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Original Research Article

Evaluation of Plastic Waste Management Strategies in the Philippines: A Hybrid Approach using Weighted DEMATEL and TOPSIS/VIKOR

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ABSTRACT

The evaluation of sustainable plastic waste management (PWM) strategies in the Philippines requires navigating the conflicting socio-economic and environmental trade-offs. Traditional decision-support tools fail to handle these multi-dimensional networks as they assume complete linear independence among evaluation parameters. This study integrates causal network mapping with dual-engine compromise modelling to isolate the non-linear interdependencies for a stable strategy ranking. The proposed multi-criteria framework maps stakeholder inputs using the DEMATEL before running parallel distance-to-ideal and compromise ranking algorithms, TOPSIS and VIKOR. Case study results reveal that social impact operates as the most prominent system driver, while positioning plastic waste-to-concrete production and mechanical recycling as the optimal intervention pathways. Sensitivity analysis confirms that the best upcycling pathways remain structurally stable against matrix variations, providing a reliable decision-support framework towards effective PMW in the Philippines.

KEYWORDS

Circular economy, Multi-criteria decision analysis, Sensitivity analysis, Systems engineering, Waste management.

INTRODUCTION

Plastic remains an indispensable material across global industrial supply chains due to its low cost, durability, and versatile mechanical properties [1]. However, the escalating generation rate of plastic severely compromises ecological systems without sustainable waste management, especially in developing countries. In the Philippines, a staggering 2.3 Mt of plastic waste is generated annually with only 28 % of plastic resin recycled [2]. This crisis is further exacerbated by inadequate waste management infrastructure, *sachet* (single-use) culture and *tingi-tingi* (micro-retail) economic structures [3]. The transition of municipal solid waste (MSW) streams from linear "take-make-dispose" configurations toward localized circular economies became a regional priority.

The current plastic waste management (PWM) strategies in the Philippines include recycling, pyrolysis, road construction, and concrete production. The Extended Producer Responsibility Act of 2022 (Republic Act No. 11898) acts as a macro-level regulatory frameworks to manage the environmental impact of products throughout their lifecycle [4]. Despite the promoted adoption of waste recovery, the post-consumption recycling efficiency

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in the region remains struggling at a rate below 10 % [5]. The pyrolysis pathway has been supported through the development of plastic waste pyrolysis plant in Naawan, Misamis Oriental [6]. However, the implementation of this strategy has yet to be explored nationwide. The use of shredded plastic waste as an asphalt additive was also recently approved by the Department of Public Works and Highways to extend pavement lifespan while reducing plastic pollution [7]. The Department of Environment and Natural Resources (DENR) recommended utilizing plastic waste as raw materials in cement production to reduce the solid waste of the country by at least 40 % [8]. It has been reported that government-approved and globally-recognized technology for repurposing qualified discarded waste is available [9]. Despite the available alternatives, there is still a challenge to assess and prioritize effective solutions for local interventions to the plastic problem.

The core of this challenge lies in the fact that evaluating these approved alternatives requires navigating highly conflicting sustainability parameters across the three pillars of green systems: (1) economic, (2) environmental, and (3) ethical. Land-use is one of the most important factor in the implementation of PWM solutions. Aside from the space requirement, it covers the harmful contamination and groundwater pollution to soil ecosystems [10]. Air pollution is also a concern in PWM as the degradation of material often results in the release of harmful pollutants, including dioxins and furans [11]. PWM advancements are also limited by energy-intensive operations [12]. Effective waste management systems provide opportunities for job creation to capitalize the social benefits of sustainability interventions [13]. The technical feasibility of waste management technologies varies based on local infrastructure and expertise. The technological implementation to local contexts is critical in ensuring the viability of the solution in being accepted and sustained [14]. It is also beneficial to consider the sustainability impact and economic benefits of the final product of waste processing [15]. Lastly, community understanding and involvement is a critical component of effective waste management programs [16]. Policies currently lack a comparative framework capable of evaluating these intricate dimensions simultaneously.

Recent literature has been reported to use several mathematical tools in navigating the conflicting sustainability parameters. Mixed-Integer Linear Programming was developed as an allocation model to create a central equity metric to balance carbon credit distribution against industrial profitability [17]. This approach enforced hard constraint limits across quantitative bounds without considering highly subjective criteria inputs. Multi-Criteria Decision Analysis (MCDA) is a structured approach that address trade-offs by evaluating available alternatives characterized by multiple attributes [18]. For instance, Analytic Hierarchy Process (AHP) was used to evaluate MSW management options by computing priority vectors within pairwise comparisons [19]. However, traditional MCDA frameworks operate under the rigid assumption of linear independence among the criteria. Technical variables directly dictate cost structures and community acceptance in complex waste management ecosystems [20]. Standard decision models fail to isolate internal cause-effect dependencies before computing priority weights. This structural limitation leads to volatile priority choices that frequently face significant implementation barriers.

This study proposes a hybrid MCDA model that integrates causal diagram with trade-off modelling towards resolving structural ambiguities in PWM strategy selection. Decision-Making Trial and Evaluation Laboratory (DEMATEL) was used in mapping interdependencies and deriving criteria weights from a diverse matrix of municipal, academic, and civic stakeholders. The derived weights are then embedded into a dual-layered selection model running parallel Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) algorithms. These models were used to rank prominent regional alternatives for PWM. Finally, a dynamic rank reversal sensitivity analysis is deployed to test the stability of the model upon structural disruptions. The results achieved through this framework successfully validated stability and systemic clarity in using a hybrid decision-making tool.

METHODOLOGY

The study used a hybrid approach of MCDA techniques to systematically assess plastic waste management (PWM) strategies. Decision-Making Trial and Evaluation Laboratory (DEMATEL) model was initially used to analyse the interdependency of each criterion. The data entry in DEMATEL requires a set of stakeholder input translated into a direct influence matrix. As shown in eq. (1), the direct influence matrix, *D*, is normalized by dividing the elements by the maximum value of the row sum:

$$N = \frac{D}{\max_i(\sum_{i=1}^{n} D_{i,j}, \sum_{j=1}^{n} D_{i,j})} \quad (1)$$

The normalized matrix is subtracted from the identity matrix, *I*, to achieve mathematical convergence. The subtraction ensures that the calculation accounts for diminishing indirect effects over time as higher powers of *N* have progressively smaller values. The total influence matrix, *T*, was calculated by taking the inverse of the previous difference, $(I–N)^{-1}$, and obtaining its matrix product with the normalized matrix, *N*. The total influence matrix captures both direct and indirect effects of the criteria on one another.

The sum of rows and the sum of columns were acquired to determine the cause-effect chain of the criteria. Row sums (*R*) represent the cause value which determines the total influence of criterion *i* on all other criteria. Column sums (*C*) represent the effect value which determines the total influence received by criterion *j* from all other criteria. The sum of *R* and *C* indicates the prominence index of each criterion in the network. On the other hand, their difference identifies cause-oriented criteria from effect-oriented ones. The positive (R_i−C_i) values correspond to the assignment of a criterion as a net cause, while the negative values suggest a net effect.

In this study, DEMATEL was also utilized as a weighting technique based on the method by Kobryń [21]. The prominence and relation indices were used to determine the weights by calculating the average of their squared values as ω_i [eq. (2)]:

$$\omega_i = ((R_i + C_i)^2 + (R_i - C_i)^2)^{1/2} \quad (2)$$

These weights are normalized using eq. (3):

$$W_i = \frac{\omega_i}{\sum_{i=1}^{n} \omega_i} \quad (3)$$

where W_i represents the criteria weights used in the decision-making tool. To ensure accuracy, the correction was done through the addition of the minimum value to each of the weight values. Therefore, the final criteria weights were obtained from the normalized values of the corrected weights in eq. (4):

$$W_i^{corrected} = W_i + \delta \quad if \quad W_i > 0 \quad (4)$$

where δ is the correction factor acquired from the minimum value of W_i. The weights are normalized using the same premise as eq. (3). Given the weights from DEMATEL, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) models were integrated into the methodology proposed.

Subsequently, the TOPSIS model calculates the distance of each alternative from the ideal and worst solutions. The matrix undergoes the criteria normalization by Agrawal [22], where eq. (5) was used for beneficial criteria, while eq. (6) was used for non-beneficial ones:

$$X'_{ab} = \frac{X_{ab}}{X_b^+} \tag{5}$$

$$X'_{ab} = \frac{X_b^-}{X_{ab}} \tag{6}$$

where X_{ab} is the performance value of the alternatives, a, based on specific criteria, b. The (+) and (–) superscript denoted the maximum and minimum values for the criteria. TOPSIS ranking was further executed with eq. (7):

$$\overline{X_{ab}} = \frac{X'_{ab}}{\sqrt{\sum_{a=1}^{n} X_{ab}^2}} \tag{7}$$

Additionally, weight allocation was done with eq. (8), wherein weights were transposed into column cells, W_b:

$$V_{ab} = \overline{X_{ab}} \times W_b \tag{8}$$

The distance from the ideal solution, d^+, in eq. (9) and the distance from the worst solution, d-, in eq. (10) were obtained using the normalized matrix, V_{ab}:

$$d^+ = \left[\sum_{b=1}^{m} (V_{ab} - V_b^+)^2\right]^{0.5} \tag{9}$$

$$d^+ = \left[\sum_{b=1}^{m} (V_{ab} - V_b^-)^2\right]^{0.5} \tag{10}$$

From here, the TOPSIS closeness index, c, is calculated with eq. (11):

$$c_a = \frac{d^-}{d^+ + d^-} \tag{11}$$

TOPSIS ranks alternatives based on which solution is closest to the ideal solution and farthest from the worst solution.

On the other hand, the VIKOR model focuses on providing a compromise solution between collective satisfaction and individual regret. The weight normalization was adopted from Chatterjee and Chakraborty [23]. The utility value, S_a, was calculated the for beneficial criteria using eq. (12), while eq. (13) was used for non-beneficial criteria columns:

$$S_a = \sum_{b=1}^{m} W_b \times \frac{f_{ab,max} - f_{ab}}{f_{ab,max} - f_{ab,min}} \tag{12}$$

$$S_a = \sum_{b=1}^{m} W_b \times \frac{f_{ab} - f_{ab,min}}{f_{ab,max} - f_{ab,min}} \tag{13}$$

The regret value, R_a, was then calculated with eq. (14):

$$R_a = \max\left(W_b \times \frac{f_{ab} - f_{ab,min}}{f_{ab,max} - f_{ab,min}}\right) \quad (14)$$

As such, the VIKOR index, Q_a, is obtained from eq. (15):

$$Q_a = v\left(\frac{S_a - S_{a,min}}{S_{a,max} - S_{a,min}}\right) + (1 - v)\left(\frac{R_a - R_{a,min}}{R_{a,max} - R_{a,min}}\right) \quad (15)$$

where *v* is the weight of the strategy for the majority of attributes. A value of 0.5 is preferred as it refers to the consensus compromise value. VIKOR yields a balance between the best and worst outcomes despite possibly conflicting criteria. The alternative with the lowest VIKOR index value is ranked first.

Sensitivity analysis was done based on rank reversal to check the stability of MCDM methods. This method involves the addition of other alternatives to, or removal from, the original cluster [24]. A robust model is expected to have minimal to no change upon addition and removal. This approach aims to assess the reliability of decision-making results by constructing dynamic matrices and evaluating the model response under altered conditions.

The hybrid use of the three MCDA techniques is proposed as a decision model for decision-makers and local government units to prioritize available PWM strategies. The method delineates the interdependencies of decision elements and the weighted ranking of alternatives faster. By systematically assessing the performance of viable interventions, this research contributes to the transition toward a circular economy of plastic in the Philippines.

CASE STUDY

The case study presents the analysis and selection of existing PWM strategies. The strategies were ranked based on eight (8) evaluation criteria for PWM. The criteria include land use (L), air pollution (A), energy requirement (En), cost (C), employment (Em), technical feasibility (T), product (P), and social impact (S).

The direct-influence matrices was derived from the qualitative determination of three groups of stakeholders in waste treatment [25]. The metrics for each criterion included no influence, low influence, medium influence, high influence, and very high influence translated into a 0-4 scale, with 0 being no influence and 4 being very high. The stakeholders were grouped into three: (1) managers from the Environmental Protection Agency of a local government and managers from municipal solid waste (MSW) treatment-related companies; (2) professors majoring in Environmental Engineering and engineers for MSW treatment; and (3) urban environmentalists and highly concerned residents. Table 1 then represents the direct-influence matrix used in DEMATEL based on the average of all three groups in each cell.

Table 1. Direct-influence matrix for the evaluation criteria of PWM strategies

Criteria	L	A	En	C	Em	T	P	S
L	0	0.667	0	0.667	3.333	0	1	3.333
A	1	0	0	0	3.333	0	0.333	4
En	3.667	3.667	0	3.667	3.667	0.333	3.667	4
C	0	0	0	0.667	3.333	0	1	3.667
Em	0	0	0	0	0	0	0	0.333
T	3.667	3.333	1.667	3	3.667	0	4	3.667
P	0	0	0	0.667	3	0	0.667	4
S	0	0	0	0	0.667	0	0	0.667

Figure 1 shows the centrality-causality diagram based on the acquired prominence and relation indices. It was found that the cost (C), employment (Em), product (P), and social impact (S) had negative causality indices that denote their dependence on other criteria. Since the centrality values of technical feasibility and energy requirement were significant, they were considered in relation to dependent criteria. For instance, energy consumption is influential on the overall cost of implementation as complex and energy-intensive technologies cost more [26]. Product value also depends on technical inputs and processing efficiency. Chemical recycling is typically more energy-intensive, yet it produces fuel that produce profit in return [27]. Likewise, employment is shaped by the complexity of technologies in which labor requirements are higher than others [28]. Social impact was then found to be largely relevant yet highly dependent on other criteria. This is consistent with the need to resolve the underlying technical feasibility constraints and energy-cost penalties in order to sustain public acceptance [29].

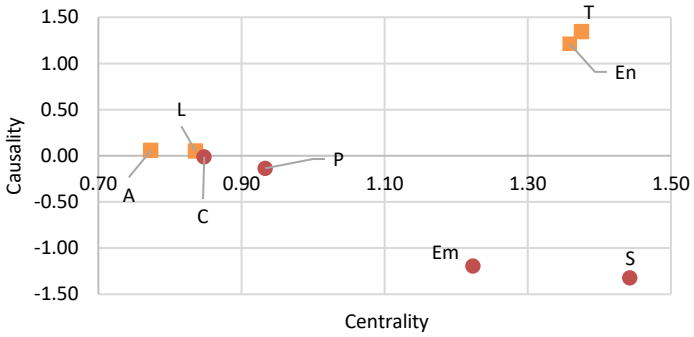


Figure 1. Relation index vs. prominence index plot

Using the weighting technique from DEMATEL, the relative weights were quantified and summarized in Table 2. Results showed that social impact holds the highest weight among all criteria. This suggests that stakeholders view social considerations as a top priority when selecting waste management technologies. Effective PWM must have substantial social, sustainability, and economic benefits, including improved public health, environmental protection, and potential for new industries and jobs [30]. In the Philippines, public perception and socio-economic factors, such as willingness to pay, are critical in the successful implementation of waste management initiatives [31]. It was also found that land use (L), air pollution (A), and cost (C) had relatively lower weights aside from low centrality values. While these factors remain relevant, their relatively insignificant influence suggests that stakeholders are more concerned with long-term societal and technical outcomes than with initial implementation barriers. The final outputs of waste processing, such as recycled material and pyrolysis fuel, were considered secondary to broader social and feasibility considerations. The current efforts are focused on reducing plastic waste rather than producing a new product in driving circular economy interventions before adding to the value chain [32].

Table 2. Criteria weights from DEMATEL

L	A	En	C	En	T	P	S
0.0606	0.0560	0.1822	0.0615	0.1639	0.2002	0.0694	0.2063

Four (4) alternatives were identified within the approved strategies for local implementation in the Philippines. This includes mechanical recycling, pyrolysis, road construction integration, and plastic waste-to-concrete production. The initial evaluation matrix was obtained from a comprehensive impact assessment of PWM in different aspects [33]. Table 3 shows the translated matrix with a scale from 1-9, 1 being the lowest and 9 being the highest.

Table 3. Initial evaluation matrix for the alternative PWM strategies based on evaluation criteria

PWM Strategies	L	A	En	C	Em	T	P	S
Recycling	3	5	5	7	3	8	7	8
Pyrolysis	3	2	8	9	9	1	1	7
Road construction	2	2	2	2	3	5	7	7
Concrete	2	1	1	1	3	5	8	7

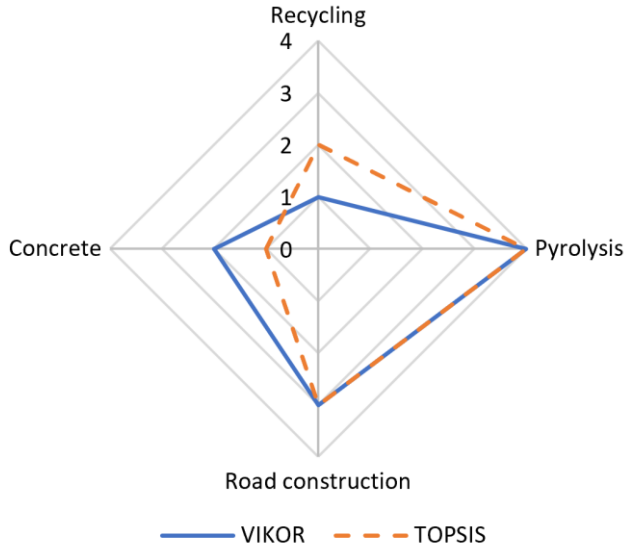
Consequently, TOPSIS and VIKOR were both applied to rank the identified alternatives (Table 4). Among four alternative strategies, recycling and concrete production were found to be the most beneficial solution to plastic waste. Innovations in concrete production include using recycled plastic as a partial substitute for sand or aggregate. This is consistent with the claim of DENR that this strategy may yield up to at least 40 % of solid waste reduction [8]. In this case, concrete production was preferred due to its high value for critical weights, such as technical feasibility and social acceptance. On the other hand, recycling had the minimum individual regret as it ranked first with the VIKOR approach. The results of VIKOR highlighted the stablished feasibility of recycling in its overall performance under the evaluation of stakeholders. In fact, micro-facilities have recently been initialized to further implement recycling in two of the largest cities in the Philippines [34].

Table 4. TOPSIS/VIKOR ranking results for alternative PWM strategies

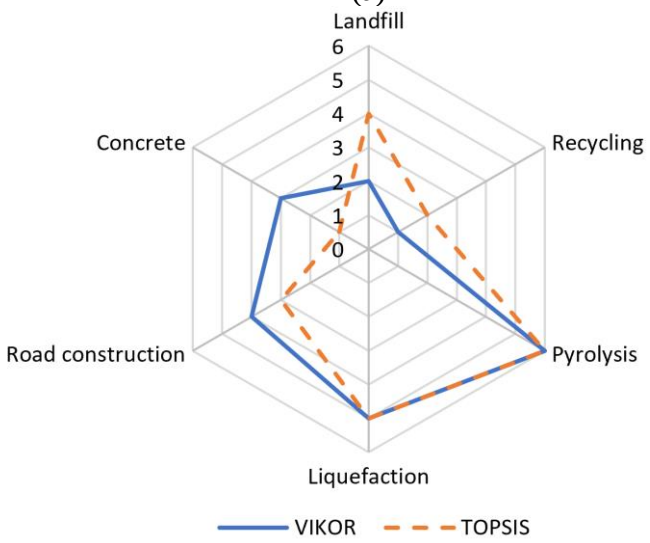
Alternative	TOPSIS			VIKOR		
	d^+	d^-	Rank	S_i	R_i	Rank
Recycling	0.170	0.136	2	0.441	0.164	1
Pyrolysis	0.203	0.096	4	0.794	0.206	4
Road construction	0.141	0.105	3	0.514	0.206	3
Concrete	0.111	0.174	1	0.456	0.206	2

Meanwhile, pyrolysis and road construction ranked consistently for both methods. The moderate scores of road construction showed the weakness of the alternative in terms of local feasibility. The Department of Public Works and Highways (DPWH) is still conducting a pilot project in Manila that assesses the viability of using shredded plastic waste in asphalt mixes [35]. Similarly, pyrolysis ranked last due to regulatory constraints. The Philippine Clean Air Act of 1999 (Republic Act 8749) prohibits incineration or direct burning of municipal, biomedical, and hazardous wastes due to environmental concerns [36]. While pyrolysis operates without oxygen, unlike incineration, it still faces regulatory scrutiny in compliance with environmental standards.

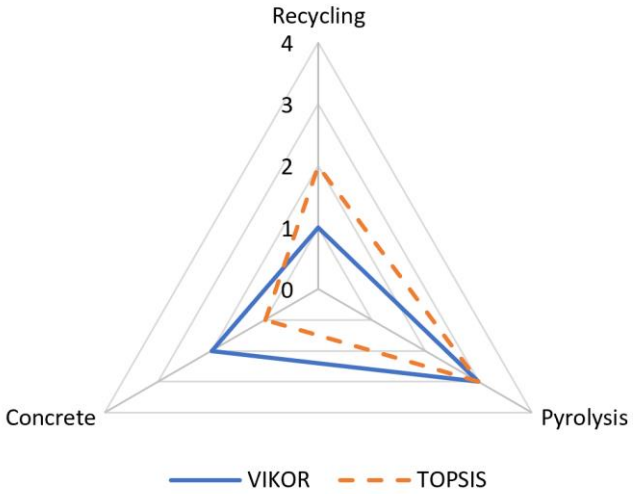
Sensitivity analysis was done to ensure the consistency of the results. The TOPSIS and VIKOR rankings were consolidated in a radar plot for the original cluster, as shown in Figure 2a. Figure 2b then validated the consistency of concrete and recycling as the best alternatives despite the addition of baseline alternatives. Landfill and liquefaction were added as alternative PWM strategies for structural matrix expansion. Plastic circularity efforts in the Philippines have been focused on diverting plastic waste away from landfills and the open environment [37]. The results revealed that landfilling ranked lower than the critical alternatives as stakeholders focuses on reducing open dump and landfills. In contrast, liquefaction has yet to be integrated in the local setting. However, it is considered as a promising alternative to the high operating conditions of pyrolysis [38]. Therefore, liquefaction ranked higher than pyrolysis primarily due to the reduced technical cost and increased safety. Pyrolysis remained the worst alternative upon consideration of the air pollution mandate. Therefore, an update on the legislation may be beneficial to realize PWM implementation. Figure 2c represents the removal of the weak PWM alternative, road construction integration. Similar rank allocation was achieved for both MCDA methods. This provides decision-makers a robust approach in selecting PWM strategies for implementation.



(a)



(b)



(c)

Figure 2. Sensitivity analysis results based on rank reversal: original cluster (a); addition of baseline alternatives (b); and removal of the lowest-performing alternative (c)

CONCLUSION(S)

The proposed hybrid approach successfully integrated conventional multi-criteria decision analysis (MCDA) models, including Decision-Making Trial and Evaluation Laboratory (DEMATEL), the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR). The developed model provides a decision-support tool for plastic waste management. It addresses a critical gap in traditional frameworks as it diverted sustainability metrics from linear independence. This work was used to isolate and weigh the complex cause-effect interdependencies inherent in regional waste ecosystems before compiling strategic rankings. The case study revealed the social impact as the most prominent net effect within the network, holding the highest individual weight of 0.2063. Recycling and concrete integration were found as the best PWM strategies due to their established feasibility and superior capability to reduce MSW. The rank-reversal sensitivity analysis confirmed that the model is robust against matrix disruptions.

Future iterations may couple this hybrid qualitative model with a quantitative Life Cycle Assessment (LCA) to introduce numerical values for environmental indicators, such as precise global warming potentials, water depletion footprints, and human toxicity impacts. It is also suggested to enhance the socio-technical resolution of the model by broadening the institutional stakeholder matrix with localized waste pickers, junk shop owners, and formal recycling union representatives alongside municipal managers and academic engineers. Future researchers should adapt to dynamic conditions through a scenario-based analysis incorporating future legislative shifts, technology breakthroughs, and market resin price volatility.

NOMENCLATURE

Symbols

c_a	closeness index of a
D	direct-influence matrix
d	geometric distance from ideal solution
f_{ab}	performance value of a with respect to b
$f_{ab,max}$	maximum performance value
$f_{ab,min}$	minimum performance value
I	identity matrix
m	total number of evaluation criteria
N	normalized direct-influence matrix
n	total number of alternative strategies
Q_a	VIKOR index
R_a	regret value of a
$R_{a,max}$	maximum regret value
$R_{a,min}$	minimum regret value
R_i	row sum of the total influence matrix
S_a	utility value
$S_{a,max}$	maximum utility value
$S_{a,min}$	minimum utility value
C_j	column sum of the total influence matrix

T	total influence matrix
v	strategic weight
V_{ab}	weighted normalized matrix performance value
W_b	transposed column cell weight
W_i	relative priority weight
X_{ab}	final normalized performance value
X'_{ab}	linear normalized value
$\bar{X}_{ab}$	normalized performance score

Greek letters

δ	weight correction factor
ω	uncorrected average squared priority vector

Subscripts and superscripts

a	system alternatives elements (a = 1, 2, …, n)
b	evaluation criteria elements (b = 1, 2, …, m)
i	causal factor row element
j	effect factor column element
+	beneficial vector
–	non-beneficial vector

Abbreviations

A	Air pollution criterion
AHP	Analytic Hierarchy Process
C	Cost criterion
DEMATEL	Decision-Making Trial and Evaluation Laboratory
DENR	Department of Environment and Natural Resources
DPWH	Department of Public Works and Highways
Em	Employment criterion
En	Energy requirement criterion
L	Land use criterion
MCDA	Multi-Criteria Decision Analysis
MSW	Municipal Solid Waste
P	Product criterion
PWM	Plastic Waste Management
S	Social impact criterion
T	Technical feasibility criterions
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
VIKOR	Vlsekriterijumska Optimizacija I Kompromisno Resenje

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APPENDIX

Table 5. Direct-influence matrix from the stakeholders (Group 1)

Criteria	L	A	En	C	Em	T	P	S
L	0	1	0	0	4	0	1	3
A	1	0	0	0	3	0	1	4
En	4	3	0	4	4	1	3	4
C	0	0	0	0	3	0	1	3
Em	0	0	0	0	0	0	0	1
T	4	4	2	3	3	0	4	4
P	0	0	0	1	3	0	0	4
S	0	0	0	0	1	0	0	0

Table 6. Direct-influence matrix from the stakeholders (Group 2)

Criteria	L	A	En	C	Em	T	P	S
L	0	0	0	1	3	0	1	4
A	1	0	0	0	4	0	0	4
En	3	4	0	4	4	0	4	4
C	0	0	0	1	4	0	1	4
Em	0	0	0	0	0	0	0	0
T	4	3	2	3	4	0	4	4
P	0	0	0	1	3	0	1	4
S	0	0	0	0	1	0	0	1

Table 7. Direct-influence matrix from the stakeholders (Group 3)

Criteria	L	A	En	C	Em	T	P	S
L	0	1	0	1	3	0	1	3
A	1	0	0	0	3	0	0	4
En	4	4	0	3	3	0	4	4
C	0	0	0	1	3	0	1	4
Em	0	0	0	0	0	0	0	0
T	3	3	1	3	4	0	4	3
P	0	0	0	0	3	0	1	4
S	0	0	0	0	0	0	0	1