Environ. Water Eng., 2025, 11(4), 551-561 https://doi.org/10.22034/ewe.2025.539730.2051

EWE

Environment and Water Engineering

Homepage: www.jewe.ir

ISSN: 2476-3683

A managerial decision model for environmental impact assessment in Yazd Compost Factory using the fuzzy analytic network process

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ARTICLE INFO

Paper Type: Research Paper

Received: 06 August 2025
Revised: 26 September 2025
Accepted: 27 September 2025
Published: ۳۰ September 2025

Keywords
Compost Factory
EIA
FANP
Fuzzy DEMATEL

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ABSTRACT

This study aimed to design and develop an evaluation model for sustainable management of environmental impacts in compost factories, focusing on the Yazd compost plant. The main objective is to reduce negative environmental effects and enhance sustainability performance. A mixed-methods approach (qualitative-quantitative) was adopted, utilizing fuzzy Delphi, thematic analysis, fuzzy DEMATEL, and fuzzy FANP methods. In the qualitative phase, key environmental indicators were identified through content analysis of interviews and documentation, and an initial conceptual model was developed using MAXQDA software. In the quantitative phase, relationships among indicators were examined using fuzzy DEMATEL, and prioritization was performed with fuzzy FANP. The final management model was validated by experts. The results indicate that, despite challenges such as securing raw materials and cost management, compost plants in Yazd can significantly reduce environmental impacts and improve economic conditions. To further enhance efficiency and sustainability, improvements in existing processes, increased public awareness, and supportive policies at local and provincial levels are essential. Additionally, the adoption of advanced technologies and process optimization methods can further reduce pollutants and enhance economic outcomes.

Highlights

- Using managerial models in assessments helps reduce environmental damages.
- Environmental evaluations prevent ecological crises and support sustainability.
- Supportive policies strengthen management and improve sustainable performance.

Citing:
Hekmatnia, N., Behbahaninia, A., Samadyar, H., & Motahari, S. (2025). A managerial decision model for environmental impact assessment in Yazd Compost Factory using the fuzzy analytic network process. *Environment and Water Engineering*, *11*(4), 551-561. https://doi.org/10.22034/ewe.2025.539730.2051

1. Introduction

Sustainability has become a key component of strategic environmental and urban policy-making due to the fast urbanization and population growth (James, 2024). Achieving sustainable development in the modern era is one of the biggest global challenges, especially when it comes to striking a balance between economic, social, and environmental demands. The efficient management of urban waste, which has grown more difficult in developing nations as a result of population growth and changing consumption patterns, is a crucial issue in this respect. The proper and sustainable management of municipal solid waste has become a significant and expensive challenge due to its increasing production (Mirzaee et al., 2016). The environment, human health, and natural resources like soil, water, and air are all negatively impacted by poor waste management techniques (Takdastan et al., 2005; Van de Walle et al., 2023).

A key element of urban and environmental planning, improving the management of industrial and urban waste is essential for sustainable development, especially in developing nations (Abedinzadeh et al., 2013). As an effective method, composting organic materials from municipal waste not only lowers waste weight and volume, minimizes leachate and odors, and makes resource recovery easier, but it also saves money and lowers pollution (Xu et al., 2024; Akbarinejad Paqaleh et al., 2013). This method reduces waste production, improves soil quality, and lessens dependency on chemical fertilizers by turning organic waste into natural fertilizer (Samadi & Morshedi, 2003). Given the high percentage of organic matter in waste composition in Iran, composting offers a viable method for recycling waste and producing fertilizer for agriculture (Hosseinpoor et al., 2022). However, there are serious risks to the environment and public health when composting industries are developed without taking environmental and health requirements into consideration (Hosseinpoor et al., 2024).

According to reports that are currently available, biodegradable materials make up a sizable amount of the waste produced in the nation. If these materials are not properly managed, they can lead to the release of pollutants and greenhouse gas emissions (Dsouza et al., 2022). Despite their advantages, composting facilities can have negative effects on the environment, such as polluting the air, water, and soil, emitting unpleasant odors, and producing greenhouse gases (Panahandeh et al., 2013; Allahdadi et al., 2024). Additionally, adding plastics and microplastics to the composting process lowers the quality of the finished product and increases the possibility of contaminating the soil and water. The presence of non-compostable materials and improper waste segregation decrease process efficiency and make compost production more difficult. According to earlier research, there are still a lot of unanswered questions about how to manage the environmental effects of composting facilities, especially with regard to greenhouse gas emissions and process sustainability (Manea et al., 2024; Murshid et al., 2024). Therefore, it is crucial to adopt cutting-edge technologies, improve assessment techniques, and improve waste management procedures (Jalalipour et al., 2025). In light of these difficulties, it is crucial to create and apply creative management models that are adapted to regional circumstances and make use of state-of-the-art technologies. Environmental assessment of projects, which employs analytical techniques like the Fuzzy Analytical Network Process (FANP) to allow for a thorough and accurate evaluation of environmental indicators and outcomes, is a crucial tool in managing environmental impacts (El-Naqa, 2005). The FANP gives decision-makers a methodical and scientific way to find, evaluate, and rank indicators by combining the advantages of fuzzy logic and network analysis.

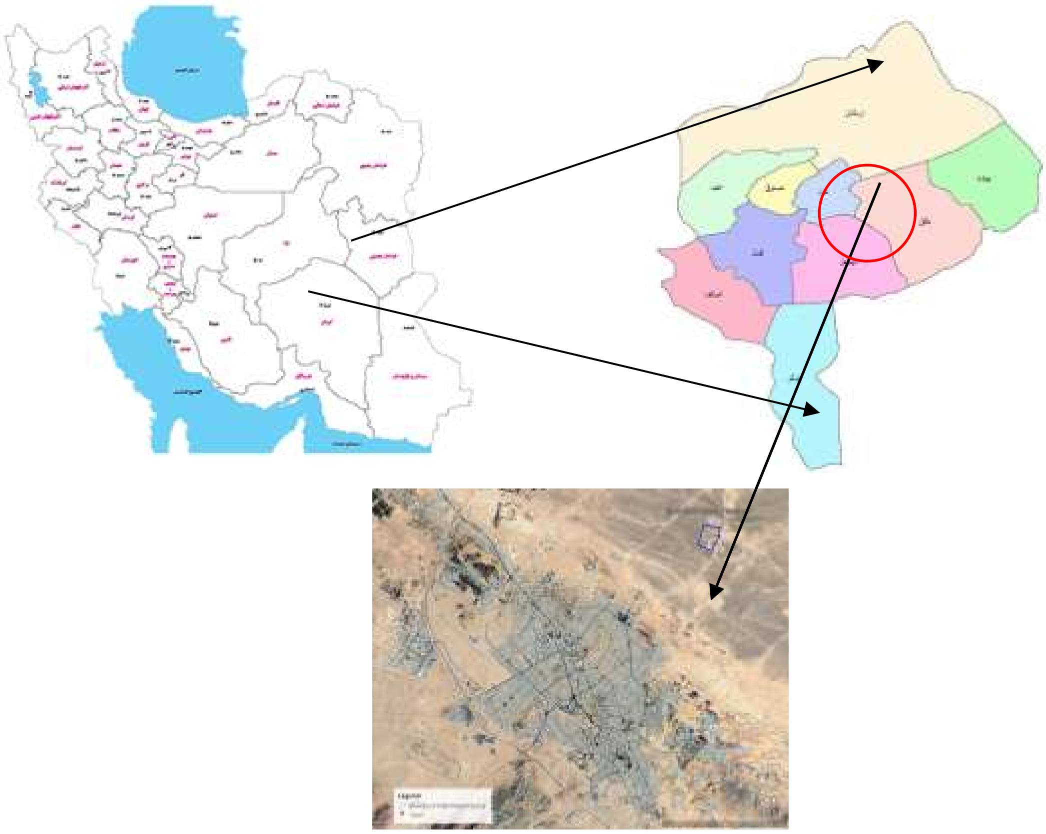
In light of this, the current study uses the Fuzzy Analytical Network Process to create a model for controlling the environmental effects of composting facilities in Yazd. In order to provide a thorough and useful model for enhancing the environmental management of composting facilities, this study uses a hybrid approach to identify and analyze important indicators. For managers, researchers, and policymakers working in the nation's waste management and environmental protection sectors, this study can be used as a scientific and practical reference.

2. Materials and Methods

2.1 Case study description

An important project for managing organic waste in Iran is the Yazd Composting facility, which was set up to produce high-quality organic fertilizer for use in green spaces and agriculture while also lowering the amount of municipal waste. The 150-hectare facility is situated between latitudes 31°57' and 31°58' N and longitudes 54°25' and 54°27' E, 3.7 kilometers northwest of Yazd city (Fig. 1).

Fig. 1 Location of Yazd Compost Company



With an emphasis on the Yazd composting facility specifically, the current study attempts to create a model for controlling the environmental effects of composting facilities. The main goal is to pinpoint the main causes of environmental impacts and offer evidence-based remedies to lessen them and improve environmental sustainability.

2.2 Overall research design

The Fuzzy Analytical Network Process (FANP), a thorough and multi-layered framework, was used in this investigation. In complex and uncertain environments, this approach makes it easier to systematically identify and analyze indicators and their relationships. Researchers can analyze and assess the variables influencing the structured management of composting facilities' environmental impacts using the FANP model.

With a mixed-methods approach and an exploratory sequential design, this study is conducted in two stages: qualitative and quantitative.

2.2.1 Qualitative phase and indicator identification

In the qualitative phase, key environmental indicators were identified through a systematic review of scientific literature and semi-structured interviews with 15 experts (a subset of the final panel, selected for their deep contextual knowledge). The interviews continued until thematic saturation was reached, meaning subsequent interviews yielded no new substantive themes. This group represented the near-entirety of the available expert population for this specific case study, including the factory's senior management, lead engineers, environmental consultants directly involved with the facility, and relevant officials from provincial environmental agencies. Recruiting a larger sample would have compromised the 'expert' criterion by including individuals without specialized, firsthand knowledge. During the qualitative interview phase, thematic analysis indicated that saturation was reached after the 12th interview, as subsequent interviews yielded no new themes or critical insights regarding the environmental impact criteria. The final panel of 15 ensured a robust and comprehensive perspective for the quantitative Fuzzy DEMATEL and FANP analyses. While the expert panel size (n=15) is a limitation for broad statistical generalization, it was determined by the highly specialized nature of the case study and represented a comprehensive sampling of the available expert population, with thematic saturation achieved during the qualitative phase. Consequently, the findings are highly relevant for the Yazd context but their transferability to other regions requires local calibration with a new panel of experts.

2.2.2 Expert panel selection and composition

The experts for this study were selected using a purposive sampling technique to ensure the panel possessed comprehensive and authoritative knowledge relevant to the environmental management of the Yazd compost factory. To be considered an 'expert,' individuals had to meet the following minimum criteria: A minimum of 5 years of professional experience in a relevant field (waste management, environmental engineering, public health, or environmental policy); and Direct professional involvement with the operations, management, or regulatory oversight of the Yazd compost factory or similar waste processing facilities in the region. The final panel of 15 experts was constituted to capture a multi-stakeholder perspective, encompassing the key groups involved in the factory's environmental performance.

All interviews were transcribed verbatim. Thematic analysis was conducted using MAXQDA 2022 software. To ensure coding reliability, two independent researchers familiar with the field coded a random sample of 30% of the transcripts. The inter-coder agreement was quantitatively assessed using Holsti's method, which yielded a reliability coefficient of 0.87, indicating a high level of consistency. Discrepancies were discussed until a consensus was reached, and the finalized codebook was then applied to the entire dataset. Techniques such as member checking (where summaries were returned to 5 interviewees for verification) and peer debriefing (review by an external researcher) were employed to enhance the credibility and trustworthiness of the qualitative findings. This rigorous process resulted in the initial set of criteria and sub-criteria used for the subsequent Fuzzy Delphi screening. Data reliability was also evaluated using the Holsti method and double-coding in two steps.

2.3 Quantitative phase and model development

Multi-criteria decision-making techniques, such as the Fuzzy Analytical Network Process (FANP) and the Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy DEMATEL), were used in the quantitative phase to prioritize the criteria and examine causal relationships between them. A purposive sample of 15 people was chosen from the statistical population, which was made up of professionals and experts in the waste management and environmental fields. Pairwise comparison questionnaires were used for data collection, and Super Decisions and Excel software were used for analysis. Additionally, the identified criteria were validated and screened using the Fuzzy Delphi method. This approach increases the credibility of the results by facilitating the elicitation of expert opinions in uncertain situations by combining fuzzy set theory, and the Delphi process.

2.3.1 Fuzzy DEMATEL method

The fuzzy direct-relation matrices obtained from the expert questionnaires were aggregated. The subsequent computational steps were implemented in Microsoft Excel as follows:

a. Normalization: The aggregated fuzzy matrices were normalized to obtain the fuzzy total-relation matrix.

b. Defuzzification: The normalized fuzzy total-relation matrix was defuzzified using the Centroid (Center of Area) method to convert the triangular fuzzy numbers (l, m, u) into crisp values using the formula (Eq. 1)

$$\text{Crisp Value}=(l+m+u)/3\text{Crisp Value}=(l+m+u)/3 \qquad (1)$$

c.Calculation of Indices: From the defuzzified total-relation matrix, the prominence (D+R) and relation (D-R) indices for each criterion were calculated to determine their causal relationships.

2.3.2 Fuzzy analytical network process (FANP)

The fuzzy pairwise comparison matrices from the experts were aggregated. The analysis was conducted using the Super

Decisions software (version 3.2) to manage the network model and complex calculations. The main steps involved were: consistency check, supermatrix formation, and weight calculation. In the first step, each individual fuzzy pairwise comparison matrix was checked for consistency. Matrices with a Consistency Ratio (CR) exceeding 0.10 were considered inconsistent and were returned to the respective expert for revision until an acceptable CR was achieved. Then, the consistent fuzzy judgments were used to construct the unweighted, weighted, and limit supermatrices within the software, following the standard FANP procedure to account for dependencies among criteria. Later, the final priority weights were derived from the stabilized limit supermatrix (Fig. 2).

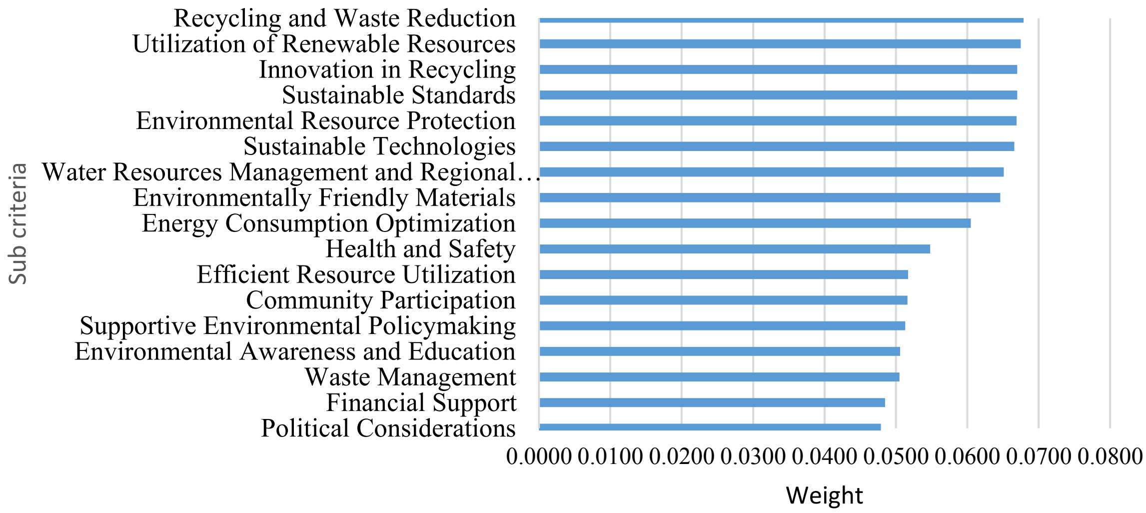


Fig. 2 Weight and final rank of subcriteria

A literature review was the first step in identifying key concepts and variables pertaining to the environmental impacts of composting facilities. To extract and validate the criteria and indicators of the model, semi-structured interviews were then carried out in three stages: (a) exploratory interviews, (b) expert surveys, and (c) final review and analysis. To ensure accurate and thorough data analysis, semi-open-ended interview questions were created, and all conversations were videotaped and transcribed. Every person or organization involved in controlling the environmental effects of the Yazd Composting facility, including facility managers and employees, environmental specialists, consultants, governmental organizations, and local stakeholders, was included in the statistical population. Purposive sampling, guided by knowledge and experience, was used to make sure that all important aspects of the study were fully covered.

3. Results and Discussion

This study identified and examined every criterion and factor affecting the management of composting facilities' environmental impacts. Relevant criteria and sub-criteria were first extracted using expert interviews and thematic analysis (Fig. 2). The degree to which each factor influences the others was then ascertained by examining the relationships between these factors using fuzzy cognitive mapping and factor analysis. The following phase involved modeling, assessing, and suggesting the best course of action for reducing the environmental effects of the Yazd composting facility using the Fuzzy Analytical Network Process (FANP).

3.1 Quantitative phase

In the quantitative phase, experts provided input through pairwise comparison questionnaires, and criteria were weighted according to their interdependencies and significance. The FANP analysis revealed that three criteria held the highest priority weights: 'waste recycling and reduction' (0.0679), 'use of renewable resources' (0.0675), and 'innovation in recycling' (0.0670). The negligible differences between these weights suggest that, for practical managerial purposes, these three factors form a group of top-tier priorities of virtually equal importance. Therefore, the model indicates that strategic efforts should focus on this cluster of criteria simultaneously, rather than pursuing them in a strict sequential order (Table 1). A key finding from the FANP results is the clustering of weights for the top three criteria. The minimal variance between them highlights a fundamental insight: improving the environmental performance of the compost factory is not dependent on a single 'silver bullet' but requires an integrated strategy that concurrently addresses core operational efficiency (waste reduction), resource input (renewable energy), and technological advancement (innovation). This underscores the systemic nature of the problem, where gains in one of these areas are likely to be reinforced by progress in the others.

The suggested model's responsiveness to the research questions was then assessed. The results show that the model exhibits a strong ability to pinpoint important elements, evaluate how different indicators relate to one another, and offer practical solutions for reducing harmful environmental effects in composting plants. Furthermore, useful suggestions were made to improve environmental control and composting processes. The study concluded by pointing out its shortcomings, such as limited access to specific data and difficulties in gathering expert opinions. In order to overcome these limitations and develop the field further, areas for future research in this area were also proposed.

Table 1 Relative and Final Weights of Factors

Criterion	Sub-criterion	Final Weight	Final Rank
Economic Sustainability and Resource Management	Regional Water Resource Management and Hydrology	0.0651	7
	Energy Consumption Optimization	0.0605	9
	Use of Renewable Resources	0.0675	2
Waste Management and Pollution Reduction	Environmental Resource Protection	0.0669	5
	Recycling and Waste Reduction	0.0679	1
	Environmentally Friendly Materials	0.0646	8
Environmental Policy and Social Responsibility	Supportive Policy-making	0.0513	13
	Financial Support	0.0485	16
	Environmental Awareness and Education	0.0506	14
	Social Participation	0.0516	12
Green Technologies and Innovation	Sustainable Technologies	0.0666	6
	Sustainable Standards	0.0670	3
	Innovation in Recycling	0.0670	4
Policy and Governance	Political Issues	0.0479	17
	Health and Safety	0.0548	10
	Waste Management	0.0505	15
	Efficient Resource Utilization	0.0517	11

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The greatest degrees of influence and interdependence within the environmental impact management system of composting facilities are shown by factors like waste management (E3), social participation (C4), and financial support (C2), according to the analysis of interactions among criteria. In the model, criteria with positive values were categorized as driving factors and those with negative values as influenced factors based on the Di-Ri index. These results highlight how important social involvement and financial assistance are to improving waste management efficiency and reducing environmental effects. Therefore, by combining economic, social, environmental, and technological aspects, the management model suggested in this study makes it easier to optimize and enhance the performance of composting facilities focused on important elements (Table 2).

Table 2 Fuzzy DEMATEL Results for Sub-criteria: Prominence (D+R) and Relation (D-R) Indices

Criterion	Code	Di (Triangular Fuzzy Number)	Ri (Triangular Fuzzy Number)	Defuzzified Di	Defuzzified Ri	Di + Ri	Di - Ri
Water Resources Management & Regional Hydrology	A1	(1.105, 0.343, 1.418)	(1.097, 0.337, 1.423)	0.622	0.619	1.241	0.003
Energy Consumption Optimization	A2	(1.101, 0.332, 1.391)	(1.095, 0.323, 1.369)	0.608	0.596	1.204	0.012
Utilization of Renewable Resources	A3	(1.105, 0.348, 1.442)	(1.118, 0.364, 1.458)	0.632	0.647	1.278	-0.015
Environmental Resource Protection	B1	(1.107, 0.354, 1.452)	(1.118, 0.366, 1.468)	0.638	0.651	1.288	-0.013
Recycling and Waste Reduction	B2	(1.140, 0.398, 1.498)	(1.122, 0.373, 1.465)	0.678	0.653	1.332	0.025
Environmentally Friendly Materials	B3	(1.111, 0.348, 1.414)	(1.117, 0.361, 1.430)	0.624	0.636	1.260	-0.012
Supportive Environmental Policymaking	C1	(1.160, 0.489, 1.934)	(1.171, 0.522, 2.018)	0.861	0.904	1.765	-0.043
Financial Support Mechanisms	C2	(2.222, 0.605, 2.181)	(1.167, 0.502, 1.969)	1.003	0.879	1.882	0.123
Environmental Awareness and Education	C3	(1.137, 0.454, 1.872)	(1.185, 0.533, 2.025)	0.821	0.914	1.735	-0.093
Community Participation	C4	(1.190, 0.544, 2.069)	(1.186, 0.536, 2.044)	0.934	0.922	1.856	0.012
Sustainable Technologies	D1	(1.101, 0.341, 1.408)	(1.095, 0.329, 1.382)	0.617	0.602	1.219	0.015
Sustainable Standards	D2	(1.097, 0.328, 1.368)	(1.108, 0.344, 1.383)	0.598	0.612	1.210	-0.014
Innovation in Recycling Technologies	D3	(1.103, 0.339, 1.378)	(1.099, 0.335, 1.389)	0.607	0.607	1.214	0.000
Political Considerations	E1	(1.121, 0.412, 1.804)	(1.155, 0.474, 1.920)	0.779	0.850	1.629	-0.071
Health and Safety	E2	(1.154, 0.480, 1.907)	(1.184, 0.531, 2.058)	0.847	0.924	1.772	-0.077
Waste Management Practices	E3	(1.191, 0.554, 2.117)	(1.148, 0.480, 1.929)	0.954	0.853	1.807	0.102
Efficient Resource Utilization	E4	(1.178, 0.531, 2.044)	(1.157, 0.493, 1.965)	0.918	0.872	1.789	0.046

The criteria of "economic sustainability," "resource management," "waste management and pollution reduction," "environmental policies," and "social responsibility" were found to be causal factors based on the results shown in Table 3 and Fig. 3, suggesting their function as drivers influencing other criteria. On the other hand, the "policy and management" criterion was found to be an effect variable that was mostly impacted by other variables.

According to this analysis, strengthening and optimizing technical, economic, and social infrastructures is a prerequisite for developing effective policies for the management of composting facilities. As a result, improving these motivating factors strategically can result in better general regulations and composting facility management. These results highlight the necessity of an integrated focus on economic, social, and environmental dimensions in policy formulation, which is entirely consistent with a systemic approach to environmental management.

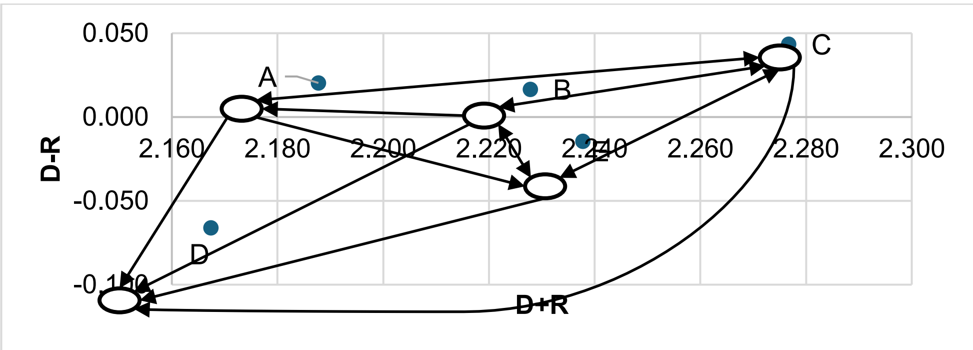
Based on the findings of the causality diagram, the criteria of "economic sustainability and resource management", "waste management and pollution reduction", and "optimal resource utilization" are driving and causal factors in the composting facilities' management system (Fig. 3). These variables have a direct impact on dependent criteria like "policy and management" and "environmental policies and social responsibility." These results highlight how crucial it is to maximize the performance of important technical, economic, and environmental criteria before developing and putting into practice overarching management policies.

Moreover, "water resource management" and "energy consumption optimization" were found to be significant sub-criteria that are essential to the growth and development of renewable resource utilization. The necessity of creating and putting into practice a thorough management model centered on enhancing and optimizing foundational infrastructure is amply demonstrated by these systemic interactions.

Table 3 Fuzzy DEMATEL Results for Main Criteria: Prominence (D+R) and Relation (D-R) Indices

Criterion	Code	Di (Triangular Fuzzy Number)	Ri (Triangular Fuzzy Number)	Defuzzified Di	Defuzzified Ri	Di + Ri	Di − Ri
Economic Sustainability and Resource Management	A	(0.218, 0.643, 2.451)	(0.210, 0.628, 2.413)	1.104	1.084	2.188	0.020
Waste Management and Pollution Mitigation	B	(0.228, 0.660, 2.479)	(0.221, 0.649, 2.447)	1.122	1.106	2.228	0.017
Environmental Policy and Social Responsibility	C	(0.244, 0.690, 2.545)	(0.225, 0.656, 2.469)	1.160	1.117	2.277	0.043
Green Technologies and Innovation	D	(0.201, 0.612, 2.339)	(0.223, 0.652, 2.476)	1.051	1.117	2.167	–0.066
Policy and Governance	E	(0.219, 0.644, 2.472)	(0.231, 0.666, 2.482)	1.112	1.126	2.238	–0.014

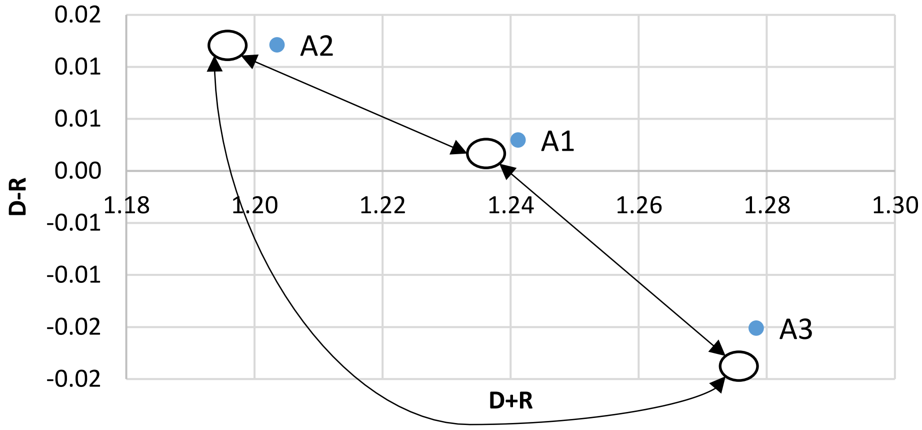
Fig. 3 Causal diagram of the main criteria



The sub-criteria for resource management and economic sustainability, "water resource management and regional hydrology" (A1) and "energy consumption optimization" (A2), were found to be causal factors that significantly impacted "use of renewable resources" (A3) (Fig. 4). According to these results, the use of renewable resources can be directly increased by better management of energy and water resources.

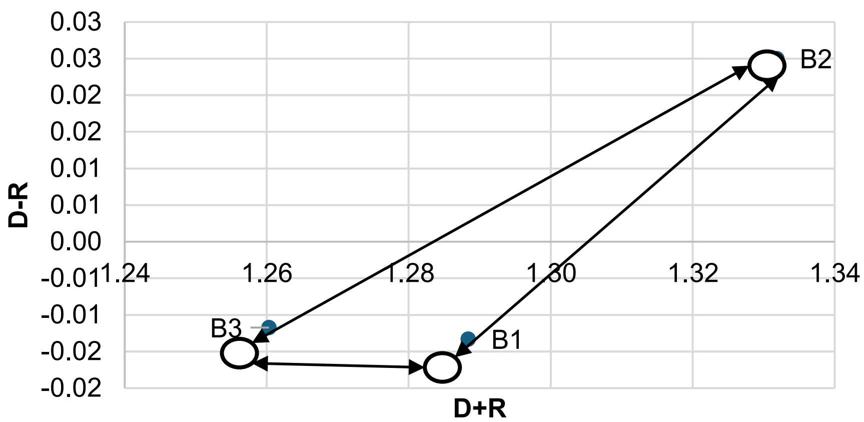
Sub-criterion A1, which has a positive D-R value, is mainly categorized as a causal factor according to the D-R index analysis. However, A1 is not only influenced by other factors, but also partially affected by them because of the relatively small magnitude of its D-R value. Stated differently, although A1 is the primary driver of other criteria, it is also somewhat impacted by A2 and A3, indicating that these sub-criteria interact with one another within the context of resource management and economic sustainability. In order to maximize resource management and improve the use of renewable resources, it is imperative that corrective actions and improvements be made simultaneously and in coordination across all of these dimensions due to the intricacy and reciprocal relationships among these sub-criteria.

Fig. 4 Causal diagram of economic sustainability and resource management sub-criteria



According to Fig. 5, the sub-criterion "waste recycling and reduction" (B2), which is part of the set of sub-criteria related to "waste management and pollution reduction," acts as a causal factor, directly influencing "protection of environmental resources" (B1) and "environmentally compatible materials" (B3), thereby promoting their improvement. Interestingly, "waste recycling and reduction" not only influences but also is influenced by these two sub-criteria, demonstrating the existence of intricate and reciprocal relationships between the sub-criteria. In other words, simultaneous and systematic improvements in these sub-criteria can play a pivotal role in increasing the effectiveness of environmental management in composting facilities. These reciprocal relationships highlight the significance of coordination and synergy among all management sub-criteria and improve waste management processes and reduce environmental pollution.

Fig. 5 Causal diagram of waste management and pollution reduction sub-criteria

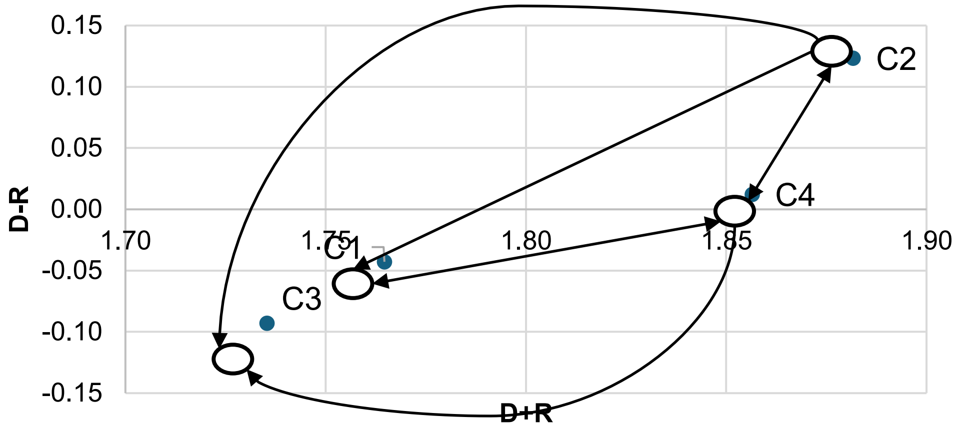


Based on the findings shown in Fig. 6, "financial support" (C2) and "social participation" (C4) were found to be causal factors within the sub-criteria of "environmental policies and social responsibility," directly influencing "supportive policy-making" (C1) and "environmental awareness and education" (C3). These results show that social involvement and financial backing are essential for the creation and improvement of environmental policies.

One noteworthy finding is that C2 and C4 have a bidirectional relationship, indicating that these two sub-criteria not only affect one another but also have an impact on one another. The significance of the synergy between social participation and financial support in enhancing the performance of other sub-criteria is underscored by these intricate and reciprocal interactions. It is also observed that C1 influences C4, highlighting the function of supportive policies in enhancing social participation. All things considered, this study shows how different elements interact and influence one another to improve environmental regulations and encourage social responsibility in composting facilities.

C2 may not have the absolute highest weight, but it is a key *causal driver* within the system. This suggests that financial investment is not just a standalone factor but a fundamental enabler that activates improvements in C1 and C3, creating a multiplier effect. This finding underscores that economic viability is a prerequisite for environmental innovation in waste management, a point emphasized by Jalalipour et al. (2025) in the context of Iranian waste systems.

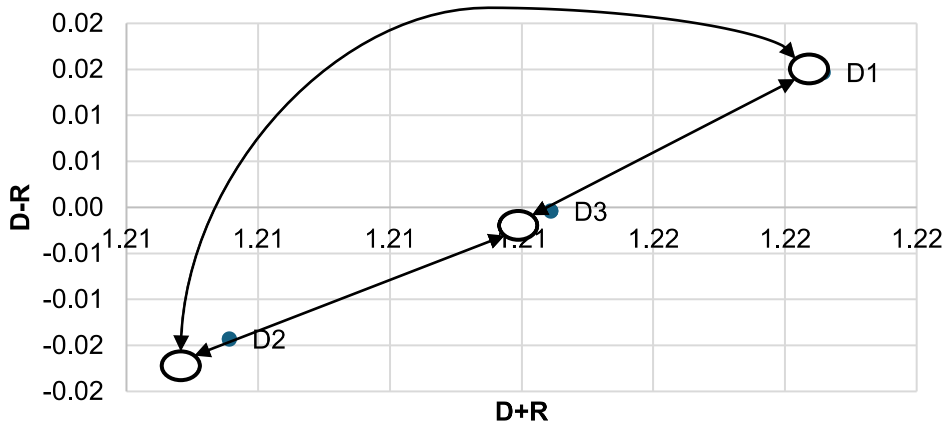
Fig. 6 Causal diagram of sub-criteria of environmental policies and social responsibility



According to the findings from Fig. 7, among the sub-criteria pertaining to "green technologies and innovation," "sustainable standards" (D2) is directly impacted by both "sustainable technologies" (D1) and "innovation in recycling" (D3). These connections suggest that the creation and use of sustainable technologies, in conjunction with creative recycling breakthroughs, offer a basis for the development and improvement of green standards. Put another way, advancing these two fields at the same time is essential to bolstering environmental regulations and ensuring the viability of green technologies.

Additionally, the recycling innovation criterion (D3) shows an equal degree of influence and susceptibility, which means that it both influences and is influenced by D1 (sustainable technologies) and D2 (sustainable standards). This reciprocal relationship reflects the intricate dynamics that shape the development of green technologies, where recycling innovations and advancements are influenced by sustainable standards and technologies while also helping to elevate and improve them. In order to accomplish an efficient and progressive process toward environmental sustainability, this analysis emphasizes the need to pursue recycling innovation in tandem with technology breakthroughs and the improvement of environmental standards.

Fig. 7 Causal diagram of sub-criteria of green technologies and innovation

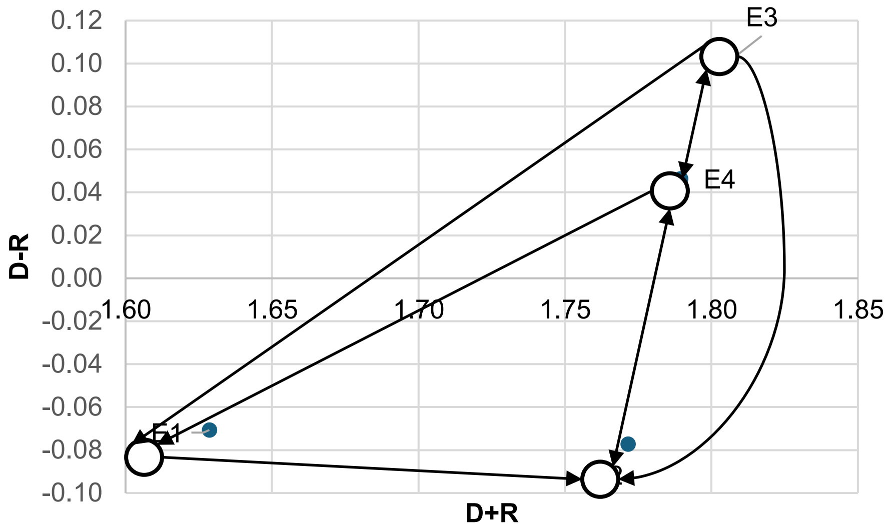


The analysis of the sub-criteria under "policy and management", based on the results shown in Fig. 8, shows that "waste management" (E3) and "optimal resource utilization" (E4) are causal factors in the system that have the biggest effects on other parts. Both "political considerations" (E1) and "health and safety" (E2) are directly impacted by these two factors. These results imply that raising health and safety standards and strengthening waste management performance and resource utilization offer a strong basis for developing more successful management policies.

On the other hand, the criterion "health and safety" (E2) was found to be a fully dependent variable because it is affected by the other three criteria, E1, E3, and E4. This means that making composting facilities safer and healthier depends on making good political choices, managing resources well, and putting waste management programs into action.

Furthermore, the bidirectional relationship between E3 and E4 (waste management and optimal resource utilization) highlights their close interdependence and interaction, such that progress in one can simultaneously enhance the other. This reciprocal relationship emphasizes how crucial it is to simultaneously improve both criteria in order to improve system performance as a whole. Our study advances the field by moving beyond single-method approaches. For instance, while Motalebi and Habibi (2022) used AHP, our FANP model captured the interdependencies between criteria, revealing that E is an *effect* of technical and economic factors, not just a primary cause. This challenges linear models of policy impact and supports a more complex, systems-oriented view of environmental management (El-Naqa, 2005). Furthermore, unlike Moudodi and Jomehzadeh (2024), who focused solely on environmental metrics, our integrated model demonstrates that social participation (C4) and economic sustainability (A) are equally critical drivers, aligning with the broader principles of sustainable development.

Fig. 8 Causal diagram of policy and management sub-criteria



In conclusion, the analysis's findings show that increasing waste management and resource utilization effectiveness should be the main priority in order to improve management policies and guarantee health and safety in composting facilities. As important motivators, these standards serve as the cornerstone for sound policymaking and the improvement of the general well-being of the system. The identification of 'Waste Recycling and Reduction' (B2) as both a high-priority weight and a causal driver suggests that managers should prioritize investments in sorting facilities and pre-processing technologies as a primary strategy, as it will concurrently improve other areas like resource protection (B1). For policymakers, the strong causal link from 'Social Participation' (C4) to effective policy suggests that public education campaigns and community engagement programs are not peripheral activities but core strategic investments for successful waste management policy implementation.

4. Conclusion

According to the study's findings, the integrated model that combines the Rapid Impact Assessment Matrix (RIAM) and the Fuzzy Analytical Network Process (FANP) is a useful tool for evaluating and ranking the environmental effects of composting facilities. This study's main strength is the way it combines quantitative and qualitative methods, which has improved the validity and accuracy of the evaluations. While the RIAM offered a clear framework for impact analysis specific to a given case, the application of FANP allowed for hierarchical weighting and took interdependencies among indicators into account.

1. The study successfully created a thorough, multi-criteria model for assessing composting facility sustainability.

2. The model produced accurate results for Yazd, but its broader applicability is limited by the localized data.

3. Integrating smart systems and renewable energy are viable methods to improve composting efficiency.

4. The model is flexible and has potential for nationwide use if the data is localized for each region.

5. Policymakers are advised to use this model to develop waste programs that prioritize green technology and public education.

Statements and Declarations

Acknowledgments

We would especially like to thank the management and staff of the Yazd composting facility, as well as all experts and professionals whose insightful opinions helped to improve the quality of this study. We also want to thank all the people and organizations that helped with different aspects of this research, such as providing data, organizing field trips, and answering questionnaires.

Data availability

The corresponding author can provide the data and findings used in this study upon request.

Conflicts of interest

The author of this paper declared no conflict of interest regarding the authorship or publication of this paper.

Author contribution

N. Hekmatnia: Conceptualization, Conducting Software and Statistical Analyses, Drafting the Initial Manuscript; A. Behbahaninia: Scientific Guidance, Editing and Reviewing the Manuscript, Verifying the Accuracy of Results; H. Samadyar and S. Motahari: Contribution to Conceptualization, Scientific Consultation, Manuscript Review, and Evaluation of Statistical Analyses.

AI Use Declaration

During the preparation of this work, the author(s) used ChatGPT to improve some sentences. The authors have thoroughly reviewed and revised the content as necessary and assumed full responsibility for the final manuscript.

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