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RESEARCH ARTICLE

Post-earthquake CDW recycling facility site prioritization in Southeastern Türkiye: A CRITIC-based COPRAS and TOPSIS approach

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Abstract

The 6 February 2023 earthquakes in Türkiye caused unprecedented destruction across 11 provinces, generating massive volumes of construction and demolition waste (CDW). Despite the scale of devastation, long-term recovery strategies regarding sustainable waste management remain limited, particularly in provinces without permanent recycling infrastructure. This study addresses the facility location problem for permanent CDW recycling plants in six highly affected provinces—Adana, Adıyaman, Diyarbakır, Elazığ, Kilis, and Osmaniye—that currently lack operational facilities. A multi-criteria decision-making (MCDM) framework is developed by integrating the CRITIC (Criteria Importance Through Intercriteria Correlation) method for objective weighting with two widely adopted ranking methods: COPRAS (Complex Proportional Assessment) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). Eight evaluation criteria encompassing economic, environmental, technical, demographic, and strategic dimensions are defined using governmental reports, spatial data, and field-based assessments. These criteria include: proximity to existing facilities, population density, distance to ecological protection zones, transportation costs, estimated CDW volume, land suitability, disaster intensity and reconstruction need, and the number of temporary waste dumping sites. Among these, land suitability emerged as the most influential criterion, reflecting the importance of terrain conditions, accessibility, and legal-planning factors in post-disaster infrastructure decisions. Results from both COPRAS and TOPSIS methods showed high consistency, with Adıyaman ranked as the most suitable province for facility investment, followed by Adana and Osmaniye. This study contributes to disaster recovery planning by proposing a reproducible, transparent, and data-driven decision support tool for sustainable waste infrastructure investment, particularly in seismically vulnerable regions.

1. Introduction

On 6 February 2023, two major earthquakes (Mw 7.7 and Mw 7.6) struck southeastern Türkiye with epicenters located in Kahramanmaraş, resulting in one of the most widespread disasters in the country's history. A total of 11 provinces—Kahramanmaraş, Hatay, Adıyaman, Malatya,

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Gaziantep, Osmaniye, Adana, Kilis, Diyarbakır, Şanlıurfa, and Elazığ—suffered significant human and material losses, with over 300,000 buildings either destroyed or severely damaged [1, 2]. The scale of this destruction triggered not only a housing and infrastructure crisis but also a massive challenge in managing and processing construction and demolition waste (CDW). Initial estimates suggested that approximately 100 million tons of CDW were generated; however, more detailed analyses indicate that the actual volume may range between 350 and 920 million tons, directly affecting more than 13 million people [3-5]. The management of such an enormous volume of waste presents not only geographical and logistical challenges but also raises critical concerns regarding environmental sustainability [6, 7].

The substantial amount of CDW produced after the earthquake has made the development of waste management and recycling infrastructure an urgent need at both regional and national levels in Türkiye [8]. While temporary dumping sites have provided short-term emergency solutions for managing CDW in disaster-affected areas, such practices pose significant long-term challenges from environmental, logistical, and planning perspectives [3, 9]. Irregular and uncontrolled disposal of waste exacerbates environmental threats-most notably soil and groundwater contamination-and hinders the recovery of recyclable materials, ultimately undermining resource efficiency. In this context, the strategic importance of establishing permanent recycling facilities has become increasingly evident, as these structures are essential for effective post-disaster waste management, minimizing natural resource consumption, and promoting environmental sustainability [10, 11].

Field observations further reveal that the availability and capacity of recycling infrastructure vary significantly across the provinces directly affected by the 6 February 2023 earthquakes. Among the eleven provinces affected, only Hatay (Altınözü/Enek) and Kahramanmaraş (Karacasu/Dulkadiroğlu) currently possess an operational waste management system supported by permanent recycling facilities. In contrast, the construction of such facilities in provinces like Gaziantep, Malatya, and Şanlıurfa is scheduled for 2025 or later [12, 13]. The remaining six provinces-Adana, Adıyaman, Diyarbakır, Elazığ, Kilis, and Osmaniye-lack any permanent infrastructure for recycling. Therefore, decision-making processes for prioritizing the establishment of recycling facilities in these provinces must not only respond to the current situation but should also be designed through long-term, multidimensional, and data-driven approaches [14, 15]. Specifically, the complexity of the planning problem-shaped by factors such as the volume of waste, transportation costs, ecological sensitivities, and post-disaster intervention capacity-constitutes a multi-objective optimization challenge for policymakers [16]. In recent literature, such complex and multifactorial decisions are increasingly addressed through MCDM methods [17]. International case studies suggest that recycling facility location decisions should consider not only economic feasibility but also environmental impacts, social acceptability, transportation infrastructure, disaster risk, and technical suitability in a comprehensive framework [18-21]. Moreover, the presence of conflicting criteria and varying levels of priority among them often renders traditional decision-making approaches insufficient, thereby highlighting the necessity of MCDM methods [22].

In decision-making domains characterized by numerous interdependent variables—such as the selection of recycling facility locations—various MCDM techniques are frequently employed. Notably, methods such as Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Complex Proportional Assessment (COPRAS), and ELimination Et Choix Traduisant la REalité (ELECTRE) are widely used to structure decision problems involving multidimensional criteria sets, thereby bringing systematic and transparent frameworks to complex evaluation processes [23, 24]. These methods have been extensively applied in areas such as waste management, infrastructure investment, and environmental planning [25- 28]. Among them, the TOPSIS method is particularly prominent due to its mathematical logic that identifies the alternative closest to the ideal solution and farthest from the anti-ideal one [29, 30]. Its ability to balance multiple, often conflicting, criteria make TOPSIS a widely preferred tool in facility location and waste management contexts [31-33]. The COPRAS method, on the other hand, is another robust MCDM tool that enables the evaluation of alternatives from both benefit and cost perspectives [34]. Numerous studies have successfully implemented COPRAS in domains such as sustainable infrastructure investment, supply chain decisions, and environmental planning [35-37].

For ranking-based decision models to function reliably, the accurate determination of criteria weights is critical. In this regard, the CRITIC method-developed to eliminate subjective biases and introduce a more objective, data-driven approach-has gained prominence, particularly in combination with TOPSIS and COPRAS models. CRITIC quantifies the importance of each criterion by considering both its information content (variance) and its correlation with other criteria, thereby reducing information redundancy and enabling a more robust weighting structure [38-40]. These integrated models have been increasingly applied to facility location problems in the context of recycling infrastructure, as demonstrated in recent studies such as Dosal et al. [41] and Hassanpour [42]. For instance, Dosal et al. [41] employed CRITIC combined with MCDM approaches to determine the optimal site selection for CDW recycling facilities in Cantabria, Spain; similarly, Hassanpour [42] utilized CRITIC-integrated MCDM models to classify recycling industries in Iran based on their input-output networks.

Despite these methodological advancements and their widespread application at the international level, studies focusing specifically on post-earthquake CDW management in Türkiye remain limited, particularly those that adopt systematic and practically oriented approaches [43]. While the international literature includes several examples of multi-criteria evaluation frameworks for recycling infrastructure, the Turkish context lacks comprehensive, data-driven models that prioritize provinces based on post-earthquake waste characteristics, spatial constraints, and long-term recovery needs [44–46]. Despite these needs, a systematic and comparative evaluation framework for prioritizing permanent CDW recycling investments remains underdeveloped in Türkiye. This study aims to address the following research questions:

(i) Which provinces among the six most affected by the 2023 earthquakes are the most suitable for the establishment of CDW recycling facilities, based on a comprehensive set of environmental, technical, and strategic criteria?

(ii) How consistent are the ranking results when applying alternative MCDM methods (COPRAS and TOPSIS) using objectively derived weights?

(iii) How can data-driven prioritization models contribute to sustainable and resilient post-disaster recovery planning in seismically active regions?

This study aims to establish a scientifically grounded decision-making framework for managing post-disaster CDW, focusing on six severely affected provinces—Adana, Adıyaman, Diyarbakır, Elazığ, Kilis, and Osmaniye—that currently lack permanent CDW recycling facilities following the 6 February 2023 earthquakes. Despite the substantial waste burden generated in these regions, waste has largely been managed through temporary solutions, exacerbating environmental risks and resource inefficiencies. To address this, a multi-dimensional and data-driven site selection model is developed, incorporating spatial, economic (e.g., transport costs, proximity to existing facilities), environmental (e.g., distance to ecological protection zones), technical (e.g., CDW volume, land suitability, number of temporary dumping areas), demographic (e.g., population density), and strategic (e.g., disaster intensity and emergency response needs) criteria. The weighting of these criteria is determined using the CRITIC method, a statistical and objective approach that accounts for the internal variability and informational content of each factor, thereby minimizing subjective bias. For the prioritization of provinces, both COPRAS and TOPSIS methods are applied to enable a comparative and cross-validated ranking based on different mathematical principles. The resulting prioritization provides actionable insights for national and local authorities (e.g., the Ministry of Environment, Urbanization and Climate Change, and municipal governments), offering a comprehensive planning tool that supports sustainable recovery through environmentally and operationally optimized infrastructure investments.

While all six provinces included in the analysis exhibit various degrees of need for permanent CDW recycling infrastructure, this study does not advocate the exclusion of any province from future investment. Rather, the adopted approach prioritizes provinces based on multi-dimensional suitability to guide staged or sequential investments, recognizing that the immediate construction of six simultaneous facilities is not financially or administratively feasible in the post-disaster context of Türkiye. The proposed framework aims to assist decision-makers in allocating resources to the highest priority province in the short term—in this case, Adıyaman—while preserving flexibility for future expansions. This prioritization logic reflects international best practices in disaster recovery, where strategic phasing is essential for efficient infrastructure deployment under constrained conditions.

2. Methodology

This study conducts a MCDM based site selection analysis for provinces in Türkiye that were affected by the earthquakes on 6 February 2023, and currently lack permanent CDW recycling facilities. The overall methodological workflow of the study is visually summarized in Fig. 1. Within the methodological framework, the study first identifies the target provinces and then develops a comprehensive set of evaluation criteria to assess their relative suitability. Following the quantification of these criteria and the identification of relevant data sources, objective criterion weights are calculated using the CRITIC method. Subsequently, the alternatives are ranked using both the COPRAS and TOPSIS methods. Accordingly, the decision-making process is structured around four main steps:

(i) definition of the study area,

(ii) identification of evaluation criteria and data collection,

(iii) calculation of criterion weights using the CRITIC method, and

(iv) ranking of alternatives using the COPRAS and TOPSIS methods.

These steps are detailed in the following subsections.

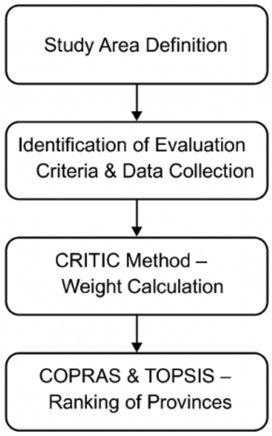

Fig. 1. Methodological framework of the study

2.1. Study area

One of the most critical infrastructure challenges following the 6 February 2023 earthquakes in southeastern Türkiye was the inability to manage the sudden surge in CDW through an effective, environmentally sustainable, and logistically feasible system. In this context, the status of permanent recycling infrastructure in the affected provinces as of 2025 emerges as a key determinant not only for immediate emergency response capacity but also for the effectiveness of medium- and long-term waste management policies. The presence or absence of such facilities significantly influences the disposal method of CDW, resource efficiency, environmental impact, and public acceptance. Therefore, systematically examining the current state of recycling infrastructure in the earthquake-affected provinces is of utmost importance. Fig. 2 presents the status of permanent CDW recycling facilities in each of the 11 provinces directly impacted by the 6 February 2023 earthquakes.

As illustrated in Fig. 2, Hatay and Kahramanmaraş stand out as the only provinces where permanent post-earthquake CDW recycling facilities have been completed and are currently operational. In Hatay, the facility is located in Altınözü/Enek, while in Kahramanmaraş, it is situated in the Karacasu/Dulkadiroğlu region. These facilities support on-site processing and environmentally controlled disposal of earthquake debris through mechanized sorting, mobile crushing units, controlled storage areas for inert materials, and integrated dust suppression and drainage systems. These environmental safeguards are based on guidelines issued by international development agencies and national environmental regulations [12]. Therefore, both provinces were excluded from the scope of this study. Although institutional planning efforts for recycling facilities have begun in Gaziantep, Malatya, and Şanlıurfa, actual investments have not yet been completed or formally scheduled. In Gaziantep, the construction of a facility has been included in the 2025 investment program, while in Malatya, the Kapıkaya region is expected to host a completed facility within the same year. In the case of Şanlıurfa, implementation is postponed to the post-2025 period [13]. Given that these three provinces have already initiated concrete steps toward integrating recycling infrastructure, they were also excluded from the study. In contrast, the six provinces that have not yet been targeted for institutional investment—Adana, Adıyaman, Diyarbakır, Elazığ, Kilis, and Osmaniye—were included as the focus of this research.

2.2. Criteria definition and data collection

In this study, the prioritization of permanent CDW recycling facilities in provinces affected by the 6 February 2023 earthquakes is evaluated using a MCDM approach. The developed decision model comprises eight main criteria (C1–C8), encompassing economic (transport costs, proximity to existing facilities), environmental (distance to ecological protection zones), technical (CDW volume, land suitability, number of temporary dumping areas), demographic (population density), and strategic (disaster intensity and emergency response needs).

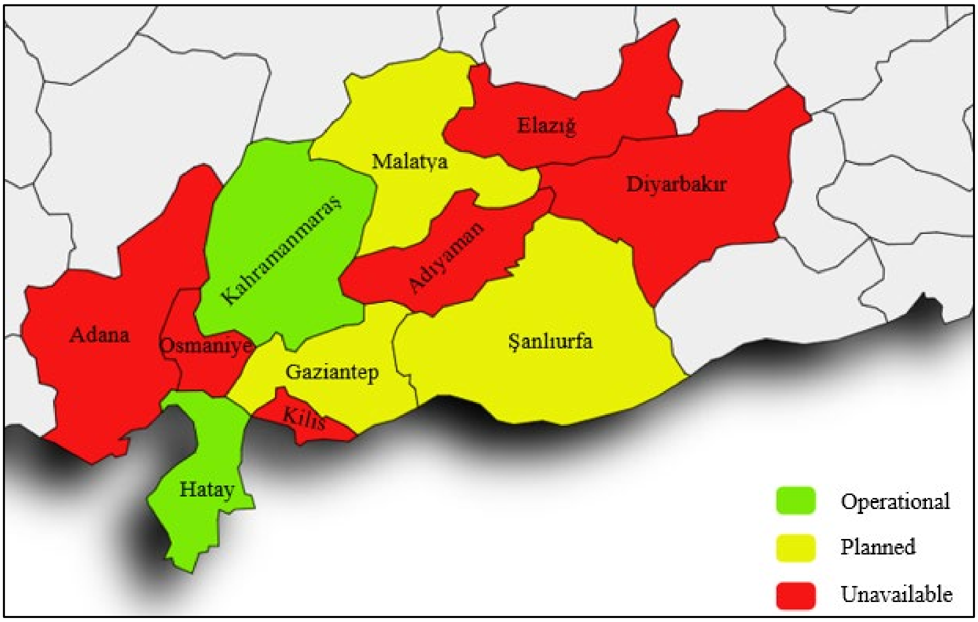

Fig. 2. Status of CDW recycling facilities in the provinces affected by the 6 February 2023 earthquakes

Each criterion's definition, its classification as a benefit or cost type, and the associated unit of measurement are presented in Table 1 along with corresponding justifications. The criterion values used in the analysis are derived from a combination of literature sources, field data, and official planning documents, and are explained in detail under sub-sections 2.2.1 through 2.2.8.

2.2.1. Distance to the nearest recycling facility (C1)

This criterion refers to the straight-line distance (in kilometers) from the city center of each province included in the study to the nearest operational or officially planned permanent CDW recycling facility by 2025. From a prioritization perspective, this distance is significant for assessing the potential to relieve pressure on existing capacity and to meet regional needs for additional facilities [47]. Logistically, greater distance to the nearest facility increases transportation time, fuel consumption, labor requirements, and operational coordination challenges. Moreover, establishing a new facility in close proximity to an existing one may lead to unnecessary resource allocation and underutilization risks. Therefore, this criterion is treated as a cost-based indicator [53]. Within the scope of the study, the road distances between provincial centers and the nearest operational or planned recycling facilities were determined using publicly available route analysis platforms and official Turkish highway data (Table 2).

Table 1. Evaluation criteria for province-based prioritization of CDW recycling facilities

Criterion	Definition	Type	Unit	Justification
C1	Distance to the nearest recycling facility	Cost	km	Provinces located farther from existing facilities are prioritized to ensure balanced load distribution and reduced access times [47].
C2	Population density	Benefit	people/km²	Higher population density indicates greater waste generation potential and increased demand for waste management services [48].
C3	Distance to ecological protection zones	Benefit	km	Distance from protected areas is critical for minimizing environmental impacts and overcoming restrictions [49].
C4	Transportation and operational cost	Cost	TL/ton	Lower logistical costs directly influence economic sustainability and operational efficiency [50].
C5	Estimated volume of CDW generated	Benefit	ton	Higher waste volumes improve plant capacity utilization and feasibility [18].
C6	Land suitability	Benefit	1–5 (ordinal)	Access to infrastructure, slope, zoning status, and ownership facilitate plant construction [49].
C7	Disaster intensity and reconstruction need	Benefit	1–5 (ordinal)	Areas with frequent seismic activity require more extensive infrastructure investments [51].
C8	Number of temporary dumping sites	Benefit	Count	A higher number of temporary sites reflects greater operational readiness and facilitates integration with permanent facilities [52].

Table 2. Road distances between the provinces and the nearest recycling facilities (C1)

Province	Nearest Facility Location	Distance (km)
Adana	Kahramanmaraş–Karacasu (Operational) / Hatay–Altınözü (Operational)	~200 km
Adıyaman	Malatya–Kapıkaya (Planned)	~130 km
Diyarbakır	Malatya–Kapıkaya (Planned)	~210 km
Elazığ	Malatya–Kapıkaya (Planned)	~80 km
Kilis	Gaziantep (Planned)	~60 km
Osmaniye	Kahramanmaraş–Karacasu (Operational)	~110 km

For example, the nearest planned facility for Adıyaman is located in the Kapıkaya region of Malatya, with an estimated road distance of approximately 130 km from the city center. Similarly, as no facility currently exists or is planned in Diyarbakır, the same Malatya site was considered, with a road distance of approximately 210 km.

2.2.2. Population density (C2)

Population density refers to the number of people per unit area, and in this study, it is calculated based on the number of inhabitants per square kilometer for each province [54]. In the context of recycling facility site selection, this criterion indirectly represents the potential for waste generation, the level of logistical demand, and the need for waste management services. Provinces with higher population density typically have more concentrated residential and infrastructure development, which may result in greater volumes of CDW in the event of future disasters. This implies a higher necessity for permanent recycling facilities in such regions. Moreover, high population density also highlights the need for careful evaluation of the environmental and social impacts of the recycling facility. Facilities established in densely populated areas may offer advantages in terms of service accessibility, logistical efficiency, and labor supply. Therefore, in this study, C2 is considered a benefit-type criterion. The population density data are derived from the 2024 Address-Based Population Registration System published by the Turkish Statistical Institute (TURKSTAT) [54] and presented in Table 3.

Table 3. Population densities of the provinces (C2) included in the study

Province	Distance (km)
Adana	169
Adıyaman	82
Diyarbakır	122
Elazığ	69
Kilis	111
Osmaniye	169

2.2.3. Distance to ecological protection zones (C3)

The distance to ecological protection zones is a key indicator for evaluating the environmental suitability of a recycling facility's location. Such areas play a critical role in preserving biodiversity, maintaining the sustainability of natural habitats, and supporting ecosystem services. Locating recycling plants at a safe distance from these sensitive zones is essential for minimizing potential environmental impacts and avoiding conflicts during Environmental Impact Assessment (EIA) processes. In this study, the C3 criterion was determined based on the road distance between each provincial center and the nearest designated ecological protection area. These areas include National Parks, Nature Parks, Nature Monuments, and Special Environmental Protection Zones as defined by the General Directorate of Nature Conservation and National Parks under the Ministry of Agriculture and Forestry of Türkiye, as well as natural and mixed heritage sites listed by UNESCO [55, 56]. Location data for these areas were obtained from official sources, and the shortest road distances from provincial centers to these areas were calculated [57, 58]. Regardless of the protection status category, the closest area was used for evaluation. Accordingly, the C3 criterion was treated as a benefit-type variable in this study, with greater distance from protected areas interpreted as higher environmental suitability. This approach aims to minimize environmental impacts and contribute to sustainable spatial planning in the siting of recycling facilities. The road distances from each provincial center to the nearest ecological protection zone or UNESCO-designated site are presented in Table 4.

2.2.4. Transportation and operational cost (C4)

Transportation and operational cost are a critical factor influencing the economic sustainability of recycling facilities. In this study, the C4 criterion is defined as the average cost (in TL per ton per km) of transporting waste from its source—such as temporary dumping areas or debris zones—to the permanent recycling facility and processing it on site.

Table 4. Road distance to the nearest ecological or UNESCO site (C3)

Province	Ecological Area	Distance (km)
Adana	Karataş Kumluk Nature Park	~49 km
Adıyaman	Gölbaşı Lakes Nature Park	~75 km
Diyarbakır	Hevsel Gardens and Tigris Valley Protection Zone	~5 km
Elazığ	Lake Hazar Nature Park	~22 km
Kilis	Hisar Pine Grove Nature Park	~40 km
Osmaniye	Çiftmazı Nature Park	~10 km

Cost components are not solely dependent on distance; they are also affected by several other variables, including road infrastructure quality, vehicle availability, labor accessibility, fuel prices, terrain slope, weather conditions, and the presence of supporting industrial infrastructure. Accordingly, the cost values for each province were estimated using sectoral reports on road transportation in Türkiye as well as quotations from logistics companies [59, 60]. Table 5 presents the calculated unit transportation and operational costs for each province included in the study.

Table 5. Estimated transportation costs (C4) for each province (TL/ton·km)

Province	Transportation Cost (TL/ton·km)
Adana	2.8
Adıyaman	3.5
Diyarbakır	3.8
Elazığ	4.0
Kilis	3.3
Osmaniye	3.0

2.2.5. Estimated volume of demolition waste (C5)

The volume of generated demolition waste is considered one of the most critical technical criteria affecting the feasibility of establishing a permanent recycling facility. This indicator is directly associated with the facility's capacity to maintain a continuous supply of input material, which is essential for sustainable operations. In this study, the values used for the C5 criterion are based on estimates developed by Temelli et al. [3], which calculate the amount of demolition waste for each province by multiplying the number of buildings that collapsed, were urgently demolished, or were declared severely damaged due to the earthquake with an average unit waste generation factor. This estimation methodology is supported by volume-to-mass conversion coefficients commonly applied in post-disaster waste management and is consistent with national-level damage assessment reports. Table 6 presents the estimated total amount of demolition waste for each province considered in the study. As such, the C5 criterion is defined as a benefit-type criterion, as a higher volume of waste indicates greater potential for facility viability and operational sustainability. Conversely, provinces with lower waste volumes pose a greater risk in terms of investment efficiency and long-term return.

Table 6. Estimated total amount of demolition waste (C5) for each province

Province	Estimated Waste Volume (tons)
Adana	~552.024
Adıyaman	~10.519.872
Diyarbakır	~1.608.574
Elazığ	~1.899.172
Kilis	~470.118
Osmaniye	~3.012.757

2.2.6. Land suitability (C6)

Land suitability represents a multi-dimensional criterion encompassing the physical, geotechnical, legal, and planning feasibility of establishing a permanent recycling facility. In this study, the C6 criterion was evaluated using an ordinal scale ranging from 1 to 5 for each province, based on several factors: the availability of flat terrain, accessibility to infrastructure, designation of land for industrial/commercial use in zoning plans, topographical and slope conditions, property ownership, and environmental constraints. The scoring system used for the land suitability assessment is presented in Table 7, while Table 8 provides the province-specific scores and justifications based on local conditions.

2.2.7. Disaster intensity and reconstruction need (C7)

The criterion of disaster intensity and reconstruction need (C7) reflects the level of physical destruction and infrastructure requirements following the earthquakes centered in Kahramanmaraş on 6 February 2023. The assessment incorporates indicators such as the number of collapsed buildings, the need for debris removal, and the required intervention capacity. As the primary data source, the 8th-Month Evaluation Report on the Earthquakes of 6 February, published by the Union of Chambers of Turkish Engineers and Architects (TMMOB) [68], was used. Official statistics and field observations from this report were directly integrated into the scoring methodology. Provinces were classified into five levels based on the number of collapsed buildings, reflecting their need for reconstruction and post-disaster intervention. This classification is summarized in Table 9.

Table 7. Land suitability scoring system

Score	Description
1	No suitable land; major topographical, legal, or physical barriers exist
2	Only small and fragmented areas are available; limited accessibility or permits
3	Restricted but usable land parcels are available
4	Restricted but usable land parcels are available
5	Extensive areas are fully suitable in terms of technical, legal, and logistical criteria

Table 8. Land suitability scores (C6) and justifications for each province

Province	C6 Score (1–5)	Justification
Adana	5	Extensive industrial parcels, flat topography, and existing infrastructure in areas such as Ceyhan and Sarıçam [61, 62].
Adıyaman	4	Northern plains offer zoned industrial areas with strong transport connections [63].
Diyarbakır	2	Mountainous and fragmented terrain, densely built environment presents technical challenges [63, 64].
Elazığ	2	Limited flat terrain and topographic constraints reduce land suitability [65].
Kilis	1	Small provincial area and border location; no large flatlands available; investment land is highly limited [66].
Osmaniye	2	Proximity to mountainous areas and high settlement density restrict available land [67].

Table 9. Scoring system for disaster intensity and reconstruction need

Score	Description	Explanation
1	Relatively low disaster impact	Minimal building collapse and casualties; minor intervention and reconstruction needs.
2	Limited damage – low intervention need	Low numbers of collapsed buildings and casualties; manageable with local capacity.
3	Moderate damage – recoverable with regional support	Considerable damage requiring support from nearby regions.
4	High damage – clear reconstruction need	Substantial collapse and casualties; long-term infrastructure and rebuilding are required.
5	Very high destruction and crisis	Widespread destruction and high casualties; urgent intervention with national/international aid.

The scoring was based on both the number of collapsed buildings and the estimated personnel required for intervention. As a result, Adıyaman received the highest score of 5, representing “very high destruction and crisis,” while Diyarbakır was assigned a score of 1, indicating “relatively low disaster impact.” The scores for the other provinces were determined using the same method and are presented in Table 10.

2.2.8. Number of temporary debris disposal sites (C8)

Effective post-disaster management of CDW depends not only on the volume of debris and transportation capacity but also on the availability of temporary debris disposal sites-one of the key elements of logistical organization. Within this context, the C8 criterion is defined as a technical and administrative indicator that reflects a province’s capacity to manage disaster-related debris swiftly and safely. Temporary disposal sites are designated areas for the rapid collection, temporary storage, preliminary sorting, and initial treatment of large volumes of debris immediately following a disaster. They serve as a critical component in the waste management chain, especially prior to the establishment of permanent recycling facilities. In this study, C8 is treated as a benefit-type criterion. A higher number of temporary disposal sites is considered indicative of enhanced emergency response capacity, greater administrative preparedness, and more robust institutional coordination. Therefore, provinces with more such sites are assumed to offer better operational flexibility and support a more effective reconstruction process. Data on the number of temporary debris disposal sites were compiled based on the “Disaster Debris Management Guide” published by Business Council for Sustainable Development Türkiye (BCSD Türkiye) [69], and are presented in Table 11.

Table 11. Number of temporary debris disposal sites in the selected provinces (C8)

Province	C8 Value (Number of Sites)
Adana	2
Adıyaman	0
Diyarbakır	1
Elazığ	0
Kilis	1
Osmaniye	4

2.3. Determination of criteria weights: The CRITIC method

In this study, the CRITIC method, a data-driven and objective weighting technique, was employed to determine the relative importance of each criterion. The CRITIC method evaluates both the amount of information contained in a criterion (via its standard deviation) and the degree of its correlation with other criteria. This dual consideration ensures that criteria with high discriminative power and minimal redundancy are assigned higher weights. Compared to subjective approaches, CRITIC offers statistical consistency and reproducibility, which makes it particularly suitable for infrastructure planning and MCDM problems involving large datasets [70-72]. In this study, the CRITIC method was implemented based on the formulation presented by Abdi et al. [73] and consists of five main steps:

Step 1: A decision matrix $A=[x_{ij}]$ was constructed, where i $i=1,\ldots,a$ represents the alternatives and ve $j=1,\ldots,b$ represents the criteria.

Table 10. Disaster intensity scores for the study provinces (C7)

Province	Collapsed Buildings	Required Personnel	C7 Score (1–5)
Adana	88	240	2
Adıyaman	5826	16180	5
Diyarbakır	21	60	1
Elazığ	56	160	2
Kilis	448	1240	3
Osmaniye	649	1800	3

Each element x_{ij} denotes the performance score of the *i* alternative under the j criterion, as shown in Equation (1):

$$A = [x_{ij}]_{a*b} = \begin{bmatrix} x_{11} & \cdots & x_{1b} \\ \vdots & \ddots & \vdots \\ x_{a1} & \cdots & x_{ab} \end{bmatrix} \quad (1)$$

Step 2: The decision matrix was normalized based on the criterion type. For benefit-type criteria (to be maximized), normalization was performed using Equation (2), whereas for cost-type criteria (to be minimized), Equation (3) was used. N_{ij} denotes the normalized value of the i[th] alternative under the j[th] criterion:

$$N_{ij} = \frac{x_{ij} - x_i^{min}}{x_i^{max} - x_i^{min}} \quad (2)$$

$$N_{ij} = \frac{x_i^{max} - x_{ij}}{x_i^{max} - x_i^{min}} \quad (3)$$

Step 3: The standard deviation σ_j was computed for each normalized criterion *j* to reflect the internal variability or discriminative power of the criterion.

Step 4: The amount of information C_j contained in each criterion was calculated based on both variability and inter-criteria correlation, as expressed in Equation (4), where r_{jk}, is the Pearson correlation coefficient between criteria *j* and *k*

$$C_j = \sigma_j \sum_{k=1}^{m} (1 - r_{jk}) \quad (4)$$

Step 5: The final normalized weights w_j were obtained by dividing each criterion's information score by the sum of all criteria's information scores, as shown in Equation (5):

$$w_j = \frac{C_j}{\sum_{j=1}^{m} C_j} \quad (5)$$

This procedure minimizes the influence of redundant information and enhances the contribution of distinct and informative criteria. Accordingly, the CRITIC method adds analytical rigor and objectivity to the decision-making framework and is particularly effective when integrated with ranking methods such as COPRAS and TOPSIS.

2.4. Ranking of alternatives: COPRAS and TOPSIS methods

The COPRAS method was developed by Zavadskas et al. [74] to comprehensively evaluate decision alternatives from both benefit and cost perspectives within the scope of MCDM. The primary objective of this method is to determine the relative significance of each alternative and provide decision-makers with a structured and comparative ranking framework. COPRAS is widely preferred in decision problems involving a large number of criteria due to its straightforward computational steps and strong explanatory power [75–77]. In this method, criteria are classified as either benefit-type (to be maximized) or cost-type (to be minimized), and the relative importance of each alternative is calculated accordingly [78, 79]. This structure makes COPRAS particularly suitable for situations where the impacts of criteria are not clearly defined or where decision uncertainty is high [80, 81]. In this study, the steps implemented by Atan and Altan [76] were followed.

Step 1: For a decision problem with m alternatives and n criteria, the decision matrix X is constructed as shown in Equation (6), where x_{ij} represents the performance score of the i[th] alternative with respect to the j[th] criterion.

$$X = [x_{ij}]_{m*n} = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}; \begin{matrix} i = 1,2,\dots,m \\ j = 1,2,\dots,n \end{matrix} \quad (6)$$

Step 2: Each element x_{ij} in the decision matrix is normalized using Equation (7), resulting in the normalized decision matrix $\bar{X}$ given in Equation (8). After normalization, the sum of the normalized values for each criterion across all alternatives equals 1, as in Equation (9):

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (7)$$

$$\bar{X} = \begin{bmatrix} \bar{x}_{11} & \cdots & \bar{x}_{1n} \\ \vdots & \ddots & \vdots \\ \bar{x}_{m1} & \cdots & \bar{x}_{mn} \end{bmatrix}; \begin{matrix} i = 1,2,\dots,m \\ j = 1,2,\dots,n \end{matrix} \quad (8)$$

$$\sum_{i=1}^{m} \overline{x_{ij}} = 1 \quad (9)$$

Step 3: Weighted normalized performance scores are calculated using Equation (10), yielding the weighted normalized decision matrix $\hat{X}$ as shown in Equation (11). In this matrix, the sum of all weighted values equals 1 (Equation 12), and the sum of weighted scores for each criterion equals the corresponding weight w_j. (Equation 13):

$$\sum_{i=1}^{m} \overline{x_{ij}} = 1 \tag{10}$$

$$\hat{X} = \begin{bmatrix} \hat{x}_{11} & \cdots & \hat{x}_{1n} \\ \vdots & \ddots & \vdots \\ \hat{x}_{m1} & \cdots & \hat{x}_{mn} \end{bmatrix} ; \begin{matrix} i = 1,2,\dots,m \\ j = 1,2,\dots,n \end{matrix} \tag{11}$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n} \widehat{x_{ij}} = 1 \tag{12}$$

$$\sum_{i=1}^{m} \widehat{x_{ij}} = w_j \tag{13}$$

Step 4: The total of benefit-type criteria S_{+I} and cost-type criteria S_{-I} for each alternative is calculated using Equations (14) and (15), respectively:

$$S_{+i} = \sum_{j=1}^{k} \hat{x}_{+ij} \ ; i = 1,2,\dots,m \ j = 1,2,\dots,k \tag{14}$$

$$S_{-i} = \sum_{j=k+1}^{n} \hat{x}_{-ij} \ ; i = 1,2,\dots,m \ j = k+1, k+2, \dots, n \tag{15}$$

Step 5: The relative significance score Q_i or each alternative is computed using Equation (16), where higher values of Q_i indicate more favorable alternatives:

$$Q_i = S_{+i} + \frac{S_{-min} \times \sum_{i=1}^{m} S_{-i}}{S_{-i} \times \sum_{i=1}^{m} \left(\frac{S_{-min}}{S_{-i}} \right)} \ ; i = 1,2,\dots,m \tag{16}$$

Step 6: The performance index P_i , which expresses the performance level of the ith alternative as a percentage of the best-performing one, is calculated using Equation (17). The alternatives are then ranked in descending order of P_i:

$$P_i = \left[\frac{Q_i}{Q_{maks}} \right] \times \%100 \ ; i = 1,2,\dots,m \tag{17}$$

The TOPSIS, originally developed by Hwang and Yoon [82], is a widely adopted and intuitive MCDM method. Its fundamental assumption is that the most preferable alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. The procedure involves several steps: normalization of the decision matrix, application of criterion weights, identification of ideal and anti-ideal solutions, calculation of Euclidean distances from these solutions, and ranking of alternatives based on relative closeness coefficients [83, 84]. One of the main advantages of TOPSIS lies in its ease of implementation and its ability to produce a clear and interpretable ranking. For this reason, it is frequently used in a wide range of applications, including engineering, finance, environmental planning, education management, and technology evaluation [85, 86]. Although it has some limitations in directly handling uncertainty and vagueness, the quantitative proximity metric provided by TOPSIS adds objectivity and flexibility to the decision-making process [87]. In this study, the implementation steps proposed by Turkoğlu et al. [77] were followed.

Step 1: The decision matrix X is constructed, where x_{ij} represents the performance score of the ith alternative with respect to the jth criterion (Equation (18)). The matrix has dimensions n×m, where n is the number of alternatives and m is the number of criteria.

$$X = [x_{ij}]_{n*m} = \begin{bmatrix} x_{11} & \cdots & x_{1m} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nm} \end{bmatrix} \tag{18}$$

Step 2: The matrix is normalized to ensure comparability across different criteria scales using the following Equation (19):

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} (x_{ij})^2}} \tag{19}$$

Step 3: The weighted normalized matrix v_{ij} is calculated by multiplying each normalized value by the respective criterion weight wj (Equation (20)):

$$v_{ij} = n_{ij}.w_j \tag{20}$$

Step 4: The positive ideal solution A^+ and negative ideal solution A^- are determined as follows Equation (21) and (22), respectively:

$$A^+ = [v_1{}^+, \dots, v_j{}^+, \dots, v_n{}^+] \tag{21}$$

$$A^- = [v_1{}^-, \dots, v_j{}^-, \dots, v_n{}^-] \tag{22}$$

For benefit-type criteria: $v_j^+ = \max_i \{ v_{ij} \}$, $v_j^- = \min_i \{ v_{ij} \}$

For cost-type criteria: $v_j^+ = \min_i \{ v_{ij} \}$, $v_j^- = \max_i \{ v_{ij} \}$

Step 5: The Euclidean distances from the positive and negative ideal solutions for each alternative are computed using Equations (23) and (24), respectively:

$$S_i^+ = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^{+})^2} \tag{23}$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^{-})^2} \tag{24}$$

Step 6: The relative closeness of each alternative to the positive ideal solution is calculated using the following Equations (25):

$$C_i = \frac{S_i^{-}}{S_i^{+} + S_i^{-}} \tag{25}$$

Step 7: Finally, alternatives are ranked in descending order based on their C_i values. The alternative with the highest C_i is considered the most preferable.

3. Results of the Decision Model

This section systematically presents the results obtained from the CRITIC-based weighting and the rankings derived from the COPRAS and TOPSIS methods. Initially, the relative weights of each criterion were calculated using the CRITIC method, based on the dataset constructed from the defined evaluation framework. Subsequently, these weights were integrated into the COPRAS and TOPSIS models to assess the relative suitability of the six selected provinces for permanent CDW recycling facility placement.

3.1. Criterion weights: Results of the CRITIC method

The CRITIC method is an objective weighting approach that evaluates the informational value of each criterion using statistical parameters. It considers both the standard deviation (i.e., variability) and the correlation structure of each criterion with others, prioritizing those with high information content and low redundancy. Table 12 summarizes the computed weights of the eight criteria, as derived from the CRITIC analysis.

According to the results, "Land Suitability" (C6) emerged as the most influential criterion, followed by "Estimated CDW Volume" (C5), "Population Density" (C2), and "Number of Temporary Dumping Sites" (C8). The remaining criteria were ranked as follows: "Distance to Ecological Protection Zones" (C3), "Transportation and Implementation Cost" (C4), "Proximity to Existing Facilities" (C1), and "Disaster Intensity and Reconstruction Need" (C7). Specifically, the low CRITIC weight for C7 can be attributed to its relatively low standard deviation across the six provinces, as well as high correlation with other criteria such as C5 and C8. This prioritization indicates that technical feasibility, waste volume, and demographic characteristics are the most critical factors in site selection decisions.

3.2. Evaluation of alternatives: COPRAS and TOPSIS methods

Using the criterion weights derived from the CRITIC method, the relative suitability of the six selected provinces was analyzed through two distinct MCDM techniques: COPRAS and TOPSIS. Both methods incorporate the criterion weights into the decision matrix and evaluate each alternative based on its performance regarding benefit and cost-type criteria.

Table 12. Criterion weights

Criterion No	Weight (%)
C1: Distance to the nearest recycling facility	10.33
C2: Population density	12.80
C3: Distance to ecological protection zones	11.82
C4: Transportation and operational cost	11.56
C5: Estimated volume of CDW generated	13.82
C6: Land suitability	17.16
C7: Disaster intensity and reconstruction need	10.29
C8: Number of temporary dumping sites	12.21

The COPRAS method assesses benefit and cost criteria separately to compute a relative utility score for each alternative, while the TOPSIS method calculates a closeness coefficient (Ci) based on the Euclidean distances to the positive and negative ideal solutions. Employing both techniques provides methodological diversity and enhances the robustness of the results through cross-validation. The rankings obtained from both methods are presented comparatively in Table 13.

The findings indicate a high degree of consistency between COPRAS and TOPSIS, suggesting strong methodological agreement. According to the results, Adıyaman ranked first in both models, followed by Adana and Osmaniye. Elazığ, Diyarbakır, and Kilis were ranked lower, with Kilis being the least favorable alternative. This outcome offers a reliable and evidence-based guide for policymakers in selecting optimal locations for permanent CDW recycling infrastructure.

4. Discussion

The prioritization outcomes derived from the CRITIC–COPRAS and CRITIC–TOPSIS methodologies in this study demonstrate the consistency and applicability of MCDM approaches in selecting appropriate locations for post-disaster CDW recycling facilities. Both methods produced similar ranking results, with Adıyaman emerging as the top priority province, followed by Adana and Osmaniye. Kilis was ranked lowest. These findings gain further relevance when interpreted in conjunction with the calculated criterion weights.

Among the eight evaluation criteria, "Land Suitability" (C6) received the highest weight at 17.16%, indicating that the availability and appropriateness of physical space for facility construction play a decisive role in the site selection process. This criterion encompasses not only flat terrain and zoned industrial areas but also directly impacts the pace of project implementation, operational costs, and environmental permitting processes [18, 88, 89]. In this regard, Adana achieved the highest score due to the presence of extensive flat industrial parcels in regions such as Ceyhan and Sarıçam. However, the fact that Adana ranked second overall in both methods suggests that spatial suitability alone is insufficient; disaster-related needs, demographic density, and waste generation potential also significantly influence the decision outcome.

Adıyaman's consistent top ranking across both MCDM methods indicates that this province holds significant strategic advantages within the decision model. Adıyaman performed strongly in multiple key criteria, including CDW volume (C5), disaster intensity and reconstruction need (C7), and population density (C2). According to the literature, sustainable operation of a recycling facility requires a consistent supply of raw materials (i.e., waste volume) and proximity to the waste generation area [90, 91]. Moreover, in regions severely impacted by disasters, waste management should not only be considered an environmental imperative but also a critical component of post-disaster social reconstruction [92, 93]. Adıyaman's extensive damage and resultant high waste volume underscore the urgent necessity for a permanent recycling facility from both environmental and economic standpoints.

Table 13. Rankings of alternatives based on COPRAS and TOPSIS methods

Province	COPRAS		TOPSIS	
	P_i	Rank	C_i	Rank
Adana	0.662179	2	0.378017	2
Adıyaman	1.000000	1	0.771673	1
Diyarbakır	0.482180	5	0.266072	5
Elazığ	0.512702	4	0.317386	4
Kilis	0.459973	6	0.258293	6
Osmaniye	0.621817	3	0.360382	3

Furthermore, its potential in criteria such as the number of temporary dumping sites (C8) reflects institutional preparedness and coordination capabilities developed during prior disaster responses. These findings confirm that the proposed MCDM model integrates not only technical but also strategic and governance dimensions into its framework. Adıyaman's top ranking, therefore, reflects a comprehensive evaluation that prioritizes functional and governance factors over mere physical suitability, aligning with literature that advocates for multidimensional assessments in post-disaster recovery planning [94-96].

The consistency between COPRAS and TOPSIS rankings not only affirms the robustness of the decision support models but also supports the validity of the CRITIC-derived weights across different MCDM algorithms. The low rankings of Diyarbakır and Kilis can be attributed to their limited performance in both technical (e.g., land suitability, waste volume) and strategic (e.g., disaster intensity, temporary site capacity) dimensions. This finding reinforces previous observations that isolated strengths in single criteria are insufficient in MCDM problems, where overall suitability across multiple domains determines success [97, 98].

This study highlights the need for data-driven, multidimensional frameworks in locating permanent CDW recycling facilities in high-risk earthquake regions like Türkiye. The consistency of rankings across both methods demonstrates the reliability of the proposed decision model and provides a scientifically grounded foundation for investment prioritization and resource allocation. Moreover, the fact that both methods yielded nearly identical rankings underscores the methodological soundness of the decision support tools used and the internal consistency of the results. The agreement also indicates that the CRITIC weighting approach is compatible with multiple MCDM algorithms and that the derived weights are valid across different computational frameworks. Previous literature has emphasized that comparative analyses using multiple MCDM methods enhance model reliability and decision quality [99]. The similar outcomes produced by COPRAS and TOPSIS based on the same decision matrix and weight set further reinforce the validity of the framework.

Adıyaman, Adana, and Osmaniye emerged as the most suitable provinces, while Diyarbakır and Kilis consistently ranked lower due to their weaker performance across numerous criteria. For instance, Kilis's limited land availability and border proximity physically constrain the establishment of large-scale facilities, while Diyarbakır's relatively low disaster impact reduces its urgency. These results indicate that a high score in a single criterion (e.g., low transport cost or high population density) is insufficient to ensure overall suitability; rather, balanced performance across multiple criteria is essential. As emphasized by Viñas [100], strategic decisions such as facility siting must be based on parametric balance and inter-criteria interactions rather than individual parameters alone. Hence, the findings not only validate the internal logic of the MCDM framework but also demonstrate alignment with field realities. This confirms that the integration of CRITIC with COPRAS and TOPSIS enhances methodological reliability and applicability for complex infrastructure planning scenarios.

5. Conclusion and Recommendations

This study proposes a data-driven, systematic multi-criteria decision support model for selecting permanent CDW recycling facility locations in six Turkish provinces—Adana, Adıyaman, Diyarbakır, Elazığ, Kilis, and Osmaniye—affected by the 6 February 2023 earthquakes and currently lacking such infrastructure. Using objectively calculated criterion weights derived from the CRITIC method, the model evaluated eight criteria (C1–C8) encompassing technical, environmental, economic, demographic, and strategic dimensions. The subsequent use of COPRAS and TOPSIS methods enabled a comparative analysis of the provinces' relative suitability.

The results revealed Adıyaman as the most favorable candidate due to its high scores in CDW volume, disaster intensity, population density, and institutional preparedness. Adana ranked second with strong land suitability and industrial infrastructure, followed by Osmaniye in third place, primarily due to its moderate technical capacity and high disaster exposure. In contrast, Kilis and Diyarbakır ranked lowest due to limitations in both physical and managerial capacities. The consistency of outcomes between COPRAS and TOPSIS reinforces the methodological credibility and practical validity of the proposed model. Based on these findings, the following recommendations are provided for policymakers and relevant institutions:

- Expedited Investment in High-Priority Regions: Particularly in severely affected areas such as Adıyaman, the rapid planning and implementation of permanent recycling facilities is essential for both environmental sustainability and social reconstruction.
- Development of Land Suitability Maps: Given that land suitability received the highest weight, regional zoning plans should be reassessed for their compatibility with industrial and waste management investments.
- Integration of Temporary Dump Sites into Long-Term Planning: The number and functionality of temporary dumping sites serve as indicators of operational capacity and should be integrated into permanent infrastructure strategies.
- Promotion of Data-Driven, Adaptive Decision Models: The CRITIC–COPRAS and CRITIC–TOPSIS frameworks used here are applicable to other disaster contexts. Public agencies should adopt similar evidence-based tools for strategic planning.
- Enhanced Inter-Institutional Coordination: In provinces with limited institutional capacity, collaborative planning involving local and national stakeholders is essential. Establishing recycling facilities is not merely a technical task but a governance challenge as well.

In summary, this study offers a scientifically grounded, objective, and sustainable roadmap for managing post-disaster waste. The proposed model is not only applicable in Türkiye but can also serve as a reference for disaster-prone regions worldwide, contributing to the development of resilient urban recovery strategies.

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Author Contributions

M. Akbas: Conceptualization, Methodology, Literature Review, Writing–Original Draft, Validation. F. D. Akın: Methodology, Formal Analysis, Data Processing, Visualization, Writing–Review & Editing.

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Data Availability Statement

All data used in this study were obtained from publicly available institutional sources. No new experimental data were generated.

Ethics Committee Permission

Not applicable.

Conflict of Interests

The author declares no conflict of interest with respect to the authorship, analysis, or publication of this article.

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