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Research paper



Intuitionistic Fuzzy DEMATEL for Municipal Solid Waste Treatment Technologies

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Abstract

Nowadays municipal solid waste (MSW) has gained attention in Malaysia. It is an unresolved issue since MSW management system applies improper and unsustainable MSW treatment technologies. According to the rapid urbanization, MSW is outstripping generated and this situation could affect the environmental, health and safety of the citizens. Thus, this study aims to visualise the most viable MSW treatment using decision making trial and evaluation laboratory (DEMATEL). Intuitionistic fuzzy (IF) sets is applied in linguistic scales of DEMATEL to deal with the linguistic imprecision and vagueness of the human judgment. Six alternatives of waste treatment technologies were identified and three experts were invited to provide linguistic evaluation in this case study. The linguistic evaluations were then analyzed using the five-step computational of intuitionistic fuzzy DEMATEL (IF-DEMATEL). The result shows anaerobic digestion as the most sustainable MSW treatment in Malaysia.

Keywords: *Municipal solid waste, Solid waste treatment, Intuitionistic fuzzy set, DEMATEL, Multi-criteria decision making*

1. Introduction

Municipal solid waste (MSW) is described as refuse or inescapable remainder discarded from residential, industrial, and institutional areas [1]. Due to the growing of global population dramatically and high production in industrialisation, the generation of MSW greatly increases and solid waste management becomes one of the critical issues in Malaysia. Rapid urbanization causes the proliferation of MSW by 28% in a period of a decade, from 5.6 Mt in 1997 to 7.65 Mt in 2007 [2] and it is predicted to further increase by 30% in 2020 and 39% in 2030[3].

Malaysia's government is seeking for the best alternative of waste treatment technologies to overcome the MSW generation issue. Three main alternatives are biological, thermal treatments and landfill. Biological treatments are divided into two. The first one is aerobic composting (decomposition of organic materials using microorganism in the presence of oxygen) and another one is anaerobic digestion (decomposition of organic materials using microorganism in the absence of oxygen). While thermal treatments are separated into three which are waste incineration, gasification and pyrolysis. Waste incineration is the technology that converts biomass to electricity and involves the combustion of organic substances contained in waste materials. Gasification is the technology approach in converting waste into fuel (syngas) while pyrolysis chemically decomposes organic materials by high temperature in the absence of oxygen.

It is necessary to analyse the relationship of waste treatment technologies alternatives and obtain the sustainable alternative for MSW treatment. Reference [4] introduces decision making trial and evaluation laboratory (DEMATEL) method to visualize the causal relationship of the models through a causal diagram. The DEMATEL has been proven as a capable multi-criteria decision making (MCDM) method in solving complicated problems and explaining the interconnected relationships among alternatives and criteria. Besides, DEMATEL method can verify the interdependence among the criteria and confirm the relation that reflects the characteristics with an essential system and evolution trend [5-7]. With the recent development of intuitionistic fuzzy (IF) set, the degree of uncertainty in human judgments is represented by three reasonable membership functions which are the degree of membership function, non-membership function and hesitancy function [8]. According to [9], IFS offers two main benefits in MCDM problems since it helps experts to express their preferences more accurately and IFS represents the extent of experts' disagreement.

In this study, IF set theory is applied in DEMATEL becomes IF-DEMATEL to obtain the sustainable alternative for MSW treatment technologies. The rest of the paper is organized as follows. Section II details the algorithm of IF-DEMATEL. Section III presents the feasibility of IF-DEMATEL to the case of alternative waste treatment technologies. Section IV shows the implementation and the results. Finally conclusions are then given in section V.

2. IF-DEMATEL

IF-DEMATEL approach developed by [10] is used to obtain the best alternative for MSW treatment technologies. The proposed five-step of the IF-DEMATEL are summarized as follows.

Step 1: Collection of linguistic data via interview with experts using preference scales of IF-DEMATEL provided by [10] as Table 1.

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Table.1: IF-DEMATEL Linguistic Scale.

Linguistic terms	Influence scores	Intuitionistic Trapezoidal Fuzzy Number	Expected Value
No influence	0	((0.0,0.0,0.0,0.0),(0.0,0.0,0.0,0.0))	0.0
Very low influence	1	((0.0,0.1,0.2,0.3),(0.0,0.1,0.2, 0.3))	0.15
Low influence	2	((0.3,0.4,0.5,0.6),(0.2,0.4,0.5,0.7))	0.45
High influence	3	((0.7,0.8,0.9,1.0),(0.7,0.8,0.9, 1.0))	0.85
Very high influence	4	((1.0,1.0,1.0,1.0),(1.0,1.0,1.0,1.0))	1.0

Step 2: Construct direct-relation matrix.
Expected value as equation (1) is used to obtain the crisp values and the average scores of experts' preferences are calculated.

Supposed $A = ((a_1, a_2, a_3, a_4), (b_1, b_2, b_3, b_4))$ be an intuitionistic trapezoidal fuzzy number in a set of real numbers.

$$\text{Thus, EV(A)} = \frac{1}{8}(a_1 + a_2 + a_3 + a_4 + b_1 + b_2 + b_3 + b_4) \quad (1)$$

Step 3: Normalization of direct-relation matrix using (2).

$$X = \frac{A}{s} \quad \text{where} \quad s = \max(\max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}, \max_{1 \le i \le n} \sum_{i=1}^{n} a_{ij}), \quad (2)$$

Step 4: Calculate total relation matrix using (3) in which *I* is denoted as the identity matrix.

$$T = X(I - X)^{-1} \quad (3)$$

Step 5: Construct causal diagram by equation (4)-(6).

$$T = \lfloor t_{ij} \rfloor_{n \times n,} \qquad i, j = 1,2,...,n \quad (4)$$

$$D = \left[\sum_{j=1}^{n} t_{ij} \right]_{n \times 1} = [t_i]_{n \times 1} \quad (5)$$

$$R = \left[\sum_{i=1}^{n} t_{ij} \right]_{1 \times n} = [t_i]_{1 \times n} \quad (6)$$

3. A Case of Alternative Waste Treatment Technologies

This study conducts a case of alternative waste treatment technologies in order to solve MSW management. On the basis of guided interview, three experts were invited to evaluate the sustainable waste treatment technology in Malaysia. The experts comprise two professors of environmental technology and an environmental engineer. They used fuzzy linguistic scale in Table I for making assessments on influential waste treatment technology in Malaysia. Six alternatives are adopted as evaluation alternatives which are aerobic composting (A_1), anaerobic digestion (A_2), waste incineration (A_3), gasification (A_4), pyrolysis (A_5) and landfill (A_6). These alternatives are concurrently considered in selecting the most viable and influenced waste treatment in Malaysia.

4. Implementation and Results

The case study is implemented using five-step of IF-DEMATEL as following.
Step 1: Collection of linguistic data via interview with experts. Example of the evaluations given by one of experts is shown in Table II.

Table.2: Evaluation by Expert 1

Criteria	A_1	A_2	A_3	A_4	A_5	A_6
A_1	0	0.15	0.45	0.45	0.45	0.85
A_2	1	0	0.85	0.85	0.85	1
A_3	0.85	0.45	0	0.45	0.85	1
A_4	0.45	0.45	0.45	0	0.45	0.85
A_5	0.85	0.45	0.45	0.15	0	0.85
A_6	0.15	0.15	0.15	0.15	0.15	0

Step 2: Construct direct-relation matrix using equation (2).

Step 3: Normalization of direct-relation matrix can be obtained using equation (3).

Step 4: Total relation matrix is calculated as presented in Table III.

Table.3: Total relation matrix

Criteria	A_1	A_2	A_3	A_4	A_5	A_6
A_1	0.11965	0.14306	0.14668	0.17804	0.18905	0.29565
A_2	0.4271	0.15153	0.31675	0.38771	0.40304	0.50992
A_3	0.41635	0.28024	0.15126	0.36384	0.40963	0.49702
A_4	0.25527	0.15618	0.16013	0.1243	0.25203	0.33333
A_5	0.20179	0.11618	0.11912	0.16481	0.10329	0.2608
A_6	0.12448	0.07601	0.07794	0.13372	0.14143	0.09514

Step 5: Construct causal diagram.
The sum of rows and the sum of columns in Table III are separately denoted as vector *r* and *c* through (4)-(6). $D_i + R_i$ is made by adding *r* to *c* and $D_i - R_i$ is made by subtracting *r* from *c* to obtain structural analysis as shown in Table II. Then, the horizontal axis vector (*D* + *R*) named "Prominence" shows the degree of importance of alternative *i* while the vertical axis (*D* – *R*) named "Relation" shows the net effect the alternative *i*

contributed to the case. When (*D* – *R*) is positive, alternative *i* is a net causer and when (*D* – *R*) is negative, alternative *i* is a net receiver. The causal diagram is constructed in Fig.1 based on structural analysis in Table IV.

Table .4: Structural analysis

	$D_i + R_i$	$D_i - R_i$
A_1	2.617	-0.473
A_2	3.119	1.273
A_3	3.090	1.146
A_4	2.634	-0.071
A_5	2.464	-0.533
A_6	2.640	-1.343

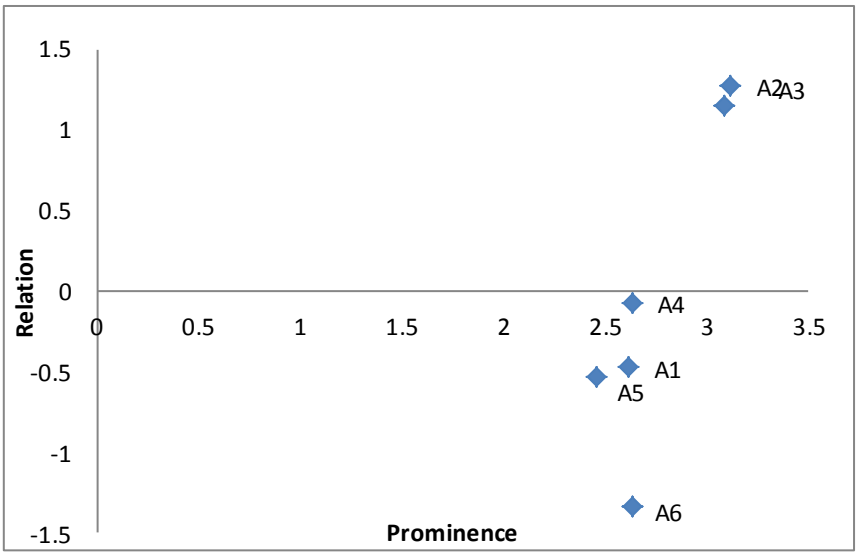


Fig. 1: Causal diagram of alternative waste treatment technologies

Table IV emerges several interesting findings. First, it can be seen that A_2 is the most important alternative since it has the highest (D + R) priority of 1.273 and most influencing alternative by the highest (D − R) priority of 3.119 while A_5 has the lowest (D + R) of 2.464 and A_6 has the lowest (D − R) priority of -1.343. According to the degree of importance (D + R), the order of alternatives waste treatment technology is identified as

$$A_2 \succ A_3 \succ A_6 \succ A_4 \succ A_1 \succ A_5 .$$

The horizontal axis of causal diagram in Fig.1 shows the importance of each alternative has, whereas the vertical axis may divide alternatives into cause group and effect group. The evaluation alternatives with positive value of (D – R); A_2 and A_3 are divided into the cause alternatives group located in upper part of causal diagram which is called net causer. On the other hand, effect alternatives group also known as net receivers contain A_1, A_4, A_5 and A_6 in accordance with the negative value of (D – R) located in lower part of causal diagram. The best strategy for MSW management is improving A_2 (anaerobic digestion) as proven in Fig.1. This result is supported by [11] that A_2 (anaerobic digestion) is the most sustainable waste treatment for Malaysian.

5. Conclusion

This study utilized the IF-DEMATEL method in order to form a structural correlation analysis and causal diagram in fuzzy environmental segmentation. With the advantages of intuitionistic fuzzy sets, IF-DEMATEL provides more reasonable characteristics for judgment where the degree of membership function, non-membership function and hesitancy degree were included to avoid an inadequate reflection of the vagueness in human judgments. Besides, this method can successfully divide alternatives into cause and effect groups through a causal diagram, thus the complexity of case study is easier to be deal and profound decisions can be made. This paper suggests that anaerobic digestion as the most sustainable MWS treatment. Waste incineration is also recommended as the viable MWS treatment. Nonetheless, this study contains some limitations. First, the shortage of experts to ensure the validity of the research, future research should conduct with more experts to achieve better exploration. Besides, it is good to employ sensitivity analysis in future research with the purpose to investigate the robustness of the method.

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