3)	Medium (1)	Medium (1)	Low (3)	Medium (1)
Social	Community acceptance[3]	-	Acceptable (3)	Acceptable (3)	Acceptable (3)	More acceptable (5)	More acceptable (5)	Unacceptable (1)
	Generation of jobs[4]	Jobs	217	207	699	669	254	800
Economic	Capital cost[4]	10^6 USD	90.35	186.14	597.99	515.80	279.27	331.97
	O&M cost[4]	10^3 USD/d	137.88	65.57	209.28	122.75	76.19	180.09
	Revenue[4]	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.							

[1] calculated from waste composition [16]
[2] calculated from properties of technologies [5],[16].
[3] adapted from [18], the number in parentheses demonstrate the ratio used in the pair-wise comparison, i.e. for community acceptance, CP (3) and LFG (1) means that CP gets 3 times(3 divides by 1) weight of LFG or CP is moderate important than LFG.
[4] calculated from the literatures [4], [5], [21]–[26]

4. RESULTS AND DISCUSSION

Based on the result of the interview and quantitative analysis, we can generate the pair-wise comparison matrices and obtain the priorities ranking through the AHP process. However, information attained from the interview can be used only to compare the importance of one indicator over another in the same aspect, not across aspect. Thus, authors generated the results by giving equal weight to all aspects. The idea was also proposed by Munda *et al.* [27] to assign equal weight to each criterion for sustainability (i.e. environmental, social, and economic) in order to reduce the social conflicts and increase fairness [18]. The assigned weight from the interview was used to generate the weight of each indicators or sub-criteria.

4.1 Priorities Ranking of MSW Treatment Technologies

From the global weight (GW) of sub-criteria in Figure 5, the judgment showed that community acceptance (SC1: 26.7%) and capital cost of the plant (EC1: 26.7%) were quoted as the most significant segments, followed by the amount of waste reduction (EV1: 20%), and GHG emission (EV2: 10%). Regarding this weight and local weight of alternatives in Table 4, we could generate global weights for all alternatives. Results showed that composting or CP (23.04%) was the preferable option for Bangkok due to the high proportion of organic materials in the wastes that allowed this technology to reduce the huge amount of landfilled wastes. It had an environmentally friendly process and low capital cost that could attract investment from private companies. However, this treatment has high O&M cost because the separation process of organic wastes from mixed MSW is difficult. Thus, the waste separation at sources is very important to gain an effective system. The second-ranked was anaerobic digestion or AD (18.62%) which has a similar process to composting, but the output is biogas that can be used to generate electricity. Furthermore, AD gained more acceptance from the community as the system looks more modern and had low operation cost. The third-ranked was gasification or GF (16.04%), followed by LFG (15.73%), RDF (14.62%), and IC (11.94%). The GF is a modern method which gained acceptance from the community same as AD. It is used to dispose of the combustible material with low moisture to produce gas for electricity generation. LFG seems to be familiar with people in society, however this method got the least acceptance from community because of the fire broke out experience in many dumping sites. RDF is ranked as the fifth alternative in this judgment, nevertheless it gains the most weight in reduce of environmental impact and low O&M cost. In Thailand, RDF from MSW is rarely seen. The last one is IC, this system can be easily seen in Thailand as well as in nearby countries. However, based on the result from AHP, IC system is the least preferable alternative among six methods presented in this study.

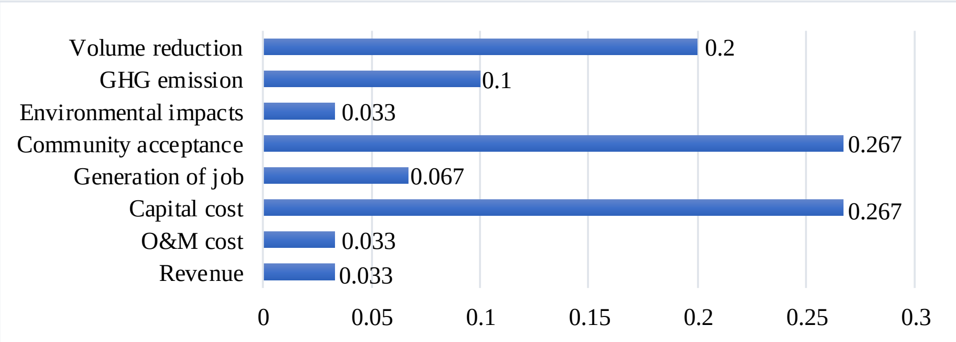

Fig. 5. Weight of sub-criteria.

Table 4. Priority weight of each option.

			EV		SC			EC		
			0.333		SC 0.333			0.333		
		EV1	EV2	EV3	SC1	SC2	EC1	EC2	EC3	
		0.600	0.300	0.100	0.800	0.200	0.800	0.100	0.100	
Rank	GW	0.200	0.100	0.033	0.267	0.067	0.267	0.033	0.033	Priority
1	CP	0.1635	0.2163	0.2500	0.1500	0.0762	0.4154	0.1340	0.2225	0.2304
2	AD	0.1914	0.1799	0.2500	0.2500	0.0892	0.1344	0.2426	0.1529	0.1862
3	GF	0.1094	0.2148	0.0833	0.2500	0.2349	0.0728	0.1506	0.2248	0.1604
4	LFG	0.3169	0.2482	0.0833	0.0500	0.2813	0.1131	0.1026	0.0202	0.1573
5	RDF	0.1094	0.0263	0.2500	0.1500	0.0728	0.2016	0.2819	0.1611	0.1462
6	IC	0.1094	0.1145	0.0833	0.1500	0.2456	0.0628	0.0883	0.2185	0.1194

4.2 *Sensitivity analysis*

Environmental criteria (EV)

First, we considered the relationship between environmental criteria and waste treatment technologies (see Figure 6 (a)). By increasing the weight of EV criteria, we could see that the weight of CP went down, while the weight of AD and LFG went up. This showed that CP had the negative feature, while AD and LFG had positive feature. The ranking of LFG changed from fourth to first when the weight of EV=0.65 or SC=EC=0.175, which was unlikely to happen. In other words, the priorities were not sensitive to change.

Social criteria (SC)

The ranking of alternatives changed from CP, LFG, AD, RDF, GF, and IC (for 0% social weight) to GF, AD, IC, CP, RDF, and LFG (for 100% social weight) (see Figure 6 (b)). Based on this consideration, it could be asserted that the weight of the social aspect affected the CP alternative negatively and influenced GF positively. Therefore, GF was the most suitable choice for social consideration. However, the first ranked was AD when SC $\geq$ 0.57 and then GF when SC $\geq$ 0.61.

Economic criteria (EC)

As could be seen in Figure 6 (c), CP had a strong positive effect on economic consideration, and RDF had a moderate positive effect while AD, GF, LFG, and IC had negative effects. Thus, CP was the most preferable option in this consideration case.

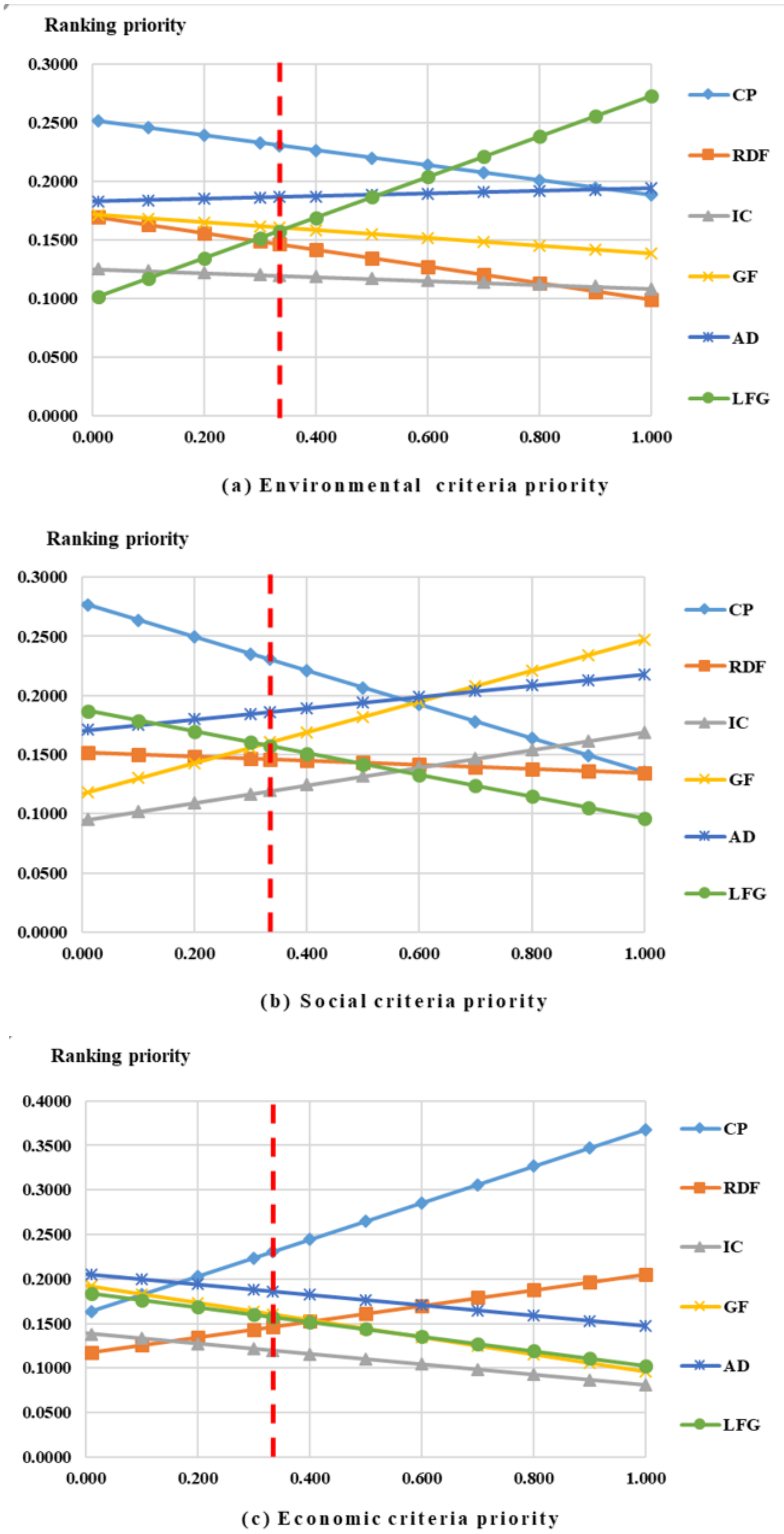

Fig. 6. Sensitivity analysis.

According to the detail presented in Table 2, GF can dispose of types of waste that cannot be done in CP and AD, such as plastic, foam, rubber, and clothes. Moreover, these types of waste were necessary to combust since they were not easy to digest by nature or need a long time to decompose. These reasons combined with the sensitivity analysis, the study can reach to the conclusion that integrated systems are proposed. The first integrated system is CP+GF which prefered in case there are market opportunities for compost products.

The second combined system is AD+GF which prefered if the stakeholders give more importance to biogas production and electricity generation. Both of these 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.

5. CONCLUSION AND RECOMMENDATION

The current status of MSW management in Bangkok can be brief as follow: over 90% of total waste generation are collected, and all collected waste is disposed in controlled treatment. Out of that MSW, 10% was composted in On-Nut transfer station, 3% was incinerated in Nong khaem transfer station, and the other 87% was sent to landfills outside Bangkok. Meanwhile, the composition can be classified into food waste, wood and leaf waste, paper, plastic, foam, glass, bubber, clothes/textiles, stone and ceramic, metal, and bone and shell with the percentage of 48.41, 6.46, 7.67, 24.83, 1.55, 2.56, 1.40, 3.99, 0.65, 11.72, and 0.76, respectively. This study evaluates a sustainable MSW management system for Bangkok by applying the AHP model. Six waste treatment options are proposed. At the same time, 3 pillars of sustainability are considered as the main criteria: environmental, social, and economic aspects. In addition, 8 sub-criteria are associated: the amount of waste reduction, 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. Without providing the weight of each criterion during the interview, the authors have designed the relationship of main criteria by giving equal weight or equal importance.

Results show that the priorities rankings are composting (CP), anaerobic digestion (AD), gasification (GF), landfill gas (LFG), refuse-derived fuel (RDF), and incineration (IC). However, each option has been developed to dispose of 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 of similar waste fractions, the integrated system of these two treatments is not recommended. The possible integrated systems are CP+GF and AD+GF. The first integrated system, CP+GF is preferable in case there are market opportunities for compost products. On the other hand, an AD+GF system is preferable if the stakeholders give more importance to biogas production and electricity generation. Both of these 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 development of technology in the near future may influence the ranking of this priority, thus the flexibility of the method should be present. For further study, the investigation on MSW management related to Environmental Impact Assessment (EIA), and Environmental Health Impact Assessment (EHIA), *etc*. will be done due to their popularity of implementation in Thailand. Recommendation for future study includes the comparison of integrated waste management systems concerning with the number of plants of the selected technology, capacity of the selected technology, siting and the financial sources.

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