MACBETH-MAIRCA Plithogenic Decision-Making on Feasible Strategies of Extended Producer's Responsibility towards Environmental Sustainability

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MACBETH-MAIRCA Plithogenic Decision-Making on Feasible Strategies of Extended Producer's Responsibility towards Environmental Sustainability

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Abstract

The environmental disarray caused by plastic usage alarms the world leaders to join hands in making coordinated efforts in creating a green globe to support environment for the future generation. The responsibility of promoting environmental sustainability is not confined to government alone as all the producer companies have equal share in mitigating the plastic waste. One of the ideal strategies of environmental conservation practiced by many of the nations at recent times is extended producer's responsibility (EPR). This research work purposes in building a multi-criteria decision-making model integrating the methods of MACBETH (Measuring attractiveness through a categorical-based evaluation technique) and MAIRCA (Multi Attributive Ideal-Real Comparative Analysis) in plithogenic environment to make optimal decisions on the plastic recycling methods subjected to four core criteria in EPR context. The efficiency of the newly developed integrated model is determined by comparing the model with other models integrating MAIRCA with the methods of CRITIC (CRiteria Importance Through Intercriteria Correlation) & FUCOM (Full Consistency Method). The sensitivity analysis helps in listing the merits and limitations of the proposed integrated model and also the consistency of the criterion weights and the ranking of the alternatives are checked.

Keywords: Plithogeny; Decision-making; MACBETH; MAIRCA; EPR; sustainability

1. Introduction

Waste is defined as the unwanted material and it is of different forms. Based on the forms, the wastes are generally classified as solid, liquid, gaseous, bio-degradable, non-biodegradable and hazardous. Based on the sources of waste generation, the wastes are classified as industrial, commercial, domestic, agricultural and chemical waste. Every nation's government is practicing various unused expelling methods such as land filling,

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composting, incineration, recycling and a few other unwanted materials processing techniques, but still waste management remains a growing challenge as the hazardous nature of the non-biodegradable wastes highly affect the environment when in contact and one such type is the plastic waste.

Plastics are synthetic substances made up of different polymers that substitute natural materials and have become an integral part of our day-to-day life. The flexibility, durability and the versatile nature of plastics are the salient features that stimulate plastic usage in different fields and these attributes have increased the production rate of plastics across the globe of more than 150 million tonnes every year. However, the increase in affinity towards plastic production and usage has resulted in the generation of plastic waste, a growing environmental concern. The recycling rate of plastic at global level is significantly low and the remaining quantity of plastic waste is disposed to the environment without proper treatment and this has resulted in air, water and land pollution. The lack of suitable eco-friendly methods of disposing plastics has caused a threat to living species of all kinds and nature. Generally, the plastics waste is handled by the conventional technique of recycling. Researchers have discussed intensely on plastic, its types, characteristics, pros and cons of plastic usage and the environmental impacts. Mechanical recycling, chemical recycling and energy recycling are the most commonly applied methods of recycling plastic wastes to usable forms. However, these methods have its own pros and cons in the context of implication in the real environment. It is a challenging task for the production sectors to make the optimal choice of feasible waste management methods and one of the ways of obtaining solutions to such challenging problems is MCDM (Multi-criteria decision-making).

Generally, in MCDM, the procedure of decision-making system involves a series of interconnected steps beginning from the input of decision data matrix based on the perspective of professionals in the respective decision field and resulting in the output of optimal decisions. The alternatives and the attributes characterize every decision-making scenario and the right choice of multi-criteria decision-making method performs a vital role in accomplishing the task of decision-making process. MCDM methods are comprehensively applied as solutions to several complex decision-making situations and waste management system is not an exception to it. In general, the decision-making system will not be deterministic in nature at all times as there are lot of possibilities of having imprecise input data. To handle the situations of uncertainty, fuzzy MCDM methods are used in decision-making problems on waste management. Fuzzy sets are extended to intuitionistic and neutrosophic sets to make data representation more realistic. Also, few other extensions such as interval-valued fuzzy sets, Pythagorean fuzzy sets, Hypersoft sets are also applied in data representation under neutrosophic environment [1-5]. Smarandache [6] generalized the above mentioned sets as Plithogenic sets (PS), which are characterized by a quintuple of the form (P,a,V,d,c) where P is a Plithogenic set, a is the attribute, V is the set of attribute value, d is the degree of appurtenance and c is the degree of contradiction. Plithogenic sets are more comprehensive in nature as it generalizes the representations of all kinds of sets. The Plithogenic representations in MCDM are more feasible as both attributes and attribute values are considered together with the degree of appurtenance between the alternatives and the dominant criterion attribute value and degree of contradiction between dominant criterion attribute value and other attribute values. The MCDM methods are integrated to develop efficient decision-making models. In general, two MCDM methods are combined one is to obtain the criterion weights and the other is to order the alternatives chronologically. Also, all decision-making situations do not deal only with quantitative data, many a times qualitative data is involved in decision – making. To solve such problems of making optimal decisions, FS, IFS, NS and PS are used to quantify qualitative data. In this work a unified Plithogenic decision-making model is put forth to make ideal decisions on plastic waste management.

The other contents of this research work are segmented as follows: section 2 presents a brief literature on the studies related to MCDM and plastic waste management along with the research works related to MACBETH,MAIRCA and EPR, section 3 comprises of the methodology of Plithogenic MACBETH and MAIRCA, section 4 applies the newly developed integrated method to a decision making situation on plastic waste management towards environmental sustainability, section 5 compares the results obtained from the proposed method of MACBETH – MAIRCA with other combinations of FUCOM-MAIRCA, CRITIC – MAIRCA to make inferences on the consistency of the results. The final segment concludes the work.

2. Literature Review

This segment consists of comprehensive review on the research works relating MCDM and plastic waste management, applications and developments in the methods of MACBETH and MAIRCA, framework of EPR.

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2.1 MACBETH

In general, the decision-makers opt simple, feasible and robust decision-making methods for obtaining criterion weights, also MCDM methods modelled using software are highly preferred and one such method is MACBETH developed in early 1990's. The characteristics of being humanistic, interactive and constructive make this method more preferable and it has adopted the approach of additive value aggregation model. Another advantage of this method is qualitative input, as quantitative input decision-making data is not possible at all times, to handle such types of instances the method of MACBETH is the right choice. Valerio and Salomon [7] suggested the manual computations of MACBETH are unreliable and suggested to develop software for computations. To make the method of MACBETH more consistent, M-MACBETH decision support system is developed to construct value trees, criteria descriptors, value functions, scoring options, weightage calculations and robust analyses. The software approach of modelling is an added feature of MACBETH. Researchers have applied the method of MACBETH to various decision-making situations such as in qualitative judgements, strategic product decisions, determining the utilities of the government in coalition formation, selecting facility layout, measuring the performance, ranking hydrogen storage technologies, finding the health value measurements. Dhouib [8] has extended the method of MACBETH in fuzzy environment to rank the alternatives in reverse logistics. Researchers have also combined the method of MACBETH with other MCDM methods such as EDAS (Evaluation based on Distance from Average Solution), MOORA(Multi Objective Optimization on the basis of Ratio Analysis), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution).The method of MACBETH is not much discussed in the either of the environments of FS, IFS, NS and PS, also the method is integrated only with few other ranking MCDM methods. This has been identified as the first gap in the proposed research.

2.2 MAIRCA

The method of MAIRCA is developed with the main objective of finding the variations between the true and the constructed alternative values. Researchers have applied crisp method of MAIRCA in in ranking the alternatives of different decision-making situations such as in making ideal choice of railway level crossing, location choice, selection of ammunition depots, evaluating the worker's ergonomics risk levels, supplier selection, evaluating supplier's performance, assessing the performance of deposit banks, selecting catering firms, material selection, assessing the operational performance of airline industry, selection of logistics centres. The compatible and robust nature of MAIRCA has made the researchers to combine the method of MAIRCA with decision-making methods. Researchers have made intensive studies on integrated method of MAIRCA with Entropy, CRITIC (CRiteria Importance Through Intercriteria Correlation), Best-worst method, FUCOM (Full Consistency method), SWARA (Stepwise Weight Assessment Ratio Analysis), DEMATEL-ANP (Decision making trial and evaluation laboratory - The Analytic Network process).

The combined methods of MAIRCA are discussed in fuzzy sense, Boral et al., [9] developed fuzzy MAIRCA (F-MAIRCA) with AHP (The Analytic Hierarchy process) to analyse failure modes and effects. Zhu et al., [10] devised DEMATEL-MAIRCA MCDM using fuzzy rough numbers. Fatih Ecer., [11] extended fuzzy MAIRCA to intuitionistic fuzzy MAIRCA and applied to make decisions on COVID vaccine selection age. Dragon et al [12] applied neutrosophic MAIRCA decision –making model to prioritize energy storage technologies. Hag et al in sustainable development [13]. Ozcil et al., [14] constructed Plithogenic MAIRCA which is a more generalized MCDM method of MAIRCA. Plithogenic decision making models are mostly preferred by the researchers in the field of decision-making as robust nature of Plithogenic sets and operators facilitate to make feasible decisions.

2.3 EPR

Presently the production rate of the products is increasing to meet the rapidly growing demands of the people. The industrial sectors make huge investment on smart production technology to maximize the annual production quantities. The responsibility of the production sectors do not get ceased with the product production alone, it get continues even after product consumption and till the end of the product lifetime. This extended responsibility of the producers is an attempt to conserve environmental sustainability from the product waste. Environmental regulations require all production areas to adhere to at least minimum quality standards in production and to implement eco-friendly strategies in waste treatment, but such regulations are not enforced after product sales and consumption. To enable the industrial sectors, realize their responsibility of environmental conservation exists even after product consumption, the EPR is introduced as a principle of environmental policy. The foundation of EPR was laid in the year 1981 and it was first accepted and implemented by European nations. Later many other developed nations and developing nations have started to

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incorporate EPR in their environmental policies. Organisation for Economic Co-operation and Development (OECD) has defined EPR as an environmental policy approach that extends the responsibility of the producer in waste disposal after the post consumption stage. Lindhqvist.,[15] have discussed about three different policy instruments of implementing EPR which are administrative, economic and informative. EPR policy is most commonly applied in managing plastic waste, E-waste, used tyres and automobile batteries. Yamini Gupt and Samraj Sahay., [16] have made an extensive study on 27 cases of EPR implementation and identified 13 common variables in dealing with upstream and downstream stages of EPR. The core aspects among the thirteen are found to be cost effectiveness, eco-friendly approach, energy efficiency and extendibility of waste to products. The studies on EPR strongly emphasize the need of including the attributes of EPR by the production sectors in the recycling process of plastic waste management and henceforth this research work has considered the criteria of selecting optimal plastic waste recycling method based on EPR elements.

2.4 Applications of MCDM in Plastic waste management

Researchers have presented numerous multi-criteria decision-making models on plastic waste management problems and are presented in Table 1 as follows

Table 1: Multi-criteria decision-making models on plastic waste management problems

MCDM methods	Objectives of Plastic Waste Management Problems	Factors of the Decision-making problem				Authors
		Criteria	Alternatives	Ranking	Addressable of EPR	
AHP (Analytical Hierarchy Process)	Prioritization of Plastic Recycling Process	Heterogeneity Supply Toxic Gas Process Energy Waste	Mechanical Recycling	1	No	(Mahendran and Mahadevan., 2014) [17]
			Chemical Recycling	3		
			Cement Klin	4		
			Blast Furnace	5		
			Road Fill	2		
TOPSIS (Technique for order preference by similarity to an ideal solution) Methodemploying similarity measures &fuzzy information	Sustainable Plastic Recycling Process	Cost Co2 Emissions Technical Capability Energy Energy Consumption	Mechanical Recycling	1	No	(Muhammad R et al,2021) [18]
			Chemical Recycling	2		
			Energy Recycling	3		
			Chemical Recycling	2		
			Energy Recycling	3		
Fuzzy AHP–TOPSIS	Making ideal choice on the methods of plastic reuse	Economic performances Resource management Technology interference Training personnel	Mechanical Recycling	1	No	(Vinodh et al., 2014) [19]
			Chemical Recycling	2		
			Energy Recycling	3		
Fuzzy AHP-Goal Programming	Choosing ideal processing method of unused plastic	Ecological impact,the managerial ability, Cost to bespent, resources available, and	Landfill	5	No	(Nirmala and Uthra., 2018) [20]
			Mechanical	1		
			Incineration	3		
			Feedstock recycling	2		

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		Potential financial benefits	Biodegradable plastic production	4		
MCDA (Multi-Criteria Decision Analysis)	Evaluating Plastic Waste Disposal Options	Environmental Economic Social	Recycling (inland)	1	No	(Saurav Bhagat et al .,2016) [21]
			Incineration	2		
			Landfill	3		
			Recycling Export	4		
Fuzzy Preference Relation	Best plastic recycling method using trapezoidal linguistic representations	Financial Benefits, Managerial ability, Environmental impacts, Use of resources	Mechanical	2	No	(Nirmala and Uthara., 2017)[22]
			Thermal	1		
			Chemical	3		

From Table 1 it is very evident that only the methods of AHP, TOPSIS and their combination are widely used in making optimal decisions on plastic waste management both in deterministic and fuzzy sense. In addition to the above-mentioned research works Ali Utku Akar et al [23] applied the method of Fuzzy AHP in making decisions on optimal method in plastic recycling process. The method of AHP is used in determining the criterion weights and the method of TOPSIS is used in ranking the alternatives. In the above decision-making problems, the concept of extended producer's responsibility is not included and majority of the problems are discussed in very generic sense of utility but not in production point of view. The notion of environmental conservation and the choice of criteria are not discussed in the context of producer's responsibility. This shows the existence of gap in the MCDM research on plastic waste management in the context of EPR and this is considered as the first gap in the proposed research. In earlier research works of MCDM and Plastic waste management, the decision –making is narrowed down only to a single dimension of utility in consumer's context but not in the joint or coordinated efforts between both producers and consumers. The two research gaps have motivated the authors to develop an integrated Plithogenic MCDM model combining MACBETH with MAIRCA to determine the most suitable and feasible plastic recycling method in the context of EPR. The developed integrated model will be more comprehensive in nature because of the following reasons (i) Plithogenic decision making model - the most generalized model

(ii) Incorporation of EPR features - very essential in analyzing waste management methods

(iii) Highly pragmatic and realistic in formulating initial qualitative decision-making matrix

3. Methodology

This segment briefs the different steps involved in the MCDM methods of MACBETH, FUCOM, CRITIC and Plithogenic MAIRCA.

3.1 MACBETH

Step 1 : The criteria considered for decision making are decided and the value tree is constructed.

Step 2 : A z×z decision matrix is framed where z signifies the number of criteria. The significant criteria are arranged from left to right and the qualitative performance levels are converted to MACBETH scale. In general, two reference levels are fixed one is upper reference level (URL) that is good and the other lower reference level (LRL) is neutral. The score value of URL is 100 and LRL is 0 but it does not indicate the best and worst performance and the worst performance respectively.

Step 3 : Pair-wise criteria comparison is done based on the differences of attractiveness using semantic scale comprising of a set of seven categories.

Step 4 : The consistency is tested using M-MACBETH software and possible alterations are made accordingly.

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Step 5 : The judgments are converted to numerical concerned linear programming problem models. The weighted global final values of the alternatives are determined using additive aggregation model.

3.2 FUCOM (Full Consistency Method)

Dragon Pamucar et al.,[24] introduced the method of FUCOM (Full Consistency Method) . This method is a new MCDM model that is used to acquire the weights of each criterion. Pairwise comparison of each criterion can be done by FUCOM technique and requires n-1 pairwise evaluation to find the weights.

The below steps are used to find the weights of each criterion.

Step 1: Criteria or sub-criteria WC= $\{WC_1, WC_2 \ldots \ldots WC_n\}$ are ranked based on decision makers opinion.

Step 2: The relative preferences of the ranking criteria were ascertained by the selection of the expert's perspective, $\varphi r_{/(r+1)}$; where r is the rank of criteria.

Step 3: Determine the weight coefficients of each criterion by using a non-linear optimization technique.

The weight scale must satisfy two constraints:

Constraint 1: $\frac{\omega_r}{\omega_{r+1}} = \varphi r_{/(r+1)}$ ---------- (3.1)

(i.e.) The weighting coefficients are equivalent to the criteria tested

Constraint 2: The condition of Mathematical Transitivity

(i.e.) $\varphi r_{/(r+1)} \otimes \varphi (r+1)_{/(r+2)} = \varphi r_{/(r+2)}$ --------(3.2)

Step 4 : Develop a NLPP model to calculate the weight coefficients

min χ

s.t $\left|\frac{\omega_{jr}}{\omega_{j(r+1)}} - \varphi r_{/(r+1)}\right| \leq \chi$, for all j

$\left|\frac{\omega_{jr}}{\omega_{j(r+1)}} - \varphi r_{/(r+1)} \otimes \varphi (r+1)_{/(r+2)}\right| \leq \chi$, $forallj$

$\sum_{j=1}^{n} \omega_j = 1$, $\omega_j \geq 0$, for all j -------(3.3)

Step 5 : Comput the weights of each criterion $(\omega_1, \omega_2, \ldots . \omega_n)^T$

3.3 CRITIC (1995)

Diakoulaki et al., (1995) [25] proposed the method of CRITIC (CRiteria Importance Through Intercriteria Correlation).This method employs the notion of standard deviation to calculate the differential concentration of each parameter. This method assures that the prime criterion possesses higher values.

The below steps are involved in this method

Step 1: Form a Decision matrix based on DM's judgment.

Step 2: Formulate an aggregate matrix by using fuzzy operators

Step 3: Obtain a Normalization matrix using the below equation

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$$x_{mn}^{*} = \frac{x_{mn}-x_j^-}{x_j^+-x_j^-} \;;\; x_j^+ = \max(x_{mn}) \;\&\; x_j^- = \min(x_{mn}) \qquad \text{------- (3.4)}$$

Step 4: Determine Standard deviation (σ_j)

Step 5: Calculate the correlation coefficient ($r_{jj'}$) between two criteria x_j & $x_{j'}$

Step 6: Using the below equation, evaluate the measure of conflict criteria

$$\sum_{j'=1}^{s}(1-r_{jj'}) \qquad \text{------ (3.5)}$$

Step 7: Determine the objective weights of criteria

$$WC_j = \sigma_j * \sum_{j'=1}^{s}(1-r_{jj'}) \qquad \text{------- (3.6)}$$

$$\omega_j = \frac{WC_j}{\sum_{j=1}^{s} WC_j} \qquad \text{-------- (3.7)}$$

3.4 Plithogenic MAIRCA

The following procedures are applied to find the rank of alternatives

Step 1: Formulate an Initial Decision-making matrix (IDM) based an expert's opinion with alternatives and criteria

DM= X= $\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$, i varies from 1 to m and j varies from 1 to n.

where, x_{rs} is the membership function of each criterion. The beneficial and cost criteria are chosen and decide the ideal value (p_j^+), the best performance of criteria and the anti-ideal (p_j^-) is the worst performance of criteria. Linguistic variables used are quantified by neutrosophic representations.

Step 2: Obtain an aggregate matrix using plithogenic aggregate operators

The plithogenic aggregate operators are defined by (Smarandache., 2018) [6]

$$\left(a \wedge_F d, \frac{1}{2}(b \wedge_F e + b \vee_F e), c \vee_F f\right)$$

$$a \wedge_F d = ad, a \vee_F d = a + d - ad$$

$$a \wedge_F b \text{ is } t_{norm} \;\&\; a \vee_F b \text{ is } t_{conorm}. \qquad \text{------------- (3.8)}$$

(T, I, F) is the Neutrosophic set N, that is converted in to intuitionistic fuzzy (IF) set (T, f) by the using impression membership technique (Solairaju and Shajahan.,2018) [26], is given below

$$f_A = \begin{cases} F_A + \frac{[1-F_A-I_A][1-F_A]}{[F_A+I_A]} \, if F_A = 0 \\ F_A + \frac{[1-F_A-I_A][F_A]}{[F_A+I_A]} \, if \;\; 0 < F_A \le 0.5 \\ F_A + [1-F_A-I_A]\left[0.5 + \frac{F_A-0.5}{F_A+I_A}\right] if \; 0.5 < F_A \le 1 \end{cases} \qquad \text{-----(3.9)}$$

$$<\Delta(A)> = <\frac{T_A}{[T_A+f_A]}>.$$

is determined by using median membership fuzzy values .

Plithogenic aggregated operators are used to formulate initial decision matrix

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Step 3: Calculate the Preferences of alternatives

$$P(A_i) = \frac{1}{r}, \sum_{i=1}^{r} P(A_i) = 1 \qquad \text{------- (3.10)}$$

Step 4: Calculate the Expected theoretical matrix

$$T_P = P(A_j)*\omega_j \qquad \text{----- (3.11)}$$

Step 5: Determine the Actual matrix

$$T_R = \begin{pmatrix} t_{r11} & t_{r12} & \dots & \dots & t_{r1s} \\ t_{r21} & t_{r22} & \dots & \dots & t_{r2s} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ t_{rs1} & t_{rs2} & \dots & \dots & t_{rrs} \end{pmatrix} \qquad \text{------ (3.12)}$$

For benefit criteria, take maximum value of preference and non-benefit (cost type), choose minimum value of preference

$$T_{Rij} = T_{Pij}*\left(\frac{x_{ij} - x_i^-}{x_i^+ - x_i^-}\right); \quad T_{Rij} = T_{Pij}*\left(\frac{x_{ij} - x_i^+}{x_i^- - x_i^+}\right) \qquad \text{----- (3.13)}$$

Here, $x_i^- = \min(x_i)$, $x_i^+ = \max(x_i)$

Step 6: Construction of Total Gap matrix (T_G)

$$T_G = T_P - T_R; \text{ where } G = g_{ij} \in (0, (T_{Pij} - T_{Rij})) \ \& T_{Pij} > T_{Rij} \qquad \text{--------- (3.14)}$$

Step 7: Ranking the Alternatives

$$Q_i = \sum_{j=1}^{n} g_{ij} \text{ ; i= 1, 2......m} \qquad \text{------ (3.15)}$$

Arrange the alternatives in descending order and choose the smallest ratio as the top value.

4. Decision Making on Plastic Waste Management

In this section the decision – making problem is to select the feasible method of recycling plastic waste based on the criteria in the context of EPR. The alternatives and the criteria are given as follows in Table 2.

Table 2: Elements of Decision -Making

Alternatives	Criteria
Mechanical Recycling (A1) Chemical Recycling (A2) Energy Recycling (A3)	Cost Effectiveness (CE) Eco friendly (EF) Energy efficiency (EE) Extendable (E)

4.1 MACBETH-Plithogenic MAIRCA

By employing M-MACBETH software, the criterion weights are determined as follows.

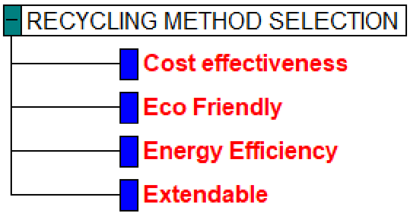

Figure 4.1: The Decision value tree

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The Pair-wise comparison matrix using semantic scale representations is presented in Fig.4.2

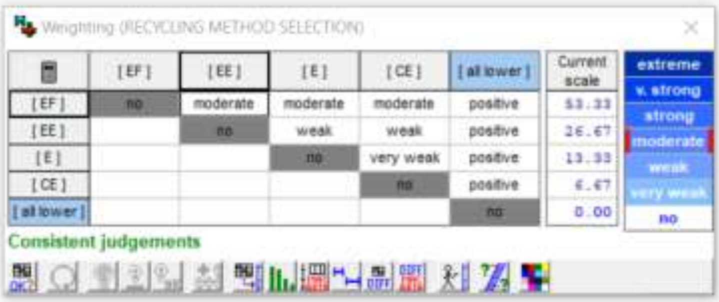

Fig.4.2 Pairwise comparison matrix

The criterion weights are represented in Fig.4.3

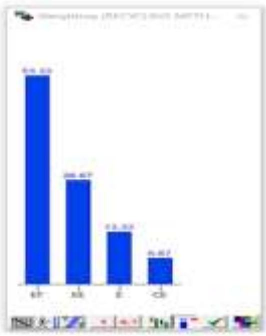

Fig. 4.3 Graphical representation of Criterion weights

The finally obtained criterion weights using M-MACBETH software are presented in Table 3

Table 3: Criterion weights

Cost effectiveness (CE)	Eco-Friendly (EF)	Energy Efficiency (EE)	Extendable (E)
0.533	0.2667	0.1333	0.067

Thus the DM's recommendations are transformed into an LP model and Utilizing M-MACBETH software, all criterion weights are determined

4.1.1 Plithogenic MAIRCA

In this section the method of MAIRCA under plithogenic environment is used to rank the alternatives. The linguistic terms used for quantification are presented in Table 4.

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Table 4: Quantification of Linguistic terms Of Fuzzy values

Very Low	VL	0.1
Low	L	0.35
Moderate	M	0.55
High	H	0.8
Very High	VH	0.95

The decision maker's opinion relating the alternatives to the criteria are presented in Table 5 and this represents the initial decision matrix (IDM).

Table 5 IDM based on Decision Makers Opinion

	DM'S	Cost effectiveness CE	Eco-Friendly EF	Energy Efficiency EE	Extendable E
Mechanical Recycling (MR)	DM1	VH	M	VL	L
	DM2	M	H	VH	M
Chemical Recycling (CR)	DM1	M	H	L	VH
	DM2	H	L	VH	M
Electrical Recycling (ER)	DM1	M	VL	VH	L
	DM2	VL	VH	H	M

IDM created utilising the quantification of linguistic terms which is presented in Table 5 is based on the opinions of two distinctive experts. The plithogenic aggregated value is presented in Table 6 using step 2 of section 3.4.

Table 6: Plithogenic aggregated value

		DM1	DM2	DM1 $\wedge_P$ DM2
A1	WC1	0.95	0.55	0.5225
	WC2	0.55	0.8	0.44
	WC3	0.1	0.95	0.095
	WC4	0.35	0.55	0.1925
A2	WC1	0.55	0.8	0.44
	WC2	0.8	0.35	0.28
	WC3	0.35	0.95	0.3325
	WC4	0.95	0.55	0.5225
A3	WC1	0.55	0.1	0.055
	WC2	0.1	0.95	0.095
	WC3	0.95	0.8	0.76
	WC4	0.35	0.55	0.1925

Table 7 comprises of the final plithogenic aggregated value obtained using the equations (3.8) & (3.9)

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Table 7: Final Plithogenic aggregated values

Criteria/ Alternatives	WC1	WC2	WC3	WC4
A1	0.523	0.44	0.095	0.193
A2	0.44	0.28	0.333	0.523
A3	0.055	0.095	0.76	0.193

Let us take the preference of alternative is $\frac{1}{3} = 0.333$ as stated in eq (3.10). Using eq (3.11) the values of the theoretical ranking matrix are obtained and it is presented in Table 8.

Table 8: Theoretical Ranking matrix

	0.533	0.2667	0.1333	0.067
0.333	0.177	0.089	0.044	0.022
0.333	0.177	0.089	0.044	0.022
0.333	0.177	0.089	0.044	0.022

The final real rating matrix is obtained using eq (3.13) and it is presented in Table 9

Table 9 : Final Real Rating matrix

0.177	0.089	0.000	0.000
0.146	0.048	0.016	0.022
0.000	0.000	0.044	0.000

All the criteria are evaluated as having the greatest possible values because they were all desired outcomes. In order to apply the normalisation process for the beneficial and non-beneficial criteria, expression (3.13) was used then the real ranking matrix (**T_r**) was produced and shown in Table 9. The total gap matrix is obtained using the eqs (3.14) & (3.15) and it is represented in Table 10.

Table 10: Total Gap matrix

	WC1	WC2	WC3	WC4	SUM Qi	Ranking of Alternatives
A1	0	0.000	0.044	0.022	0.0667	**1**
A2	0.031	0.041	0.029	0.000	0.1012	**2**
A3	0.177	0.089	0.000	0.022	0.2886	**3**

The alternatives' performance rankings have been obtained and are listed in Table 10.

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4.2 CRITIC-Plithogenic MAIRCA

Table 11: IMD of the Decision makers

	DM'S	Cost effectiveness CE	Eco-Friendly EF	Energy Efficiency EE	Extendable E
Mechanical Recycling (MR)	DM1	VH	M	VL	L
	DM2	M	H	VH	M
Chemical Recycling (CR)	DM1	M	H	L	VH
	DM2	H	L	VH	M
Electrical Recycling (ER)	DM1	M	VL	VH	L
	DM2	VL	VH	H	M

Table 11 presents IDM, which was developed using the quantification of linguistic concepts given in Table 4 and is based on the insights of two different experts.

Table 12: Fuzzy Aggregated values

		DM1	DM2	DM1 $\wedge_F$ DM2 (Crisp Value)
A1	WC1	0.95	0.55	0.55
	WC2	0.55	0.8	0.55
	WC3	0.1	0.95	0.1
	WC4	0.35	0.55	0.35
A2	WC1	0.55	0.8	0.55
	WC2	0.8	0.35	0.35
	WC3	0.35	0.95	0.35
	WC4	0.95	0.55	0.55
A3	WC1	0.55	0.1	0.1
	WC2	0.1	0.95	0.1
	WC3	0.95	0.8	0.8
	WC4	0.35	0.55	0.35

Using the fuzzy aggregate operators in step 2 of the CRITIC method, IDM is developed based on the opinions of two key experts, as shown in table 12.

Table 13: Aggregated Expert's opinion

	WC1	WC2	WC3	WC4
A1	0.55	0.55	0.1	0.35
A2	0.55	0.35	0.35	0.55
A3	0.1	0.1	0.8	0.35
Max	**0.55**	**0.55**	**0.8**	**0.55**
Min	**0.1**	**0.1**	**0.1**	**0.35**

The initial decision matrix was computed using data from table 12, and it is presented in table 13.On applying the expression (3.4), the normalized decision matrix is created and is shown in Table 14.

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Table 14: Normalized Decision making Matrix

	WC1	WC2	WC3	WC4
A1	1.00	1.00	0.00	0.00
A2	1.00	0.56	0.36	1.00
A3	0.00	0.00	1.00	0.00
Standard deviation	**0.577**	**0.501**	**0.507**	**0.577**

The Pearson correlation is typically used to assess the consistency between two sets of weights obtained from two different methodologies. The correlation between two data arrays may not be correctly represented by the Pearson correlation coefficient. So, consistency was measured using the correlation. Table 15 displays the calculated correlation between each pair of criteria using step 5.

Table 15: Correlation between the criteria

	WC1	WC2	WC3	WC4
WC1	1	0.896	-0.936	0.500
WC2	0.896	1	-0.995	0.064
WC3	-0.936	-0.995	1	-0.163
WC4	0.500	0.064	-0.163	1

Table 16 provides a measure of the conflict each criterion creates using the eq (3.5)

Table 16: Measure of the conflict created by criterion

	WC1	WC2	WC3	WC4	$\sum_{j=1}^{m}(1-r_{ij})$
WC1	0.000	0.104	1.936	0.500	**2.540**
WC2	0.104	0.000	1.995	0.936	**3.035**
WC3	1.936	1.995	0.000	1.163	**5.094**
WC4	0.500	0.936	1.163	0.000	**2.599**

Determining the amount of data in accordance with each criterion, an objective weight is obtained from the relation (3.5 & 3.6), which is shown in Table 17.

Table 17: Objective weight of the criteria

Criterian	Standard Deviation (σ_j)	$\sum_{j=1}^{m}(1-r_{ij})$	$WC_j = \sigma_j * \sum_{j=1}^{m}(1-r_{ij})$	$w_j = \frac{WC_j}{\sum_{j=1}^{n} WC_j}$
WC1	0.577	2.540	1.47	0.2073
WC2	0.501	3.035	1.52	0.2151
WC3	0.507	5.094	2.58	0.3654
WC4	0.577	2.599	1.50	0.2122

Each criterion's weights is determined using the eq (3.6), which is displayed in Table 18

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Table 18: Weights of each criterion

Criteria	WC1	WC2	WC3	WC4
Weights	0.2073	0.2151	0.3654	0.2122

4.3 FUCOM-Plithogenic MAIRCA

The preference of the criteria based on Experts opinion is presented in Table 19 using table 4 and (3.8)

Table 19: Preference criteria of the Experts

	DM1	DM2	DM1	DM2	DM1^DM2
WC1	M	VH	0.55	0.95	0.55
WC2	H	M	0.8	0.55	0.55
WC3	H	VH	0.8	0.95	0.8
WC4	M	L	0.55	0.35	0.35

On making pairwise comparisons of the criteria using the method of FUCOM the criterion coefficient values are obtained. It is possible to order the criteria in the above way. Table 20 can be used to identify and display the criteria's order of priority.

The preference of the criteria based on Experts opinion

$$WC3 > WC2 > WC1 > WC4$$

Table 20: Priority of the criteria

Criteria	WC1	WC2	WC3	WC4
$\emptyset r/_{(r+1)}$	1	2.2	3.5	4

Comparative Priority/ Importance of the Criteria

$\emptyset_{\left(\frac{C_3}{C_2}\right)} = \frac{2.2}{1} = 2.2$, $\emptyset_{\left(\frac{C_1}{C_4}\right)} = \frac{4}{3.5} = 1.143 \emptyset_{\left(\frac{C_2}{C_1}\right)} = \frac{3.5}{2.2} = 1.59$

Values of weight coefficients are obtained from (3.1 &3.2)

Condition: 1

$\frac{w_3}{w_2} = 2.2$, $\frac{w_2}{w_1} = 1.59,$ $\frac{w_1}{w_4} = 1.143$

Condition : 2

Mathematical Transitivity

$\left(\frac{w_3}{w_2}\right)*\left(\frac{w_2}{w_1}\right)=\left(\frac{w_3}{w_1}\right)$ = 2.2*1.59=3.498,

$\left(\frac{w_2}{w_1}\right)*\left(\frac{w_1}{w_4}\right)=\left(\frac{w_2}{w_4}\right)$ = 1.59*1.143=1.817

Using (3.3), the final typical for finding weight coefficients are as follows,

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Min Ψ

$$\text{s.t}\begin{cases}\left|\frac{w_3}{w_2}-2.2\right|\leq\Psi,\left|\frac{w_2}{w_1}-1.59\right|\leq\Psi,\left|\frac{w_3}{w_4}-1.177\right|\leq\Psi,\left|\frac{w_1}{w_4}-1.143\right|\leq\Psi,\\ \left|\frac{w_3}{w_1}-3.498\right|\leq\Psi,\left|\frac{w_2}{w_4}-1.817\right|\leq\Psi,\\ \sum_{j=1}^{5}w_j=1,\quad w_j\geq 0,\forall j\end{cases}$$

By using LINGO software, Solving the above LPP model, the weight coefficients are determined. The weight coefficients are $w_1 = 0.0697$, w_2= 0.1109, w_3 = 0.2439, w_4 =0.5755, The Objective function Ψ= 0

Table 21: Criterion weights

Criteria	WC1	WC2	WC3	WC4
Weights	0.0697	0.1109	0.2439	0.5755

The formula for figuring out what the ideal weight coefficient values should be is expressed in expression (3.3).The values of the weight coefficients of the criterion determined by the FUCOM model are displayed in Table 21.

5. Discussion

The results obtained using the integrated method of MACBETH-Plithogenic MAIRCA is compared with two other integrated methods of FUCOM –Plithogenic MAIRCA and CRITIC- Plithogenic MAIRCA. Table 22 presents the results obtained in all of the three methods and it is inferred that the result obtained using the first method is consistent and the mechanical method of recycling is ordered first in all of the three methods. The numerical results also validate the theoretical arguments in favour of mechanical recycling.

Table 22: Ranking Results of the Decision Methods

Plastic recycling methods	MACBETH-Plithogenic MAIRCA	FUCOM – Plithogenic MAIRCA	CRITIC-Plithogenic MAIRCA
Mechanical Recycling (A1)	1	1	1
Chemical Recycling (A2)	2	2	2
Energy Recycling (A3)	3	3	3

This leads to the conclusion that the weight coefficient values for the criteria were identical to their ideal values. The same ranking is produced by the Plithogenic FUCOM-MAIRCA, CRITIC-MAIRCA, and MACBETH-MAIRCA algorithms were presented in table 22.

6. Conclusion

This paper proposes an integrated method of making decision using the methods of MACBETH and Plithogenic MAIRCA to rank the effective plastic recycling methods incorporating the principles of EPR as criteria. The method is simple and feasible as software facilitates computations. The consistency of the method is tested with other integrated combinations. The consideration of EPR aspects in criterion decision is the new initiative of this paper. The proposed integrated MCDM method shall be extended to complete Plithogenic method by discussing the method of MACBETH in plithogenic sense.

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References

[1] Smarandache, F. Neutrosophic set, A Generalization of the Intuitionistic Fuzzy Set, International Journal of Pure and Applied Mathematics, Vol. 24, No. 3, 287-297.2005.

[2] Zaki, S., & Ismail, M, Interval-Valued Neutrosophic Hypersoft Sets (IVNHSs) for enterprise resource planning selection. Journal of Neutrosophic and Fuzzy Systems, 5(2), 60-70,2023.

[3] Şahin, R., & Liu, P, Correlation coefficient of single-valued neutrosophic hesitant fuzzy sets and its applications in decision making. Neural Computing and Applications, 28, 1387-1395,2017.

[4] Maria, C. B., Ximena, I. Q., & Javier, P. P, Multi-Criteria Data Analysis with Interval-Valued Neutrosophic Sets to Decrease Plastic Pollution rivers. International Journal of Neutrosophic Science (IJNS), 19(1), 2022.

[5] Geetha, N. K., & Bridjesh, P. (2021). Combinatorial rough neutrosophic multi attribute decision making approach for selection of waste plastic oil–Diesel blends. Materials Today: Proceedings, 37, 979-981.

[6] Smarandache, F.. Plithogeny, Plithogenic Set, Logic, Probability and Statistics, preprint arXiv:1808.03948. 2018., https://doi.org/10.48550/arXiv.1808.03948

[7] Valério A. P. Salomon. An Example on the Unreliability of MACBETH Applications., 4th International Conference on Production Research - ICPR Americas. 2008.

[8] Diala Dhouib. An extension of MACBETH method for a fuzzy environment to analyze alternatives in reverse logistics for automobile tire wastes., Omega (Elsevier), 42, 25-32.2014 https://dx.doi.org/10.1016/j.omega.2013.02.003

[9] Boral, S., Howard, I., Chaturvedi, S. K., McKee, K., &Naikan, V. N. A. An integrated approach for fuzzy failure modes and effects analysis using fuzzy AHP and fuzzy MAIRCA. Engineering Failure Analysis, 108, 104195. 2020. https://doi.org/10.1016/j.engfailanal.2019.104195

[10] Zhu G. N., Ma J., & Hu J. Evaluating biological inspiration for biologically inspired design: An integrated DEMATEL-MAIRCA based on fuzzy rough numbers. International Journal of Intelligent Systems, 36(10), 6032-6065.2021.

[11] Fatih Ecer. An extended MAIRCA method using intuitionistic fuzzy sets for coronavirus vaccine selection in the age of COVID-19., Neural Computing and Applications, 34:5603–5623. 2022. https://doi.org/10.1007/s00521-021-06728-7.

[12] Dragan Pamucar, Muhammet Deveci, Dorin Schitea, Levent Eris kin, Mihaela Iordache, IoanIordache. Developing a novel fuzzy neutrosophic numbers-based decision-making analysis for prioritizing the energy storage technologies. International journal of hydrogen energy, vl-45. 2020. https://doi.org/10.1016/j.ijhydene.2020.06.016

[13] Haq, R. S. U., Saeed, M., Mateen, N., Siddiqui, F., & Ahmed, S. (2023). An interval-valued neutrosophic based MAIRCA method for sustainable material selection. Engineering Applications of Artificial Intelligence, 123, 106177.

[14] Abdullah Ozcil., Aysegul Tus., Gulin Zeynep Oztas., Esra Aytac Adali & Tayfun Oztas., The Novel Integrated Model of Plithogenic Sets and MAIRCA Method for MCDM problems. International Conference on Intelligent and fuzzy systems. 733-741. 2020. doi:10.1007/978-3-030-51156-2_85

[15] Lindhqvist T. Extended Producer Responsibility in Cleaner Production. The International Institute for Industrial Environmental Economics. Sweden, Lund: Lund University. 2000.

[16] Yamini Gupt and Samraj Sahay. Review of extended producer responsibility: A case study approach., Waste Management & Research. 2015.DOI: 10.1177/0734242X15592275

[17] Mahendran S., Mahadevan M.L. Prioritization of Plastic Recycling Process Using Analytical Hierarchy Process., International Colloquium on Materials, Manufacturing and Metrology. 2014.

[18] Muhammad Riaz, Dragan Pamucar, Anam Habib, Mishal Riaz. A New TOPSIS Approach Using Cosine Similarity Measures and Cubic Bipolar Fuzzy Information for Sustainable Plastic Recycling Process., Hindawi Mathematical Problems in Engineering, Article ID 4309544, 18 pages. 2021.

[19] Vinodh S., Prasanna M., Hari Prakash N. Integrated fuzzy AHP- TOPSIS for selecting the best plastic recycling method: A Case Study., Appl. Math. Modelling.2014.

[20] Nirmala, Uthra. Fuzzy AHP- Goal Programming Technique for Selecting the Best Plastic Waste Management Method. International Journal of Mathematics Trends and Technology. 55. 388-392.2018.

[21] Saurav Bhagat, Avdesh Bhardawaj, Piyush Mittal, Prateek Chandak, Mohammad Akhtar, Paaras Sharma., Evaluating Plastic Waste Disposal Options in Delhi using Multi Criteria Decision Analysis., IIOAB Journal.2016.

[22] Nirmala and Uthara. Selecting Best plastic recycling method using trapezoidal linguistic Fuzzy Reference Relation., International Journal of Civil Engineering and Technology (IJCIET) Volume 8, Issue 6, pp. 850–855. 2017.

Doi: https://doi.org/10.54216/IJNS.220210
Received: April 26, 2023 Revised: June 29, 2023 Accepted: September 20, 2023

[23] Ali Utku Akar., Sukran Yalpir., Suleyman Sisman,Gamze Goktepeli., Esra Yel. A deterministic approach in waste management: delineation of potential territories in Turkey for industrial symbiosis of olive pomace, marble wastes and plastics by integrating Fuzzy AHP to GIS. Environment, Development and Sustainability.2022. https://doi.org/10.1007/s10668-022-02415-2

[24] Dragan Pamucar, ŽeljkoStevic., Sinisa Sremac. A New Model for Determining Weight Coefficients of Criteria in MCDM Models: Full Consistency Method (FUCOM)., Symmetry, 10, 393,2018. “doi:10.3390/sym10090393”.

[25] Diakoulaki, Danae, George Mavrotas, and Lefteris Papayannakis. Determining objective weights in multiple criteria problems: The CRITIC method. Computers & Operations Research 22.7: 763-770. 1995. https://doi.org/10.1016/0305-0548(94)00059-H

[26] Solairaju A and Shajahan M,. Transforming Neutrosophic Fuzzy Set into Fuzzy Set by Imprecision Method, Journal of Computer and Mathematical Sciences, Vol.9(10),1392-1399.2018.

Doi: https://doi.org/10.54216/IJNS.220210
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