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Selecting the Suitable Waste to Energy Technology for India Using MULTIMOORA Method under Pythagorean Neutrosophic Fuzzy Logic

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Abstract. Municipal solid waste (MSW) development has increased on a global scale, posing significant socio-economic and environmental challenges. Waste to energy conversion is strategic because it can determine the best waste-to-energy technology. Recognizing the significance of waste in energy selection, this research aims to select the best technology based on its eco-friendliness. A two-phase methodology is used for presenting a framework for waste to energy technology selection. The first phase involves the selection of criteria for this problem and the perspectives of decision makers. Ranking the selected criteria using a novel SWARA method, and ranking the technology of WtE with respect to selected criteria weights are obtained. In this paper, we investigate the WtE technology problem using the novel concept of the Pythagorean Neutrosophic fuzzy set (PNFS). This set is a hybrid of the Pythagorean and Neutrosophic fuzzy sets. In this paper, we propose the best WtE technology for India. We employ the MULTIMOORA method in the Pythagorean Neutrosophic fuzzy environment for this purpose. Sensitivity and comparison analyses are also performed to ensure the framework's robustness. The findings of this study are useful in ranking the technology, and as a result, waste management can replicate the proposed framework for waste disposal for their new platform.

Keywords: Pythagorean Fuzzy Set, Neutrosophic Fuzzy Set, Pythagorean Neutrosophic Fuzzy Set, Multi-Criteria Decision Making, MULTIMOORA, WtE Technology.

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1. **Introduction**

Real-world decision-making problems are typically so complex and organized that traditional decision-making techniques cannot be applied. Human decisions are represented as precise numbers in traditional decision-making techniques. In many real applications, however, the information may be incomplete, or the experts may be unable to assign precise statistical measures to the assessment. As some of the judging criteria are subjective and descriptive in nature, it is challenging for the decision maker to express his or her priorities using precise statistical measures [1]. Rather, decision-makers generally focus on making linguistic assessment processes in the decision matrix. Moreover, conventional decision-making strategies are far less capable of coping with the imprecise or ambiguous nature of linguistic evaluations [2].

The increasing industrialization, urbanisation, and changes in lifestyle that accompany the process of economic growth result in the generation of increasing amounts of waste, posing increased environmental threats. In recent years, technologies have been developed that not only aid in the generation of a significant amount of distributed energy but also in the reduction of waste for safe disposal. The Ministry is promoting all available technology options for establishing projects for the recovery of energy in the form of biogas, bio-CNG, and electricity from renewable agricultural, industrial, and urban wastes, such as municipal solid wastes, vegetable and other market wastes, slaughterhouse waste, agricultural residues, and industrial wastes and effluents [3].

Solid waste management (SWM) disposal is at an advanced stage in India. There is an imperative need to build facilities to treat and dispose of growing amounts of MSW. More than 90% of waste in India is thought to be dumped in an unsatisfactory fashion. Waste dumps are estimated to have occupied approximately 1400 km^2 in the past few years, and this figure is expected to rise in the future. Waste disposal that is properly engineered protects public health and preserves critical environmental resources such as groundwater, surface water, soil fertility, and air quality [4]. Globally, solid waste generation is steadily increasing. According to the World Bank [15], worldwide annual waste generation has been rapidly increasing. This significant increase in MSW generation is affected by a variety of factors like economic growth, rising population, technological growth, urban growth, and rural-to-urban migration, among others. Along with the increasing quantity of waste, the concentration of MSW is becoming more diverse and complicated as a result of the development of developing societies based on consumer-based lifestyles [15, 16]. There is an urgent need to develop WtE technology, which can significantly reduce waste while also protecting the environment and public health.

Real-world problems, such as decision-making problems, are complicated and involve ambiguity and fuzzy logic. This motivated Zadeh [5, 6] to develop fuzzy set theory as a means to describe and transform information that was not accurate, but rather imprecise. Fuzzy logic theory provides a mathematical foundation for capturing the uncertainty and risk related to human thought processes such as logic and understanding [7]. Because of the complexity of information and the ambiguity of the human mind, the membership function of the fuzzy set is not always sufficient to reveal the characteristics of things. To address this limitation of the fuzzy set, Atanassov [8] transformed it into an intuitionistic fuzzy set (IFS) by including a non-membership function and a hesitancy function. An IFS can describe things in three ways: superiority, inferiority, and hesitation, which are typically represented by intuitionistic fuzzy numbers (IFNs) [9]. Yager [10–12] recently proposed the concept of Pythagorean fuzzy set (PFS) as a different assessment feature to obtain more valuable information under imprecise and ambiguous environments, which is characterised by the membership and non-membership degree satisfying the condition that their square sum is not greater than 1. Zhang and Xu [13] developed the Pythagorean fuzzy number concept and provided a comprehensive computational model for PFS.

In 1998, Smarandache [14] proposed the concept of Neutrosophic set and Neutrosophic probability, as well as their logic, which has three distinct logic components: truthfulness, indeterminacy, and falsity. This concept also includes the concept of hesitation, which gives the research a significant impact in various research areas. In a Neutrosophic fuzzy set, truth membership is denoted by T, indeterminacy membership by I, and falsity membership by F. These are all independent, with a sum of $0 \leq T + I + F \leq 3$, while uncertainty in IFS is determined by the degree of membership and non-membership, the indeterminacy factor in Neutrosophic fuzzy sets is independent of the truth and falsity values. The uncertainty, falsity, and hesitation information of a real-life problem can be described using a Neutrosophic fuzzy number. In this paper, we use the proposed method to combine two sets, such as Pythagorean and Neutrosophic fuzzy sets, to provide a more reliable solution to the WtE problem. In addition, many researchers studied the WtE problem using various types of fuzzy sets in various MCDM methods.

Several studies have been conducted to propose criteria for selecting waste-to-energy technologies. Abdel-Basset et al. [17] proposed and defined some operational rules for an advanced type of Neutrosophic technique in a type 2 environment. Farooq et al. presented appropriate MSW waste-to-energy technologies [18]. Yap and Nixon [19] used multi-criteria decision making based on the analytical hierarchical process to evaluate and compare WtE technologies. Different types of waste to energy technology for MSW were evaluated by Atwadkar et al [20] for Kolhapur. A life cycle assessment (LCA) of WtE treatment plants for electricity generation was proposed by Ayodele [21]. Abdel-Basset et al. [22] discussed the creation of an evaluation strategy to help Egypt choose the best renewable energy sources. Beyene et al. [23] discussed the most recent updates on WtE technologies, which convert waste into electricity, hydrogen gas, and other chemical feedstocks while being environmentally friendly. Chiu et al. [24] investigated the feasibility of using microbial fuel cells to convert solid waste organics into energy under a variety of operational conditions. To locate sustainable photovoltaic farms, Abdel-Basset et al. [25] used a hybrid multi-criteria decision-making approach in a neutrosophic environment. Khan et al. [26] explored the effects of renewable electricity generation from waste. Kurbatova and Abu-Qdais [27] used AHP to evaluate various WtE options in order to select the most appropriate technology for the Moscow region. Malav et al. [28] discussed the difficulties associated with WtE projects in India. Reddy [29] examined MSW WtE conversion in India. Abdel-Basset et al. [30] evaluated the sustainable bioenergy production through a case study in Egypt and further suggested that converting municial wastes to biogas is the most suitable sustainable bioenergy technology.

Different WtE technologies were reviewed by many researchers. All of the studies reviewed were aimed at identifying the most feasible WtE options for various countries using MCDM methods that are rapidly developing waste management. As a result, the aim of the research was to create a general framework for selecting the most appropriate WtE technologies for India based on environmental, socioeconomic, and technological factors. To achieve this, we employ the MULTIMOORA method, which employs a Pythogorean Neutrosophic fuzzy set to select the best solution.

2. Preliminaries

Definition 2.1. [31–33] Let U be a universal set. Then, a Pythagorean fuzzy set P, which is a set of ordered pairs over U, is defined by the following:

$$P = \{(u, \phi(u), \gamma(u))|u \in U\}$$

where $\phi_P(u) : U \to [0, 1]$ and $\gamma_P(u) : U \to [0, 1]$ define the degree of membership and the degree of non-membership, respectively, of the element $u \in U$ to P, which is a subset of U, and for every $u \in U$:

$$0 \leq (\phi_P(u))^2 + (\gamma_P(u))^2 \leq 1$$

Suppose $(\phi_P(u))^2 + (\gamma_P(u))^2 \leq 1$ then there is a degree of indeterminacy of $u \in U$ to P defined by $\pi_P(u) : \sqrt{1 - [(\phi_P(u))^2 + (\gamma_P(u))^2]}$ and $\pi_P(u) \in [0, 1]$. In what follows, $(\phi_P(u))^2 + (\gamma_P(u))^2 + (\pi_P(u))^2 = 1$. Otherwise, $\pi_P(u) = 0$ whenever $(\phi_P(u))^2 + (\gamma_P(u))^2 = 1$.

Definition 2.2. [31–33]

Let U be a universal set. A Neutrosophic fuzzy set N on U is an object of the form:

$$N = \{(u, \phi_N(u), \Omega_N(u), \gamma_N(u)) : u \in U\}$$

where $\phi_N(u), \Omega_N(u), \gamma_N(u) \in [0, 1], 0 \leq \phi_N(u) + \Omega_N(u) + \gamma_N(u) \leq 3$ for all $u \in U$, $\phi_N(u)$ is the degree of membership, $\Omega_N(u)$ is the degree of indeterminacy and $\gamma_N(u)$ is the degree of non-membership. Here, $\phi_N(u)$ and $\gamma_N(u)$ are dependent component and $\Omega_N(u)$ is an independent components.

Definition 2.3. [31–33] Let U be a universal set. A Pythagorean Neutrosophic fuzzy set (PNFS) with T and F are dependent Neutrosophic components D on U is an object of the

Table 1. Pythagorean Neutrosophic fuzzy linguistic scale

Linguistic term	membership values	indeterminacy values	non-membership values
Extremely high (EH)	0.85	0.10	0.15
Very high (VH)	0.75	0.20	0.25
Medium High (MH)	0.65	0.30	0.35
Medium (M)	0.55	0.40	0.45
Medium Low (ML)	0.35	0.60	0.65
Very Low (VL)	0.25	0.70	0.75
Extremely Low (EL)	0.15	0.80	0.85

form

$$D = \{(u, \phi_N(u), \Omega_N(u), \gamma_N(u)) : u \in U\}$$

where $\phi_N(u), \Omega_N(u), \gamma_N(u) \in [0,1]$, $0 \leq (\phi_N(u))^2 + (\Omega_N(u))^2 + (\gamma_N(u))^2 \leq 2$, for all $u \in U$, $\phi_N(u)$ is the degree of membership, $\Omega_N(u)$ is the degree of indeterminacy and $\gamma_N(u)$ is the degree of non-membership. Here, $\phi_N(u)$ and $\gamma_N(u)$ are dependent component and $\Omega_N(u)$ is an independent components.

Definition 2.4. [32] The score function of the Pythagorean Neutrosophic fuzzy sets with dependent Pythogorean Neutrospohic components I and F are defined as:

$$S_D(u) = (T + (1 - I) + (1 - F))$$

with the condition $0 \leq (\phi_N(u))^2 + (\Omega_N(u))^2 + (\gamma_N(u))^2 \leq 2$.

Definition 2.5. Linguistic variable deals with many real-world decision-making problems which are more complex and uncertain. Many research studies have different linguistic variables with fuzzy numbers [34]. Here, the linguistic variables with Pythgorean Neutrosophic fuzzy number to evaluate the WtE technologies based on selected criteria and the linguistic scale is presented in Table 1.

3. Mathematical Methods

MULTIMOORA is one of the most proficient MCDM models that emerged from the important contributions of Brauers and Zavadskas [35]. The MOORA method is the ancestor of the MULTIMOORA method. It employs three methods: the ration system (RS), the reference point (RP), and the full multiplicative form (FMF). The MULTIMOORA method algorithm is as follows: [34, 36]

3.1. *Ration system approach:*

The overall significance of the i^{th}alternative is as follows:

$$X_i = x_i^+ - x_i^- \tag{1}$$

where

$$x_i^+ = \sum_{j \in B} a_{ij} \tag{2}$$

$$x_i^- = \sum_{j \in C} a_{ij} \tag{3}$$

where, x_i^+ and x_i^- denote the sum of the normalized performance ratings of the importances obtained on the basis of the benefit and cost criteria; a_{ij} denotes the normalized performance ratings. Here, B and C represents the benefit and cost criterion respectively; $i = 1, 2, 3, ..., s$ and $j = 1, 2, 3, ..., t$.

The normalized performance ratings are obtained as:

$$a_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{x} (x_{ij})^2}}$$

where x_{ij} is the performance rating of the i^{th} alternative to the j^{th} criterion. The compared alternatives are ranked in descending order based on their x_i values, with the alternative with the highest x_i value being the best ranked.

3.2. *The reference point approach:*

The optimization based on the reference point can be shown as below:

$$R_i = min_i(max_j W_j \times d(p_j - a_{ij})) \tag{4}$$

Here, R_i is the overall performance of the reference point approach and $d(p_j - a_{ij})$ is the distance between the reference point and the normalized matrix, which is multiplied by the criteria weights.Here, p_j represents the j^{th} coordinate of the reference point, as:

$$\begin{aligned} p_j &= max_i \; a_{ij}; j \in B \\ p_j &= min_i \; a_{ij}; j \in C \end{aligned} \tag{5}$$

The compared alternatives are ranked in ascending order based on their r_i values, and the alternative with the lowest value of r_i is the best ranked.

3.3. *Full multiplicative form:*

In this approach, the overall utility of the alternative can be calculated as follows:

$$F_i = \frac{B_i}{C_i} \tag{6}$$

where B_i is the product of the weighted performance ratings of the benefit criteria and C_i is the product of the weighted performance ratings of the alternative's cost criteria. The compared alternatives are ranked in descending order and the highest value of F_i is the best result.

The MULTIMOORA was used to determine the final ranking of alternatives. Generally, different parts of the MULTIMOORA approach provide different ranking orders. The dominance theory was proposed by Brauers and Zavadskas [37] in order to describe the ranks provided by three approaches of the MULTIMOORA and determine the final ranking values.

3.4. *SWARA weighting method*

Kresuliene et al. [38] propose the SWARA method, which assists experts in determining criteria weights. The SWARA method is described below: [34]

Step 1: Rank the criteria based on their importance.

Step 2: Determine its relative importance β_i.

Step 3: To calculate the coefficient value Γ_j, where $\Gamma_j = \beta_j + 1$.

Step 4: Calculate the initial weights ω_j, $\omega_j = \frac{\beta_{j-1}}{\beta}$.

Step 5: Obtain the final weight of the criteria W_j, where $W_j = \frac{\omega_j}{\sum \omega_j}$.

4. **Application**

Nowadays, the amount of waste is rapidly increasing day by day due to population growth and a wide range of technologies. The government authorities are implementing different kinds of disposal methods to reduce the waste, but they are still finding the best solution for this problem without any harmful impact on the environment and society. In the current situation, waste management is facing many difficulties in reducing the waste that comes from industries, houses, institutes, hospitals, etc. Therefore, we make it necessary to reduce the waste in a good manner and we make energy from that waste. Developing countries are focusing on advanced technologies to make energy from MSW wastes, which helps to find environmentally friendly energy while at the same time reducing the amount of waste. In this study, we proposed the MULIMOORA method to obtain the best WtE technologies for India using a Pythagorean Neutrosophic fuzzy set. For this, we chose four types of WtE technologies based on economic, environmental, social, and technology aspects.

Table 2. Weight values of the criteria

Criteria	β_j	$\Gamma_j = \beta_j + 1$	$\omega_j = \frac{\beta_{j-1}}{\beta}$	$W_j = \frac{\omega_j}{\sum \omega_j}$
Technology	0	1	1	0.392
Society	0.25	1.25	0.8	0.314
Environment	0.35	1.6	0.5	0.196
Economic	0.4	2	0.25	0.098

5. Numerical example

In this section, we discuss the WtE technology problem under the Pythagorean Neutrosophic fuzzy set using the MULTIMOORA method. Here, the experts evaluate this problem based on the selected criteria. The WtE technologies are M_1- chemical and mechanical methods; M_2-new trends in WtE; M_3-biochemical methods; and M_4-thermal conversion method. To solve this problem, experts evaluate the WtE technologies using the proposed method. The linguistic scale is used to form a decision matrix. We are now analyzing the problem using the suggested model.

5.1. *SWARA method:*

Using the SWARA method, we obtain the weight values of the criteria, which are shown in Table 2.

5.2. *MULTIMOORA method:*

The WtE technologies and the criteria are given below:

M_1 – Chemical and mechanical method

M_2 – New trends in WtE method

M_3 – Biochemical method

M_4 – Thermal conversion method

Table 3. The ratings of the WtE technology obtained from the expert

Criteria / WtE	C_1	C_2	C_3	C_4
M_1	(0.75, 0.40, 0.45)	(0.25, 0.70, 0.45)	(0.15, 0.30, 0.15)	(0.85, 0.70, 0.45)
M_2	(0.85, 0.40, 0.35)	(0.55, 0.80, 0.25)	(0.35, 0.20, 0.75)	(0.85, 0.60, 0.45)
M_3	(0.55, 0.20, 0.35)	(0.25, 0.40, 0.65)	(0.75, 0.70, 0.65)	(0.85, 0.20, 0.65)
M_4	(0.85, 0.30, 0.65)	(0.85, 0.60, 0.75)	(0.85, 0.30, 0.65)	(0.15, 0.40, 0.65)

Table 4. Decision matrix

	C_1	C_2	C_3	C_4
M_1	1.9	1.1	1.7	1.7
M_2	2.1	1.5	1.4	1.8
M_3	2.0	1.2	1.4	2.1
M_4	1.9	1.5	1.9	1.1

$$\begin{aligned}&C_1 - \text{Economic}\\&C_2 - \text{Society}\\&C_3 - \text{Environment}\\&C_4 - \text{Technology}\end{aligned} \tag{7}$$

The experts then assess the WtE technology using the evaluation criteria they have chosen. Table 3 shows the expert evaluation results and which shows the ratings in the form of the PNFNs obtained as the result of the transformation of the linguistic variables from Table 1.

5.3. *Ratio system approach:*

The ranking results and the ranking order of the WtE technology were obtained on the basis of the RS approach. Using the PNFSs score function to create the decision matrix shown in Table 4, by applying Eqs. (2) and (3), we calculate the normalized decision matrix, which is shown in Table 5. The final ranking result of the RS approach is given in Table 6 using Eq. (1).

5.4. *Reference point approach*

By applying the procedure of RP, we obtained the weighted distance between the reference point and the normalized decision matrix using Eqs. (4), it is presented in Table 7. The reference point is calculated by applying Eq.(5) which are (0.4805, 0.5609, 0.5885, 0.5939) and the final ranking results are given in Table 8.

Table 5. Normalized decision matrix

	C_1	C_2	C_3	C_4
M_1	0.4805	0.4113	0.5266	0.5048
M_2	0.5311	0.5609	0.4337	0.5345
M_3	0.5058	0.4487	0.4337	0.5939
M_4	0.4805	0.5609	0.5885	0.3266

Table 6. The final ranking results for RS

WtE	Ranking values	Rank
M_1	0.9622	4
M_2	0.998	1
M_3	0.9705	3
M_4	0.9955	2

Table 7. Weighted distance between reference point and the normalized matrix

	C_1	C_2	C_3	C_4
M_1	0	0.0469	0.0121	0.0349
M_2	-0.0049	0	0.0303	0.0232
M_3	-0.0024	0.0352	0.0303	0
M_4	0	0	0	0.1047

Table 8. The final ranking results for RP

WtE	Ranking values	Rank
M_1	0.0469	3
M_2	0.0303	1
M_3	0.0352	2
M_4	0.1047	4

5.5. *Full multiplicative form:*

The ranking results and the ranking order of the WtE technology obtained on the basis of the FMF approach, by applying Eq (6), are shown in Table 10. For this, we first obtained the weighted normalized matrix, which is given in Table 9. The final ranking results are obtained using dominance theory, it as presented in Table 11.

Table 9. Weighted normalized decision matrix

	C_1	C_2	C_3	C_4
M_1	0.0470	0.1291	0.1032	0.1978
M_2	-0.0520	0.1761	0.0850	0.2095
M_3	-0.0495	0.1408	0.0850	0.2328
M_4	0.0470	0.1761	0.1153	0.1280

Table 10. The final ranking results for FMF

WtE	Ranking values	Rank
M_1	0.0560	2
M_2	0.0596	1
M_3	0.0545	3
M_4	0.0495	4

Table 11. The final ranking results of MULTIMOORA method

WtE	RA	RP	FMF	Final rank
M_1	4	3	2	2
M_2	1	1	1	1
M_3	3	2	3	3
M_4	2	4	4	4

From this Table 11, M_2- New trends in WtE technology is the most suitable and environment friendly method to convert the waste into energy.

6. **Comparison and sensitivity analysis**

6.1. *Comparison Analysis*

This section compares the proposed approach to a number of existing methods from the literature in order to demonstrate the method's efficiency and performance in comparison to those methods. The proposed methodology was compared to two existing techniques: the VIKOR [39] and the MOORA model [40]. These MCDM methods use the proposed criterion weights. The results of the ranking order comparison are shown in Table 12. The proposed ranking yields different results than the existing VIKOR and MOORA models. As a result, when compared to other MCDM models, the proposed approach yields more reliable findings.

Table 12. Comparison analysis results

WtE	VIKOR	Rank	MOORA	Rank	Proposed method
M_1	0.8010	4	0.3651	4	3
M_2	0	1	0.4248	1	1
M_3	0.4508	2	0.4160	2	2
M_4	0.5384	3	0.3762	3	4

Table 13. Weights in sensitivity analysis

WtE	Case 1	Case 2	Case 3
M_1	0.392	0.314	0.098
M_2	0.196	0.392	0.314
M_3	0.314	0.098	0.196
M_4	0.098	0.196	0.392

Table 14. Sensitivity analysis results-Case 1

WtE	RA	Rank	RP	Rank	FMF	Rank	DT
M_1	1.1787	3	0.0480	4	0.0559	2	2
M_2	1.3402	1	0.0388	2	0.0495	3	3
M_3	1.2615	2	0.0412	3	0.0396	4	4
M_4	1.1424	4	0.0388	1	0.1027	1	1

Table 15. Sensitivity analysis results-Case 2

WtE	RA	Rank	RP	Rank	FMF	Rank	DT
M_1	1.1787	3	0.0387	1	0.0401	4	4
M_2	1.3402	1	0.0412	2	0.0756	1	1
M_3	1.2615	2	0.0824	4	0.0744	2	2
M_4	1.1424	4	0.0697	3	0.0585	3	3

6.2. *Sensitivity analysis*

The sensitivity analysis of this model compares the results of three cases. Case 3 is the outcome of this study, and Cases 1 and 2 are the other outcomes discovered using different weights of the criteria. Sensitivity analysis shows that modifying the weights of the criteria has an effect on the ranking order.

7. Conclusion

The most widely used waste-to-energy technology for residual waste uses combustion to provide combined heat and power. Adopting maximum recycling with waste-to-energy in an integrated waste management system would significantly reduce dumping in India. Waste-to-energy technologies are available that can process unsegregated low-calorific value waste, and the industries are keen to exploit these technologies in India. Several waste-to-energy projects using combustion of un-segregated low-calorific value waste are currently being developed. Alternative thermal treatment processes to combustion include gasification, pyrolysis, production of refuse derived fuel and gas-plasma technology [4]. However, these WtE technologies have some drawbacks and in order to overcome this problem and selecting the best solution for waste to energy from new trends in WtE to achieve to reduce the sustainability factors resulting from the presence of many different indicators, this paper applies a hybrid multi-criteria decision-making approach under a Pythagorean Neutrosophic fuzzy environment.

Waste to energy (WtE) technologies have been identified as a promising solution for dealing with the problem of complexly composed and ever-increasing waste volumes in developed countries such as the European Union and the United States, among others. However, governments and policymakers continue to face significant challenges in selecting appropriate WtE technologies to design sustainable waste management systems for India. As a result, this study was carried out in order to propose a general systematic framework that can assist policymakers in identifying the most appropriate WtE technologies for designing waste management systems in India. In this paper, the score function of PNFS and the PNF-MULTIMOORA method based on it have been presented. The characteristic of each WtE technology is taken in the form of PNFNs. Based on the proposed method to find the best solution for this problem, New trends in WtE have been identified as the safest and most beneficial WtE technology in the current scenario, which is obtained from the proposed method. This method contributes to waste reduction while also producing energy, which will help with future energy demand issues.

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