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Article

A Multi-Criteria Decision Analysis of Waste Treatment Options for Food and Biodegradable Waste Management in Japan

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Abstract: Dealing with large-scale Food and Biodegradable Waste (FBW) often results in many logistical problems and environmental impacts to be considered. These can become great hindrances when the integration of solid waste management is concerned. Extra care is needed to plan such waste disposal or treatment services and facilities, especially with respect to the ecological impact. Decision-making with regards to the sustainable use of these facilities also involves tradeoffs between a number of conflicting objectives, since increasing one benefit may decrease the others. In this study a Multi-Criteria Decision Analysis (MCDA) is presented to evaluate different waste management options and their applicability in Japan. The analytical process aims at selecting the most suitable waste treatment option, using pairwise comparisons conducted within a decision hierarchy that was developed through the Analytical Hierarchy Process (AHP). The results of this study show that anaerobic digestion should be chosen as the best FBW treatment option with regards to resource recovery. The study also presents some conditions and recommendations that can enhance the suitability of other options like incineration and composting.

Keywords: multi-criteria decision analysis; analytical hierarchy process; food and biodegradable waste; waste treatment and decision-making

1. Introduction

Sustainable food and biodegradable waste management (FBWM) in the municipal solid waste management system is beginning to attract more attention due to environmental concerns. The enormous amount of FBW generated in Japan is due to the preference for raw food, such as raw vegetables, raw egg, or raw fish or meat (sashimi, sushi, *etc.*). In particular, fresh fruits and other food, population growth, and improvements in the standards of living and lifestyle have introduced many logistical problems that result in massive amounts of FBW [1,2]. The environmental impacts of this problem can become a hindrance to integrated solid waste management. Reduction, reusing, and recycling of FBW, and setting up the right waste disposal/treatment services, facilities, and locations will contribute significantly to the success of FBWM sustainability.

In Japan, about 19×10^6 t of food related waste is generated yearly. Out of this total, 11.3×10^6 t stems from food related industries, while 7.7×10^6 t stems from households. According to MAFF [1,3] and Stuart [4], 6×10^6 t of household food waste is considered edible. In essence, out of the 11.3×10^6 t generated in food-related industries, food manufacturing generates about 5×10^6 t, eating-out businesses generate about 3×10^6 t, and food retailing generates about 2.6×10^6 t, while food wholesaling generates about 0.7×10^6 t [1,3].

Food and biodegradable waste have become a serious concern for both the government and the general public [5–7]. However, this waste presents a great opportunity if it is put to better use. As such, approaches to FBWM are being reevaluated in and across Japan, and strategies to divert FBW from incinerators are being developed [7,8]. Despite these efforts, incineration has been the main process for discarding and reducing the volume of FBW in Japan [7,9–11]. Currently only 38% of Japan's 1234 incinerating plants are capable of thermal energy recovery.

There is also an emerging plan in waste prevention measures to reduce, reuse, and recycle the amount of FBW from households collected by local authorities. The Waste Management and Recycling Department (WMRD), which is financed by the Ministry of Environment (MOE), Japan, is an essential agent in controlling waste generation, promoting reduction, reusing, recycling, and appropriate disposal systems, from the perspective of conserving existing environments and putting natural resources to valuable use [12,13]. WMRD consequently has established both a Food Waste Recycling Law and the Sound Material-Cycle Society [12].

In line with the above situation, this study examines the municipal solid waste situation in Japan, with the objective of increasing the understanding of the benefit of separate treatment of food and biodegradable waste. The evaluation will be done in the framework of "Waste Management and Public Cleansing Law (Waste Management Law)" (WMPL) [12], relevant legislation on waste management, and the treatment technologies currently available.

The Waste Management Law was established in 1970 and has undergone major revisions in response to political, environmental, and social changes. This law is aimed at controlling waste generation, including material recycling, by setting targets, promoting proper waste management, reinforcing regulation, monitoring the setup of waste treatment facilities, and regulating waste treatment businesses. Furthermore, this law has safeguards to protect the living environment and improve public health, through the establishment of waste management standards.

The process of selecting the right FBW disposal method is complex and complicated and it involves many criteria and factors including public health, environmental, social, cultural, political, technological, and economic concerns. The selection of the right and proper disposal/treatment technique will not only save money and time, but will also help in reducing negative environmental impacts. Moreover, it will protect human health and social amenities, and reduce risks to water, air, soil, plants, and animals.

This study will examine methods of FBW treatment recommended in the waste management laws and regulations, such as composting, animal feeds, anaerobic digestion (or methanation), rendering of oil and fat products, and the two primary disposal methods currently in use, namely, incineration with thermal energy recovery (electricity and heat), and landfill without any form of energy recovery [1].

In order to plan such waste disposal/treatment services and facilities, extra consideration beyond the ecological impacts is required. Decision-making with regards to the sustainable use of these facilities involves tradeoffs between a number of conflicting objectives, since increasing one benefit could decrease the others. That is, considering the environmental, sociocultural, political, technical, and economic dimensions, reducing conflicts between stakeholders and integrating these realities in the proposed framework can be seen as an optimization process.

There have been numerous studies that use Multi-Criteria Decision Analysis (MCDA) to resolve waste management matters [14–17]. This study focuses on demonstrating the AHP and MCDA approach to address Japan's FNWM dilemma via an appraisal of several different FBWM technologies options commonly employed in Japan. The proposed course of action developed in this study will not only complement the current solid waste management system, but will support and recommend the development of a comprehensive, integrated solid waste management plan in the future and the long term.

2. Multi-Criteria Decision Analysis Application to Waste Management

2.1. Overview

MCAD is defined by Belton and Steward [18] as "an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter." In MCDA, the desirable objectives and criteria are coupled within a given decision framework [19,20]. It is mostly functional as a tool for ecological assessment where a complex and inter-connected range of environmental, sociocultural, technical, financial, and economic concerns are taken into consideration, and where necessary tradeoffs among competitive objectives and criteria are also considered. It is mainly applicable to situations where a single criterion approach fails, and where significant ecological and social impacts cannot be monetarily evaluated, for example by cost-benefit analysis (CBA) or cost-effectiveness analysis (CEA) [21]. It presents a strong and transparent decision-making structure, making clear the key attributed values and considerations while enhancing the participation by stakeholders and the community [22].

MCDA can be applied at any level of decision-making (choice of alternatives), from the consideration of project alternatives or evaluation in physical planning to broad-reaching policy decisions leading to a changeover towards sustainable development [23,24]. The strength of MCDA is that the real measurements of alternatives or indicators are not in financial terms, but rather are frequently set through the scoring, ranking, and weighting (quantitative analysis) of a broader range of qualitative impacts on the criteria. Different environmental and social criteria could be developed alongside economic costs and benefits, and a clear understanding that a variety of both monetary and non-monetary objectives could influence policy decisions [19,21].

The Analytic Hierarchy Process (AHP) is an MCDA technique that supports decision makers in solving and constructing complex decisions [16,23–28]. However, AHP is capable of quantifying intangible criteria and evaluating choices in a multilevel, hierarchical structure of objectives with respect to criteria, sub-criteria, and alternatives. Pairwise comparisons are used to obtain the weights of importance for the decision criteria, and the relative performance measures of the alternatives in terms of each decision criterion. If the comparisons are not perfectly consistent, then AHP will provide a system for improving consistency [25–27]. The AHP procedure is listed below:

1. Problem Definition and Goal Determination
2. Identification and Hierarchy Structure of Criteria
3. Calculating Relative Weights
   a. Construction of Pairwise Comparison
   b. Relative Weights Computation
   c. Consistency Assessment of Pairwise Judgment
4. Preference Order of Options/Alternative Comparisons

2.2. Application to Waste Management

For over three decades, waste management problems have been addressed through the use of MCDA techniques. This typically involves the integration of environmental, political, social, cultural, and economic values alongside the preferences of stakeholders while considering the challenges of monetizing essentially non-monetary factors [21,29]. A number of applications of MCDA techniques to waste management have been presented recently [16,24,30–33]. Most of these studies start with reasonable decision-making concerning waste management requirements by considering a broad range of impacts, including social, cultural, environmental, economic, land use and resource use, reuse, and recycling.

Although MCDA is a structured approach, it is flexible enough to allow the use of value judgment, and quite suitable for problems where monetary estimates are not available. In most cases, it enables a more practical representation of the decision problem selected, and particularly for the tradeoffs to be made. It is clearer, more flexible, and open when compared to other methods such as CBA. In most cases, the objectives and criteria chosen by the decision-making group or decision maker are open to analysis and change if they are considered to be unsuitable [21,22]. Furthermore, MCDA presents the option of introducing qualitative data along with quantitative data. This is relatively useful in many cases because decision makers are often faced with difficulties when dealing with qualitative data [21,22]. However, the technique is used to consider both qualitative and quantitative information in real decision situations, and sophisticated techniques such as fuzzy set theory are used to accommodate data uncertainty [20,21]. Pairwise comparison is the most frequently used interactive technique used, in order to establish trade-off relationships between criteria [25,26].

AHP approaches have proved to be useful decision-making tools in real-life applications. Vaidya and Kumar [28] group the application areas as follows: selection, evaluation, benefit-cost analysis, allocations, planning and development, priority and ranking, and decision-making. Also, Williams [34] went further to elaborate that the natural simplicity and enormous flexibility of AHP have made it gain even wider applicability; for instance, it is adopted in education, engineering, government, industry, management, manufacturing, personnel, politics, society, and sports [28,35]. Further illustrations have been reported by Ishizaka and Labib [35], Aragones-Baltrau *et al*. [36], Khan and Faisal [37], and Williams [34]. The rationale for applying APH in this study, as has been done in other applications of MCDA (e.g., ELECTRE, MacBeth, MAUT, MAVT, TOPSIS, SMART, PROMETHEE, and UTA) is based on its simplicity, familiarity, and flexibility. Particularly appealing was APH's ability to evaluate criteria and alternatives with both quantitative and qualitative types of data together on the same preference scale of nine levels, when dealing with groups of stakeholders [27,35,38]. In general, the advantage of AHP is clarified in comparison to and in combination with other methods of MCDA [27,35]. However, Huang *et al*. [38] pointed out that no matter which MCDA methods were used, similarities in the outcome of the methods is nearly guaranteed. Consequently, the choice of method is mainly based on the preference of the decision maker [38]. In this study, the actual application of this method will be described by selecting the best treatment option for FBWM in Japan.

3. Methodological Process

Decision-making in the context of the environment is quite complex and multidimensional in nature, in such a way that decisions have to be made in view of diverse spheres of influences. Examples include decisions involving waste recycling and the development of new facilities for waste disposal. Making these decisions could affect diverse domains, from individuals to authorities and organizations, or to society as a whole. The interactive and participatory nature of AHP makes it easier for both the analyst and the decision maker (who could be a number of groups of stakeholders or consensus experts) to learn more about the problem in detail and make sure that the interests of all the stakeholder groups are represented and taken into consideration [19,35].

The analysis uses the AHP approach to identify options or alternatives for suitable waste disposal. The AHP helps to break down the problem into small parts with the aim of assisting decision makers in preference assessment [25–27]. First, the problem is constructed into a structured hierarchy (Figure 1). The top of the hierarchy represents the goal level; the next level is that of criteria and sub-criteria (in some cases), and the lowest level denotes options. Pairwise comparisons permit the analyst to concentrate only on one element at a time: "how strongly important is one criterion related to another with regards to the goal?" The comparisons are input into a matrix. If the matrix is sufficiently consistent, priorities can be calculated with the formula:

$$AW = \lambda_{max} W, \quad (1)$$

where A is the comparison matrix, λ_{max} is the principal eigenvalue, and W is the priority vector. The comparison matrix usually includes unnecessary information, and, as such, it helps mainly in synthesizing the final result, to ensure that it makes the approach less dependent on a single judgment. The AHP model gives feedback to the decision maker on the consistency of the entered judgments through the measurement of consistency ratio (CR):

$$CR = \frac{CI}{RI} \quad (2)$$

$$CI = \frac{\lambda_{max} - n}{n-1}, \quad (3)$$

where CI is the consistency index, n is the dimension of the comparison matrix, λ_{max}, is the principal eigenvalue, and RI is the ratio index. The ratio index or Random Consistency index (RI) is the average of the consistency index of 500 randomly generated matrices (see Table 1) [25–27]. If the consistency ratio is less than 0.1 (<10%) the matrix is regarded as consistent, otherwise the matrix is inconsistent, and it is suggested to modify the comparisons in order to reduce the inconsistency [16,35]. If all sub-priorities are available, they are aggregated with a weighted sum in order to obtain the overall priorities of the alternatives so as a final judgment can be made based on the ranking [25,27].

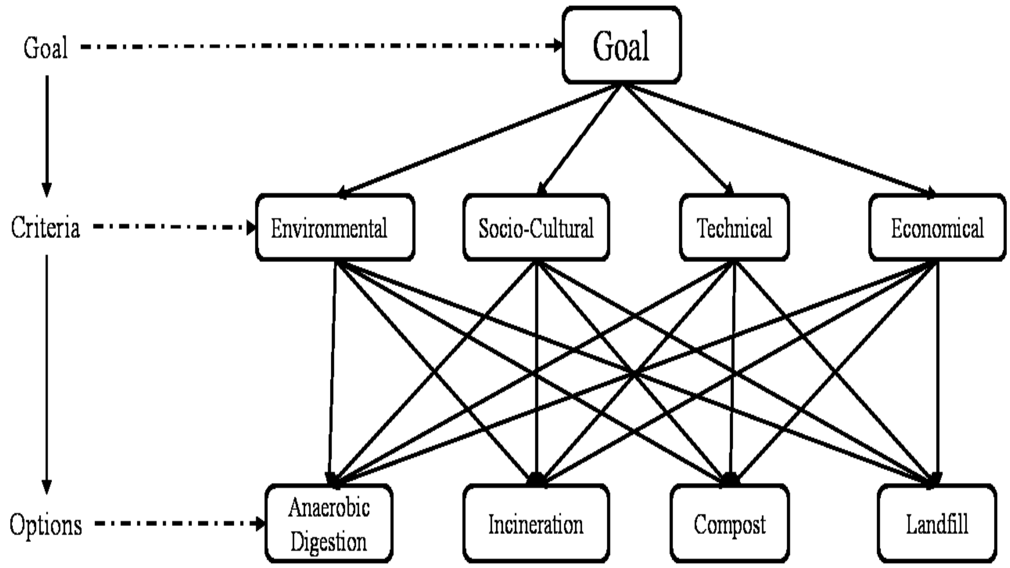

Figure 1. Hierarchy model showing the criteria and options.

Table 1. Random Consistency Index (RI).

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

3.1. Selecting the Most Suitable Options/Alternatives for FBWD

The MCDA framework is proposed in order to achieve the objective of this study, which is to assess the suitability of different waste treatment options or alternatives as a useful and potentially applicable method of handling FBW. The MCDA framework (which is based on the AHP approach) is used to structure and analyze the problem, using a hypothetical decision maker's standpoints [20]. In this regard, this study bases its courses of action on WMPL, with the aim and purpose of preserving the living environment and improving public health through the restriction of waste discharge, appropriate sorting, storage, collection, transport, recycling or disposal of waste, and the conservation of clean living environment [12]. Details about the analytical procedure are given below.

3.2. Problem Definition and Goal Determination

The selection of the proper and right disposal treatment will not only save money and time, but will also help in reducing the environmental impacts. The right choice also protects human health and reduces risks to water, air, and soil systems, as well as to plants and animals. At the same time, it causes no nuisance through odor or noise, and does not disturb rural areas or locations of specific interest (airports). Moreover, this disposal method should be able to be located as close to the waste generators as possible.

The goal of this investigation is to determine which waste treatment option would be the most suitable for treating the amount of FBW generated. The most suitable option with regards to the goal would be defined in such a way that two equally important sub-goals would be satisfied. A decrease in the amount of FBW to the incinerator will automatically lead to an increase in efficiency rate, which, in turn, will lead to other favorable results such as reduction in air pollution, maintenance, and operating costs, renewable energy generation, better resource recovery, and environmental conservation. The second and equally important option is sustainable FBW treatment, leading to integrated food and biodegradable waste management.

3.3. The Hierarchical Identification of Criteria and Options

The criteria in general have to be clearly defined in order to outline the clarity of the structural hierarchy. The multi-criteria decision analysis used in this study is based on criteria obtained from the Waste Management and Public Cleansing Law document [12] and related literature [14–17,24,30–33]. From these, several criteria were identified and initially grouped into the following nine categories: politics, society, culture, economics, environment, technology, public health, finance, and land use. After consultation with WMRD and experts on waste management, the nine criteria were then reduced to four main groups (classified by ranking of significance, preference, and relevance to the objective of this study) in order to make the evaluation process simpler. Kemal Korucu and Erdagi [17] described environmental criteria by taking into equal consideration the safety of human beings and that of nature. From this viewpoint, it appears logical to combine the environmental and public health criteria into one, *i.e.*, the environmental criteria. Social and cultural criteria were combined to form the socio-cultural criteria, while economic and technical criteria remain the same. Financial, political, and land use criteria were left out, and will more likely be considered in a later study. Under these considerations, the criteria are then categorized into four main groups (according to WMRD) as follows: the environmental, economic, sociocultural, and technological criteria.

The preliminary criteria selected here may be valued by a large variety of participating stakeholders in the decision-making process, such as waste management administrators, municipal officers, researchers, waste consultants, and experts in ecological matters. Thus, the above criteria are well suited for those with the intention of finding the most complete, operational, and essential set of criteria [33].

The main aim of this study is to select the best waste treatment technology for FBW, and at the same time to increase the standard of FBWM in sustainable waste management. The goal is broken down into sub-objectives in order to find the number of goals and objectives suited to the current situation in Japan. For this purpose, the main aim of the study and the number of criteria have been identified, as related to the four main areas of concern (environment, society and culture, technology, and the economy). A brief description of each of these criteria is given hereafter.

3.3.1. Definitions of Criteria

Environmental Criteria

This deals with any change, positive or negative, to land, ecosystems, and human health as a result of action resulting from waste mismanagement. Disposing of waste has its own specific environmental impacts and can cause severe problems to public health. As a result, all the options were judged against the following list of impacts first, and the ones possessing high potential for reducing environmental impacts were selected.

a. Air and Water Pollution
b. Exposure to Pathogens
c. Land Use, Requirement, and Contamination
d. Material Recovery
e. Waste Coverage and Elimination
f. Net Energy Recovery
g. Disamenity, such as Noise and Dust

Sociocultural Criteria

Waste generation is usually determined by socioeconomic characteristics and people's attitudes. It is known that campaigns, educational measures, and public awareness positively influence people's approach to waste. This criterion supports the aim to improve working conditions, earnings, and access to social services, and also evaluates each option based on the following list:

a. Acceptance
b. Perception and Complexity
c. Usability and Compatibility
d. Flexibility of Administration Principles
e. Policy
f. Implementation and Adoptability
g. Vulnerability of the Area

Technical Criteria

Technical criteria are particularly valuable when selecting waste disposal options. Their importance is usually in view of the possibility of subsequent increases in the daily tonnage of waste that the facility will be required to manage, for added processing capabilities. These criteria also determine what equipment and training will be necessary to perform the waste management responsibilities. Among others, this study considered the ones in the list below:

a. Possibility and Robustness
b. Local Labor Working Experience
c. Adaptability to Existing Systems
d. Handling Capacity and Continuous Process (materials)
e. Prospective Future Improvement

Economic Criteria

Economic evaluation is a significant part of tactical planning and investment programming for any waste disposal facility. Estimating the preliminary investment capital requires long-term operating and maintenance costs in relation to the different waste management activities. It will also include an appraisal of the public's willingness and capability to pay for the service. Evaluation was based on the items in the list below:

a. Capital and Construction Cost
b. Operating and Maintenance Cost
c. Revenue Generation and Marketability
d. Financial Planning
e. Employment and Job Creation
f. Waste Volume and Composition, *i.e.*, Wet and Dry Waste
g. Resource Recovery, *i.e.*, Nutrient Reuse and Energy Recovery

3.3.2. Identification of Waste Options/Alternatives

Numerous disposal methods have been adopted to treat FBW in different parts of the world, including Japan [7,39,40]. Examples of the most well-known methods are open dumping, sanitary landfilling, incineration, and composting [1,41]. A subset of the methods prescribed by the FWRL was considered in this study. For the development of the AHP hierarchy structure, it was essential to identify the options and criteria that could fulfill the aims and objectives of the study. A subset of four waste treatment technology options proposed by the FWRL was considered for this study. The options are mentioned below, and at the lowest level of the hierarchy structure (Figure 1):

a. Anaerobic Digestion
b. Incineration
c. Compost
d. Landfill

The goal, criteria, and options identified so far are represented in a hierarchical structure (Figure 1) made up of the three following levels: the first level identifies the goal category of FBWM, the second level shows the criteria influence, and the last level shows the disposal options. This, in turn, helps to facilitate the procedure for assigning weights and scores.

4. Results

4.1. Relative Weights

The first step in pairwise comparison process is to form a pairwise comparison matrix for all the criteria after constructing the hierarchy structure (Figure 1). This is the decision hierarchy structural model for choosing the best treatment option. In determining the relative weights, one of two basic approaches is applied: (1) the group judgment (consensus expert/decision makers), or (2) a single judgment (the decision maker or author's judgment) [14,25,26]. Provided that the quality of the output can be estimated by how logically satisfactory the final results are through the estimated consistency, one can observe what is instinctively expected as a reasonable outcome [25]. In either case, the judgment has to be based on making a pairwise comparison of each element in a given hierarchy structure (Figure 1) in relation to the other elements in the same level. Thus, this study used the second approach and those criteria were divided into three main levels in the computation process. The first level is with respect to the goal. The second level is the criterion in concern, and the third level is based on the waste treatment options. The degree of preference for each pairwise is quantified based on a nine-point scale, from 1 to 9, displayed in Table 2 [25,27].

Usually the comparisons are based on a numerical scale that indicates how many times more important one factor is over another with respect to the criterion in regards to the overall goal [25,27]. With regard to the above facts, the weights in the pairwise matrix given in Tables 3 to 7 are based on a critical review of regulation and policy documents relating to MSW management in Japan. The following questions were asked in order to draw a comparison between criteria and options:

- ✓ With regards to the goal: "How strong and significant is one criterion relative to another within an FBW treatment scheme based on the Waste Management and Public Cleansing Law in Japan?"
- ✓ Then the four criteria were compared according to their degree of importance regarding each of the four waste disposal options. The question here was (for each waste disposal option): "How much stronger or more important is one criterion over another in the treatment of FBW?"

Table 2. Nine-point scale for pairwise comparison.

Intensity of Pairwise Comparison	Importance
1	Equal importance, two activities contribute equally to the object
3	Moderate importance, slightly favors one over another
5	Essential or strong importance, strongly favors one over another
7	Demonstrated importance, dominance of the demonstrated importance in practice
9	Extreme importance, evidence favoring one over another of highest possible order of affirmation
2, 4, 6, 8	Intermediate values, when compromise is needed

There are a total of five pairwise comparison matrix tables: the first one is the criteria relating to the goal. This is illustrated in Table 3. There are four comparison matrices for the four options regarding all the "criteria concerned," where the criteria in all levels are connected to the options. Tables 4–7 illustrate the pairwise comparisons for the remaining four criteria. The consistency ratios of all comparisons were less than 0.1, which indicates that the weights used are consistent.

Table 3. Pairwise comparison matrix of the key criteria with regards to the goal.

Criteria	*Environmental*	*Sociocultural*	*Technical*	*Economical*	*Priority Vector*
Environmental	1	3	7	7	0.5887
Sociocultural	1/3	1	5	3	0.2552
Technical	1/7	1/5	1	1/2	0.0606
Economical	1/7	1/3	2	1	0.0955

Note: λ_{max} = 4.1177, Consistency Index (*CI*) = 0.0392, Consistency Ratio (*CR*) = 0.04 < 0.1.

Table 4. Pairwise comparison matrix for the options with regards to environmental criteria.

Options/ Alternatives	*Anaerobic Digestion*	*Incineration*	*Compost*	*Landfill*	*Priority Vector*
Anaerobic Digestion	1	3	5	8	0.5638
Incineration	1/3	1	2	7	0.2522
Compost	1/5	1/2	1	4	0.1374
Landfill	1/8	1/7	1/4	1	0.0466

Note: λ_{max} = 4.1715, *CI* = 0.0572, *CR* = 0.0635 < 0.1.

Table 5. Pairwise comparison matrix for the options with regards to sociocultural criteria.

Options/ Alternatives	*Anaerobic Digestion*	*Incineration*	*Compost*	*Landfill*	*Priority Vector*
Anaerobic Digestion	1	2	5	8	0.5219
Incineration	1/2	1	2	7	0.2814
Compost	1/5	1/2	1	5	0.1517
Landfill	1/8	1/7	1/5	1	0.0449

Note: λ_{max} = 4.1719, *CI* = 0.0551, *CR* = 0.0612 < 0.1.

Table 6. Pairwise comparison matrix for the options with regards to technical criteria.

Options/Alternatives	*Anaerobic Digestion*	*Incineration*	*Compost*	*Landfill*	*Priority Vector*
Anaerobic Digestion	1	2	5	7	0.5253
Incineration	1/2	1	2	5	0.2695
Compost	1/5	1/2	1	4	0.1500
Landfill	1/7	1/5	1/4	1	0.0552

Note: λ_{max} = 4.1411, *CI* = 0.0470, *CR* = 0.0522 < 0.1.

Table 7. Pairwise comparison matrix for the options with regards to economic criteria.

Options/Alternatives	*Anaerobic Digestion*	*Incineration*	*Compost*	*Landfill*	*Priority Vector*
Anaerobic Digestion	1	2	7	8	0.5267
Incineration	1/2	1	5	8	0.3438
Compost	1/7	1/5	1	2	0.0801
Landfill	1/8	1/8	1/2	1	0.0495

Note: λ_{max} = 4.0954, *CI* = 0.032, *CR* = 0.035 < 0.1.

4.2. Preference Order of Option/Alternatives Comparison

Priorities in each matrix were obtained from the comparison matrices, while the rankings of the options were given against the four criteria of concern as in Table 8. Then synthesis of all the matrices was done. Synthesis is the process of multiplying each criterion ranking by the priority vector and adding that to the resulting weights to get its final priority vector for each option. The overall priority (Table 8) shows consistency since the overall consistency ratio (CR'), which is measured with the formula below, is less than 0.1 [24–26].

$$CR' = \frac{CI\prime}{RI\prime} = \frac{\sum_{i=1}^{n} WiCIi}{\sum_{i=1}^{n} WiRI}, \tag{4}$$

where CI' is the consistency index in all level of the hierarchy, RI' is the earlier mentioned ratio index in Table 1, and W_i *is* the relative weight or priority vector (the local priority weight) with respect to the criteria.

Table 8. Composite weight for all criteria: synthesizing to obtain the final results.

Criteria/Alternatives	*Environmental*	*Sociocultural*	*Technical*	*Economical*	*Overall Priority*
Anaerobic Digestion	0.3319	0.1332	0.0318	0.0503	0.5472
Incineration	0.1485	0.0718	0.0163	0.0328	0.2695
Compost	0.0809	0.0387	0.0091	0.0076	0.1363
Landfill	0.0274	0.0115	0.0033	0.0049	0.0470

Note: *CI′* = 0.0995, *RI′*= 1.8, *CR′* = 0.0552 < 0.1 Overall consistency of the hierarchy is less than 1.

The final result shown in Table 9 is called the ideal form, and this is done by dividing each priority by the largest one, which is 0.5472 (for anaerobic digestion). The outcome is to make the largest option ideal, and for the others to receive their proportionate values. Subsequently, the interpretation of the result implies that incineration has 49% of the appeal of anaerobic digestion, composting has about 22% of the appeal of anaerobic digestion, and landfill is about 9% as appealing as anaerobic digestion.

Table 9. Final results, illustrated as normalized priorities and idealized priorities.

Criteria/Alternatives	*Normalized Priority*	*Idealized Priority*
Anaerobic Digestion	0.5472	1.000
Incineration	0.2695	0.492
Compost	0.1363	0.249
Landfill	0.0470	0.086

Based on the present analysis, the most suitable waste disposal facility for FBWM using the AHP technique was identified to be anaerobic digestion, followed by incineration and composting, while landfill is the least suitable option to be considered. Anaerobic digestion was shown to be the most suitable not only in the overall goal, but also in all levels of the criteria (Figure 2).

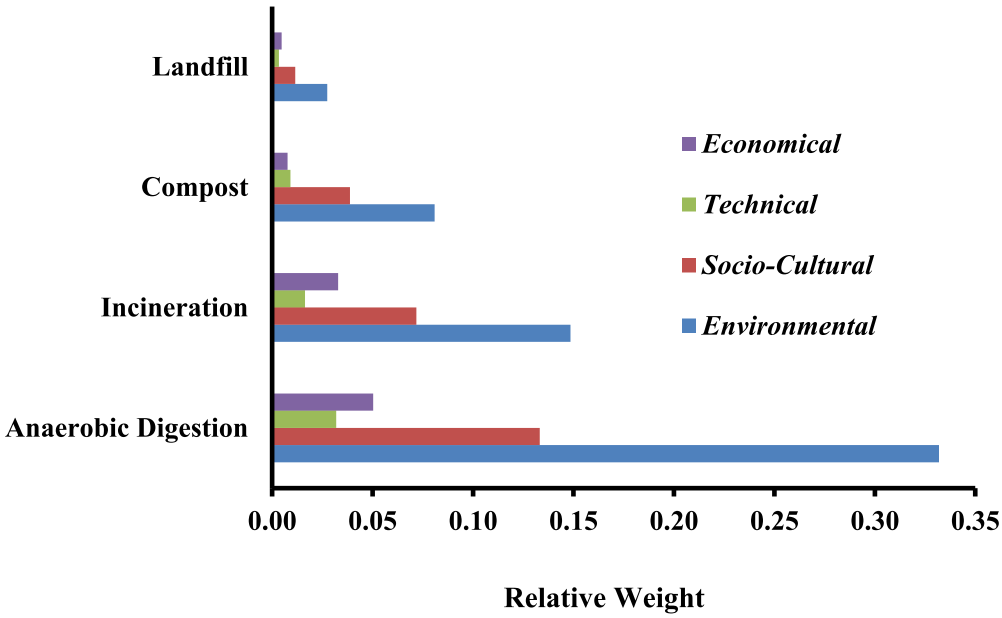

Figure 2. Overall ranking of all options.

4.3. Sensitivity Analysis

Sensitivity analysis is an essential technique used in MCDA to determine the robustness of the results and to show how different relative weights in the criteria level of the hierarchy will influence the final choice [15,16,29]. Thus, it is possible to explain the different preferences that the decision makers could make with respect to the criteria applied, and how they impact the study outcomes.

The analysis was carried out by changing the relative weight of the criteria one at a time and taking a record of the changes in the rank results. This is done by using four situations:

(a) The first situation is where three (out of four) criteria are given zero (0) relative weight and one criterion is assigned the whole relative weight in a combination of four possibilities. The result of the analysis, given in Figure 3a, shows that anaerobic digestion ranked as the best performing option, and incineration and compost could also be considered as options for FBW treatment since they ranked second and third, respectively, with landfill being the worst.

(b) The second situation is where relative weights of 0.5 are given to two of the criteria while the other two are given zero (0) relation weights in a combination of six possibilities; one example of the six possibilities (same result) is illustrated in Figure 3b. It can be deduced from Figure 3b that the result of the analysis is similar to the result in Figure 3a.

(c) The third situation is where three criteria are given a relative weight of 0.33 each while the other one is given a relative weight of zero (0) in a combination of four possibilities; one example of the four possibilities is presented in Figure 3c. The result also shows that the best performing option is anaerobic digestion, followed by incineration and compost, with landfill been the least suitable option.

(d) The last situation is where all four criteria have the same relative weight of 0.25; the result is shown in Figure 3d. This analysis shows a clearer result since the performance of anaerobic digestion over another option is carried out against all the criteria. Hence it is clear that anaerobic digestion is the best option for FBW treatment, followed by incineration and compost, while landfill remained the worst.

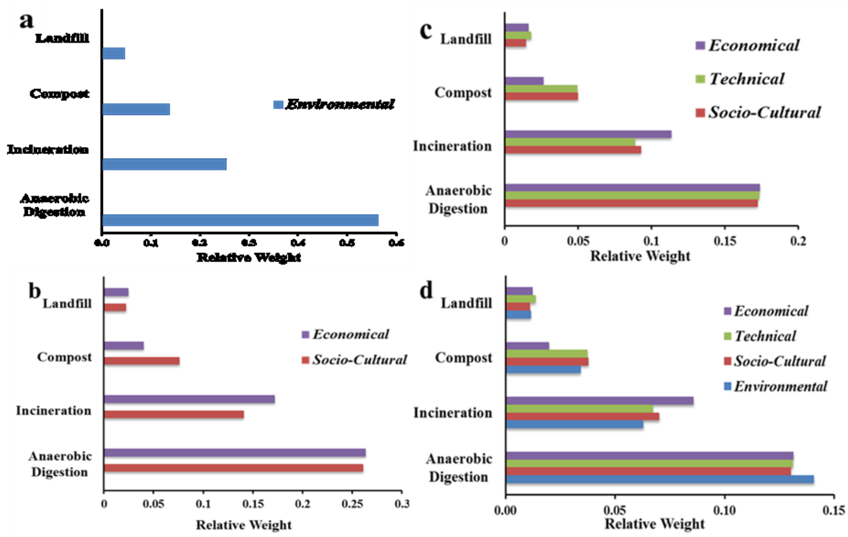

Figure 3. Sensitivity analysis: (**a**) one of the criteria has a relative weight of 1 while the others are at 0, (**b**) two criteria have a relative weight of 0.5 each while others are at 0, (**c**) three criteria have a relative weight of 0.33 each while the other is at 0, and (**d**) all criteria have an equal relative weight of 0.25.

The sensitivity of the results across all four situations shows a similar pattern that can be deduced from Figure 3 (no change in the rank options). It also shows that the best choice for FBW treatment is anaerobic digestion, which remained the same in all situations and was followed by incineration and composting, while it is evident to say that landfill is the worst option to be considered.

The parameters used in the four situations mentioned above are comparable to the cases used by Karagiannidis *et al*. [16] in a similar study. Criteria weight combinations can lead to an infinite number of states, but there are some feature cases that show clearly how the results perform when weights change. This analysis shows that the results are robust and suggests that further investigation using alternative scenarios of stakeholders with different preferences would be desirable.

5. Discussion

This study presents an evaluation of the existing food and biodegradable waste management system (FBWS) in Japan as a whole, including an assessment of the WMPL and the FWRL. The investigation in this study is based on the following key factors: waste generation, waste disposal practices, waste collection, reuse, recycling, and reduction. It is important to mention that prevention of FBW and the promotion of sound material recycling in Japan are attributable to an increase in environmental pressure and to a decrease in landfill space and capacity [10,11]. Currently large quantities of food waste from households and from wholesale/retail and manufacturing industries are simply incinerated [7], hence there is a pressing need for methods that will meet the demand with respect to the criteria chosen by WMPL.

The results presented in Tables 3 to 7 show how pairwise comparison is used to obtain priorities between the criteria and waste options. The synthesis results of the priorities of the criteria with respect to goals (local priorities) and those of the options to obtain the best desired options (global priorities), as illustrated in Table 8, show that anaerobic digestion and incineration are perceived to perform better on all four criteria for the treatment of FBW (Figure 2). Compost and landfill follow suit, with landfill being less desirable in all categories with regards to resource recovery and ecological concerns. The poor performance of composting technology can primarily be explained by the current practice of composting in Japan: most composting operations are small-scale and operated by individuals with limited FBW accepted from other sources (FBW not generated by the operator of the composting operation). The current situation can be improved upon to create a more centralized composting system so that more materials can be recovered. A similar result was also observed by Abba *et al*. [14] and Hanan *et al*. [15], where they applied MCDA (AHP) in the selection of waste treatment options and their ecological impacts. The consistency ratio for the final result is 0.0553, which is less than 0.1, therefore showing that the judgment is consistent and robust, as previously pointed out in the analyzed results.

Sensitivity analysis is used to evaluate the robustness of the selected treatment options. A "What if Analysis" (Figure 3) was performed to see if there were any changes among the selected treatment options. The results show no changes in the ranked results, as anaerobic digestion remained the most suitable option for the treatment of FBW. The performance of the treatment options based on the criteria mentioned earlier is a robust one similar to the synthesis results.

It should be mentioned that the judgment (weights) used in the analysis was based on the collective appraisal of a few experts (single judgment) and information on MSW management regulations and policies that mainly represents the FBW situation in Japan [25,26]. Consequently, decision-making based on a different set of judgments would produce different results based on a different set of criteria. As such, the MCDA model presented in this study could be seen as a flexible, but robust, framework that can be adapted to fit a variety of criteria or more levels of sub-criteria and options. It can also be seen as a guiding framework in a decision-making process that would involve a panel of experts or group of stakeholders for the selection of alternative options for FBW treatment or as a benchmark towards actualizing and providing sustainable FBWM operations.

It is important to take into account that, while planning to implement solid waste management policies and regulation of systems such as FBWS, planners will have to face a number of challenges, some of which may involve local and municipal authorities, waste management practitioners, environmentalists, the citizens, supermarket operators, and food-related industries (both small and large). In such instances, the framework presented in this study can play a vital role not only as a final way of selecting the most suitable options, but also as a tool that has the skill and knowledge to facilitate the decision-making process in terms of defining, informing, guiding, and getting feedback on the current situation of FBWM. At the same time, it provides room for participation, training, and involvement of representatives from all the above mentioned areas.

6. Conclusions

The increasing FBW generation may be influenced by waste management policies and regulations [7]. Feedback on these policies and regulations could be included in a long-term waste management planning program, in order to evaluate the entire solid waste management system. This is because waste treatment facilities are somewhat related to the type of waste included in the waste stream. Furthermore, these policies and regulations should support and promote the sales and marketing of resources from waste treatment facilities, not only for waste reduction. Fortunately, there is a growing awareness of the enormous volumes of FBW generated through wasteful lifestyles and of how resource recovery can be a main part of the waste stream. This study focused on examining the environmental, sociocultural, technical, and economic benefits of this waste disposal method in Japan.

In this study, the multi-criteria decision-making approach is identified as a useful means for an integrated evaluation of the suitable treatment options for FBW. There have been numerous studies that use MCDA methodology to resolve waste management matters. The present study has shed some new light in this regard by demonstrating how the AHP approach in MCDA can be used to address the FBWM dilemma. The methodology presented here can be used as a well-organized, strategic decision supporting tool for decision makers, politicians, and planners. It is essential to have consistent goals and objective information about the evaluation process of anaerobic digestion suitability for food and biodegradable waste treatment based on environmental, sociocultural, technical, and economic criteria.

The results have shown that anaerobic digestion of FBW is the most suitable choice with respect to all recognized criteria, as seen in the relevant sensitivity analysis. It would be the first choice when the recirculation of nutrients and weight volume reduction are considered. If all resources from waste can be fully reused, anaerobic digestion and central composting with nutrient recovery appears to be the best combined option and a strong solution for FBW treatment. Furthermore, investments in this waste management facility can be considered to offer another source of revenue generation for waste management practitioners. Consequently, they facilitate and at the same time lighten the burden of waste management incurred by the municipal government.

This recommendation for the treatment of FBW in Japan relies, to some degree, on the assessment of the criteria and waste treatment options, and the impact of the respective weights are very significant. A group decision-making process using a panel of experts and non-experts could be carried out in future work, using the same or a different set of criteria in order to examine the effectiveness of the framework.

The implementation of both MCDA and CBA could also be carried out in order to check for the consistency of the proposed framework and to gain more confidence in the obtained results.

The integration of FBW management as a separate form of municipal solid waste management is desired in order to tackle waste problems. Due to the complexities of FBW management, a full-scale investigation is needed as to where to place the chosen waste option (anaerobic digester) in order to recommend any solution or plan for further development. As a result, investigating a suitable site for an anaerobic digestion plant using a case study in Japan under the same criteria will help to instill more confidence and increase the worth of integrating FBW management as part of decision-making support and forecasting in the management of MSW.

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Conflicts of Interest

The author declares no conflict of interest.

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