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MAKING A DECISION USING ANALYTICAL HIERARCHY PROCESS (AHP) IN SELECTING SUITABLE FOOD WASTE MANAGEMENT METHOD: A CONCEPTUAL FRAMEWORK

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Abstract: Food waste in Malaysia has the highest composition in municipal solid waste (MSW) stream which, occupied around 44.5% of the total waste in mass. As food wastes are commonly disposed to landfill, during the process of degradation, it produces harmful pollutants such as leachate which cause contamination to the water sources while landfill gases lead to global warming and climate change. However, land scarcity is an issue in Malaysia where it is soon coming into a limit in spaces for landfilling. Hence, it is vital to look into a suitable food waste management method upon the issues. The application of Multi Criteria Decision Making (MCDM) is important in assisting the decision-making process by suggesting suitable food waste management treatment method. It helps to select shortlisted criteria that fulfill the requirements in line with the preferences and suggest on suitable treatment selection for decision. Analytical Hierarchy Process (AHP), which is one of the MCDM techniques, able to provide a rational decision-making framework by incorporating many relevant criteria and alternative that is support by scientific values of the suggestion. With the aid of the decision-making technique, food waste can be properly managed through suitable management treatment method and promotes on circular economy, reducing impacts towards the environment. From the results analyzed through MCDM, it is encouraged to practice on Anaerobic digestion (AD) treatment as it results in significant reduction of impact towards the environment. The use of AD treatment has significantly show contribution towards the environment. This study allows in showing on how food waste can be management properly in the suitable and preferred method that allows in the reduction of environment pollution.

Keywords: anaerobic digestion, analytical hierarchy process, decision making, food waste management

Introduction

Food waste is defined as the reduction of the amount or quality of food as the results of retailer, food service provider, and the decision and behavior from customer. It is usually being wasted in many ways such as in household kitchen and eating facilities where large amount of food that are still edible are frequently underutilized and left over and at last being abandoned. Food that are beyond the best before date are also being discard, fresh products that have unpleasing shape, size, color are also being discard and remove during the sorting process (FAO, 2020). Food waste can be categorized into 3 groups: (1) food losses (food that are lost during the prepare, process and production stage, however it is still edible in most of the major situation), (2) unavoidable food waste (spoilt part of the food, for

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instance fruit peels, bone, egg shells that cannot be eaten under normal condition) and (3) avoidable food waste (food that actually still can be consume through another way of preparation but being wasted and throw away) (Parfitt *et al*., 2010; Thi *et al*., 2015).

Food waste is recognized as the major and huge problem along the worldwide (Ghafar, 2017). The major problem is due to the improper treatment of food waste that leads to several impacts towards the environment. Nearly 1.3 billion tonnes of the world annual food production were being wasted according to Food and Agriculture Organization (FAO) (FAO, 2020). The amount of food waste generated is directly proportional to the growth of population in the country. As the population increase, the amount of food waste also increases. Food waste is one of the major environmental issues faced by most of the local authorities besides the air and water pollution (Alias *et al*., 2017). Moreover, it is also due to the habits and behavior of the individual which they are able to effort more different food product as the living standard increases. Most of the food waste were being disposed to the landfill (Ghafar, 2017; Lim *et al*., 2016). As the organic substance degrades anaerobically, it produces harmful gas such as greenhouse gases that cause global warming potential, leachates that pollutes groundwater and soil contamination. In the meantime, the energy and resources used to produce food for instance, producing, transporting, processing and preparation are also wasted.

As food waste is being disposed, it degrades on site under anaerobic conditions, producing methane gas (CH4) which is 25 times powerful than carbon dioxide (CO_2). Methane gas is a part of the greenhouse gases that contributes to global warming (Berdeen, 2019). It is reported that household municipal solid waste (MSW) is the third largest anthropogenic source of methane emissions, 11% for the total global emission on methane. Besides, waste is being disposed under the linear economy concept where raw materials are being used to produce the product and ended up being disposed as waste after using it. In contrast with circular economy, the waste materials are being used many times until its limit before dispose (Kamar Zaman & Yaacob, 2022).

The implementation of the Multi Criteria Decision Method (MCDM) allows to handle on problems and issues that involve multiple criteria, producing a quality decision making among various alternatives provided. Throughout this study, it focusses on how to decide on a suitable food waste management using MCDM method that allows the stakeholder to decide based on their preference of selection. The application of AHP provides a consistency measure which leads to a more effective and appropriate results. A proper treatment on the food waste produced able to reduce the impact towards the environment and also resolve on the land scarcity issues in Malaysia.

Literature Review

Food waste in Malaysia is categorized as solid waste under the Solid Waste and Public Cleansing Management Act 2007 (Act 672) (Hashim *et al*., 2021). The act was gazette in 2007 and enforced on 1st September 2011. There are about 16,688 tons of food waste being generated per day and the average amount of food being discard in household are around 0.5-0.8 kg uneaten food per day in Malaysia (Ghafar, 2017). It is also estimated that the amount of food waste will increase tremendously to 4.16 billion tons from 2.78 billion tons by 2025 (Ren *et al*., 2017). Food waste is known as organic waste as it has properties that can biodegrade easily. It has the characteristics of being readily degradable, high moisture content, high solubility and low pH value, this reflects that it has a higher energy content per dry mass (Izhar *et al*., 2021). As it degrades, it produces methane gas and carbon

dioxide, which is one of the greenhouse gases. The production of greenhouse gases will lead to global warming potential, climate change, land and water footprint issues.

There are major treatments on food waste in Malaysia which are landfill, recycling, composting, incineration, inert landfill and sanitary landfill (Alias *et al*., 2017). Nearly 80% of the food waste generated was being disposed in landfill. Although landfilling is listed as the most undesirable option method for waste disposal, however it is still remained as the most preferred selection due to its cost efficiency and low technical requirement (Hashim *et al*., 2021). However, landfill in Malaysia is soon reaching its capacity and it is difficult to continue disposing waste into it. Thus, it is important to look into the land scarcity issues (Lim *et al*., 2016). Furthermore, the authority is facing challenges in handling food waste. The improper segregation and separation of the waste has cause attribution on the production of greenhouse gas in landfill (Lim *et al*., 2016). Methane gas and carbon dioxide contributes impacts towards the environment during landfilling. Methane gas is the main agent causes for ozone depletion, 21 times more harmful than carbon dioxide (Hashim *et al*., 2021). It is the poor food waste management that leads to pollution towards the environment including air, soil and water. From the study by (Intan *et al*., 2020) , the global warming potential impact caused by food waste was 2555kg CO_2 eq/ 1 Mg.

As the major food waste treatment in Malaysia is landfilling, it releases harmful gas that leads to environmental pollution and global warming during the decomposition process. There is a total of 146 landfill in Malaysia; however, only 18 of them are sanitary landfill, which are site that waste is isolated from the environment until it is safe to be. During the decomposition process of food waste, leachate is produced. It will pollute the groundwater, causing soil contamination, issue on land and water foot print. This eventually cause impacts towards adverse health of public and also the environment. Besides, the country is also facing land scarcity, thus it is vital to look into a better and suitable food waste management method.

It is very struggling to choose and decide between alternatives that has multiple attributes. It is more difficult when the alternative selection is imprecise, subjective and uncertain. However, when it comes to considering many criteria, MCDM allows selecting the best alternative by analyzing the different scope and weighting of the criteria. It provides a strong decision making in the domains where the selection on the alternative is complex (Aruldoss *et al*., 2013). There are a few important steps while working on the decision-making technique such as determine the relevant criteria and alternative based on the goals to achieve, attaching the numerical measures to the relative importance of the criteria and to the impacts of the alternatives based on the criteria and process the numerical data to rank on each alternative.

Many methods that are widely used in MCDM such as Analytical Hierarchy Process (AHP), Fuzzy Analytical Hierarchy Process (Fuzzy AHP), TOPSIS, Elimination ErChoix Traduisant la REalite (ELELECTRE), Grey analysis, Weighted Sum Model (WSM), PROMETHEE and so on. In order to select on the methods to apply in study using MCDM, it is important to understand the strength and weakness of the method before selecting on it (Velasquez & Hester, 2013). Besides, the information available in the study must be first determined. For instance, grey analysis supports when there is incomplete data to carry out, goal programming works on goals that are more than one which conflict with each other, ELECTRE selects on the best choice with maximum advantage and least conflict on

the criteria. Thus, the goals must be determined at the beginning before selecting the suitable MCDM method to be applied in the study.

Analytical Hierarchy Process (AHP) is also known as analytic hierarchy process. It is a multi-criteria decision-making method that was developed by Thomas Saaty in 1970. It is used when it comes to selecting the best alternative that has multiple criteria based on ranking method. It based on the ranking score of the criteria and making decision on the best alternative for the user (Aruldoss *et al*., 2013). In short, it focused on the best decision selection instead of the correct decision selection. Besides, AHP is most widely used among the various method in MCDM (Song & Kang, 2016).

There are a few studies that has implement the use of AHP method, such as the study by Boonkanit & Kantharos 2016) on industrial waste management method which an evaluation method that can aid decision to prioritize and select industrial waste management method and Azahari *et al*., (2021) on sustainable solid waste management system. Meanwhile study by Iacovidou & Voulvoulis (2018) focus on the use of MCDM method to assess and compare on the sustainability performance of food waste management options based on area-specific characteristics through decision support framework. They compare on the use of FWDs and the anaerobic co-digestion of food waste with sewage sludge in terms of their sustainability performance; however, the data collected is based on literature review instead of opinion from experts. As for the study by Babalola (2020), the research of food waste treatment using AHP was carried out in Japan. Anaerobic digestion had the highest overall benefit while composting had the least cost overall, followed by composting method. The study by Abu Samah *et al*. (2006) is quite similar to this study, where it structures solid waste management problems into hierarchy to assist in decision making process in order to select the best and appropriate technology for solid waste management. However, the study was carried out in 2006, quite a few years back. Promethee application is used in the study by Erceg & Margeta (2019) which evaluate different waste management options and their applicability. It studies that the overall problem of food waste can be solved by the treatment of organic waste from the WWTP using composting method.

The major characteristic from AHP is the implementation of pairwise comparison that compares the alternatives with respects to its criteria through weightage calculation. AHP allows the user to weight on the coefficient and compare the alternative selection based on the case study. The method majorly works on 3 parts which are firstly focusing on the issues required to be resolved, secondly is one the alternative solutions and method that are able to solve on the issues and lastly is on the concern while choosing the alternative solution where evaluation is carried for decision- making. Figure 1 show the flow process involved in AHP.

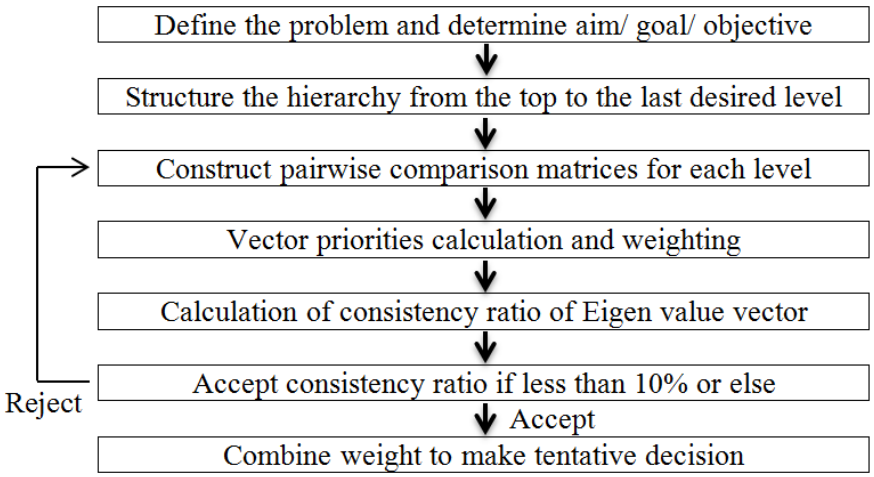

Figure 1. AHP process flow

The first step starts off with identifying the problems and determine on the objectives and goals to achieve during the study. Next is on structuring the hierarchy that consists of goal, criteria, sub-criteria and alternative. Evaluation of the data is collected from the judges in groups. During the evaluation of the data, judges vote based on the relative importance of the decision criteria. Pairwise comparison is then carried out to determine the priorities of the criteria and alternatives. Weightage calculation is also carried out to determine the weights of the criteria and the priorities of the alternatives of the study.

Methodology

The study tools focused in this study is on the application of Analytical Hierarchy Process (AHP) which is under the umbrella of Multi Criteria Decision Making (MCDM) to select on the most suitable food waste management system. It helps to organize and analyze complex decision, using math and psychology. AHP was developed by Thomas L. Saaty since 1970s and useful when there are multiple of criteria to consider while achieving the objectives. AHP allows to rank between the criteria considering the values of each other from high to low, most important to least important. It is a complex decision-making tool that involves both quantitative and qualitative. AHP is selected as the study tool as it captures and provide a framework that consists of criteria and alternative options to consider while making decision relating to goals. It allows the stakeholders to compare the importance of the criteria through the use of pairwise comparison, comparing two criteria at the same time. The AHP method define the problem into three parts. First part refers to the issues that need to be resolved, second part is on the alternate solution suggested or provided to solve the problem and third is on the concern of the criteria that is used to evaluate the alternative solution.

Figure 2 shows the basic and fundamental process and steps that involve during the study of AHP. It starts off with defining the problem of the study and proceed with understanding the goals to achieve, selecting the criteria and alternative solution method. Pairwise comparison is being carried out in order to check on the priority factors among the hierarchy structure. Next, the consistency is calculated to ensure it is below 0.1 or 10%, an acceptable level. Lastly, the weightage of each criterion and alternative is being calculate in order to evaluate on the best and suitable food waste management method.

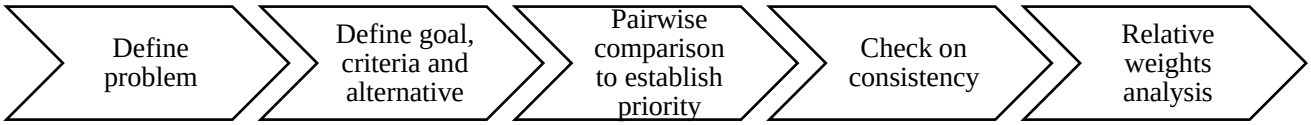

Figure 2. Research design framework

Construction of hierarchy structure

As the problem of the study is first determined, which is on the improper food waste management, the goal is set up to solve the problem. In the meantime, the criteria and alternative are also determined which is required to be evaluated. The goal, criteria, sub-criteria and alternatives built up the hierarchy structure.

Figure 3 shows the framework of AHP model specifying the goal, criteria, sub- criteria and alternative. The hierarchy structure of AHP is set up based on the problem of the study. It relies on breaking down the problem statement into sub- problem and evaluate the solution to emerge on it.

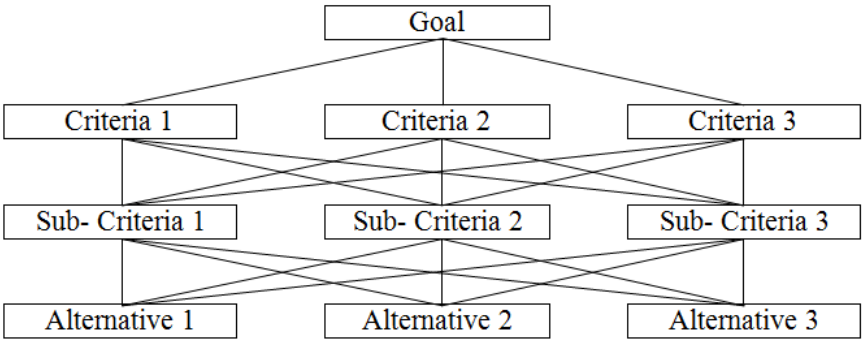

Figure 3. AHP hierarchy model

The hierarchy is structured into 4 levels such as goal, criteria, sub- criteria and alternative. It is developed by (Saaty, 2009), with 7 (+/- 2), maximum 9 criteria or alternative selection during the set-up of hierarchy structure for decision making. As the hierarchy structure is set up, the next step is on pairwise comparison, where 2 criteria are used to compare together at the same time.

Pairwise comparison

Pairwise comparison method is basically a process on comparing the entities in pairs to evaluate and judge on which entity is much more preferred. It determines the relative priorities of the alternatives with respect to the criteria. It can be one has greater amount of some quantitative property or either the two entities are identical to each other. The pairwise comparison matrix is implemented during the process which is used to compute on the relative priorities of the criteria or the alternatives selection.

Before carrying out the pairwise comparison, experts and judges were required to judge on the relative preference for the elements in each level. Questionnaires is first designed which includes the criteria, sub- criteria and alternative to consider during food waste management. The experts and judges answer the questionnaire based on their expertise and knowledge on food waste management. The results were collected and analyzed using Saaty's 9-point scale. The scale consists of 9-point

which represent on the different intensities of the importance level. Table 1 below shows the Saaty's scale based on 9-point scale. 1 indicates that the 2 criteria compared is equally important to each other; whereas 9 indicates that one criterion is extremely important or favoring over one another.

Table 1: Saaty's nine-point scale

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

Source: (Saaty, 2009)

Weightage calculation

As the pairwise comparison was being carried and tabulated into the comparison matrix from, weightage calculation can be carried out. The calculation involved in eigenvectors, consistency index, consistency ratio based on each pairwise comparison matrix. The eigenvalues of the pairwise comparisons were obtained using the equation below:

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

A refers to the comparison matrix; λ_{max} is the principal eigenvalue while W is the priority vector and I is the unit matrix.

For different systems and also different implementers, the results of the comparison matrix A is not the same with each other. The weighting coefficients of each of the indicator can be attained through the calculation of principal eigenvector from the comparison matrix. As the eigenvectors of the study was obtained, it was then proceeded to the consistency checking which is used to evaluate the experts' judgement based on the reasonability. Consistency Index (CI) were used with n as the pairwise comparison matrix.

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad (2)$$

CI refers to the consistency index; λ_{max} represent the maximal eigenvalue of the comparison matrix A which n refers to the dimension of the matrix.

$$CR = \frac{CI}{RI} \qquad (3)$$

The CI value was calculated using the number is random consistency indices (RCI) as show in table 2. The value of RCI range from the dimensional matrices of 1-10. The consistency ratio (CR) was

calculated by dividing CI with RCI. CR is used for the consistency judgement which is also an appropriate index.

Table 2: Random Consistency Indices (RCI)

n	1	2	3	4	5	6	7	8	9	10
RCI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: (Saaty, 2009)

The consistency ratio (CR) should not be over 0.1, considering the data is consistent and acceptable. It is advice to review and adjust on the data weight if the CR is over 0.1.

Results and Discussion

Figure 4 shows the AHP hierarchy structure which is built up into goals, criteria, sub-criteria and alternative preference selection. In this study there is a total of 1 goal, 4 criteria, 27 sub-criteria and 4 alternative treatment selection which built up the AHP hierarchy structure. The goal of the study is to select on the suitable food waste management method based on the 4 criteria which are environment, social, financial and technical. There are 4 different alternative treatment provided as the selection which are vermicomposting, backyard composting, aerated windrow composting and anerobic digestion. The common features among the 4 alternatives are they help to reduce the amount of waste being diverted to the landfill. As the AHP structure is built, pairwise comparison is then carried out to check on the consistency ratio to see if the results are consistent and acceptable.

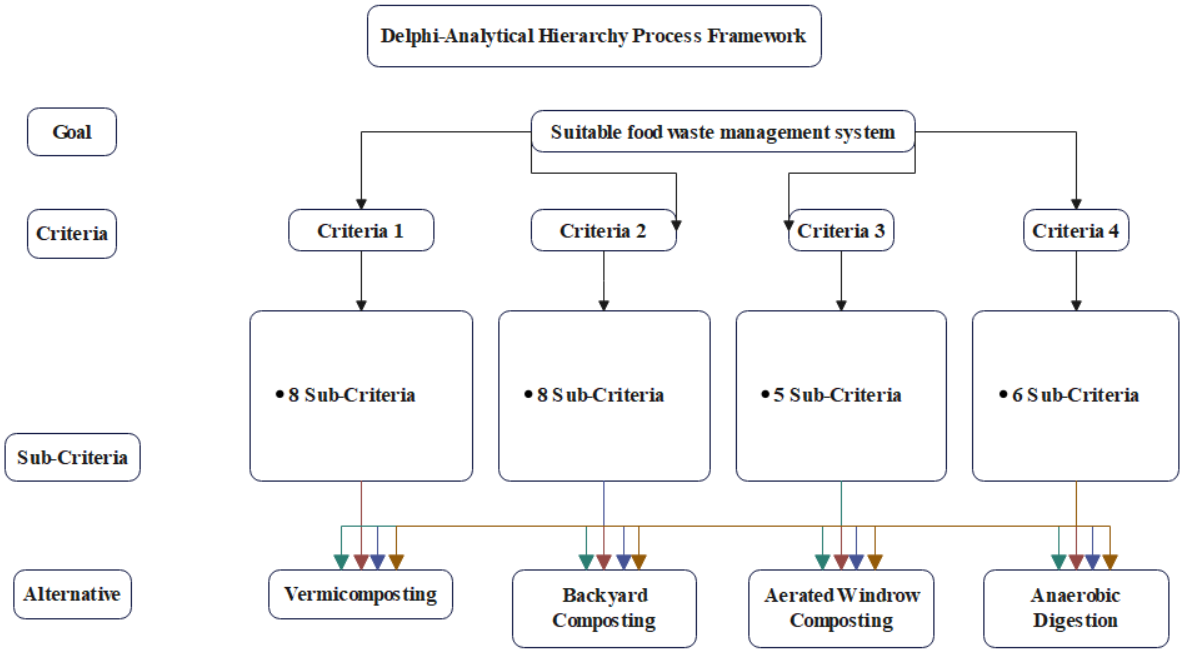

Figure 4. AHP hierarchy structure

The pairwise comparison is carried with the results of environment having the most weightage among the criteria, followed by social, financial and lastly on the technical. Among the sub-criteria of environment, air pollution, unpleasing odour and soil contamination are the most occupied weightage. As for social, the most weightage stands for public health, location wise and space. While for the

criteria of financial, it considers on operation and maintenance cost, resource recovery and revenue and income. For the technical criteria, efficiency, reliability and maintenance occupied the most among the other sub-criteria. Looking into the alternative treatment selection, it encourages on the AD, follow by vermicomposting, aerated windrow composting and finally backyard composting method.

For the environment, it focusses on the pollution that possible contributes by the food waste such as air pollution that leads to global potential and climate change, the soil contamination refers to the leachate produce as food waste degradation which can pollutes on the water resource. The social focus on the public health which is due to vector breeding if food waste is not treated properly, and for the location wise and space refers to a suitable place to carry out the food waste management treatment process. For the financial, it is vital is consider on the affordable of the stakeholder to maintain for the treatment system with respect to the operation and maintenance cost, resource recovery from food waste and also the revenue and income that can be attained from food waste. Lastly on the technical part which highly focus on the efficiency of the treatment, reliability and less frequent maintenance which able to brings the maximum value of the system.

MCDM is often used in the waste management. There are different method MCDM is also widely implemented, however AHP is selected to apply in this study. AHP is an ideal method as it breaks down the problem into constitutive elements and present it into relation to the main goal. It allows to reduce the number of comparisons and cognitive errors and confirm on the response consistency by comparing the criteria with multiple attributes through the hierarchy structure and group them accordingly on their entities and its characteristic. AHP is ideally suitable in making decision for food waste management system where is involve in various stakeholders having different consideration. Besides, during the AHP, it involves in evaluating the criteria on the importance weights based on the stakeholder's opinion. The approach in AHP supports on the selection of choice, evaluation, benefit-cost analysis, planning and development, decision- making, priority and ranking where it can be widely adopted such as in education, engineering, industry, management, manufacturing, society and others. AHP is widely used in solving problem on environmental management. As there are a few available and suitable food waste management treatment can be operated in Malaysia, thus it is important to determine on the criteria to consider before making decision on the food waste treatment system selection. Criteria to consider are such as the geography of the location, characteristics of food waste and so on.

In line with the circular economy, it is important to consider on AHP is encouraged to implement in the study as it supports on different criteria to consider while making decision. Decision making in food waste management issues is in line with Sustainable Development Goal (SDGs) particularly SDG 11 Sustainable cities and communities and SDG 12 Responsible consumption and production. It is vital to look into the use of sustainable methods and solution, implementing in food waste treatment. The sustainable method tends to produce a systemic approach that seeks to reduce food waste and its associated impacts towards the environment and human being. The circular economy also promotes in sustainability by having a sustainable food waste management treatment. It is a model of production and consumption that includes the production, consumption, reuse, repair, refurbish, recycling of the existing materials and products as long as possible.

Conclusion

From the results studied and analyzed above, it clear shows that AD is the most suitable treatment selection among the other treatment provided. It is easy to maintain on it and able to accept different kind of food waste unlike other system only acceptable plant-based product as animal product is hard to treat and maintain on it. The limitation for this study is on the food waste habits performed by human being. As each treatment has it unique feature to treat on each food waste characteristics, hence, by understanding the consumer food waste habits, more precise food waste treatment system can be arranged to treat on the food waste. In a nutshell, to ensure on having a more sustainable food waste management, it is encouraged to implement on the use of AHP while making decision. It is known that it is difficult when it comes to making a precise and accurate decision when there are different various criteria to consider on and alternative selection, thus the implementation of AHP helps to reduce cognitive errors. Besides, during the use of AHP, it priories on the criteria and alternative which it aims to achieve the goals set such as carrying out weightage calculation allows to discover on the important criteria to consider on while making decision. Most importantly is that AHP support on multi criteria decision making where is allows stakeholder to look into different alternative and provide judgement based on each pairwise comparison and constructing the hierarchy structure.

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