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A Smart Decision Framework for Sustainable Management of C&D Waste Using Picture Fuzzy Decision Model

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ABSTRACT

Urbanization and rapid population growth have significantly accelerated the development of urban infrastructure, resulting in an unprecedented surge in construction and demolition (C&D) waste. The unregulated accumulation of this waste poses severe environmental and societal challenges, including greenhouse gas emissions, groundwater contamination, and land degradation. This issue is particularly critical in developing countries, where waste generation is directly linked to population density and industrialization. Given the limited availability of landfill space and the adverse environmental impacts of conventional dumping, the implementation of efficient and sustainable waste management strategies has become imperative. Although several waste treatment and recycling methods exist, selecting the most suitable alternative remains a complex multi-criteria decision-making (MCDM) problem due to the interplay of technical, environmental, and economic factors. This study proposes a systematic decision-making framework under a picture fuzzy MCDM environment to evaluate and rank sustainable C&D waste management solutions. A subjective weighting technique is utilized to determine the relative importance of each criterion, while a compromise ranking method is applied to identify the most promising alternative. The findings reveal that carbonation emerges as the optimal solution due to its potential for maximum waste reduction and enhanced sustainability. The proposed framework provides valuable insights for industry professionals and policymakers, facilitating effective C&D waste management practices and contributing to broader global sustainability objectives.

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1. Introduction

Construction and demolition (C&D) waste has emerged as one of the largest contributors to the global waste stream, accounting for a substantial portion of total solid waste generation worldwide [1]. Rapid urbanization, infrastructure development, and renewal projects have significantly increased C&D waste generation, posing serious environmental challenges such as land degradation, ground-water contamination, and greenhouse gas emissions. The waste typically comprises concrete, metals, wood, bricks, and other materials, each requiring specialized treatment or recycling methods. Managing this diverse waste stream demands efficient and sustainable waste management strategies to minimize environmental harm and promote resource recovery.

Recent studies have explored machine learning (ML) applications in C&D waste management to improve waste estimation, handling, transportation, and disposal processes. Gao *et al.*, [2] reviewed 98 articles published between 2012 and 2023 and found that models such as artificial neural networks, deep learning, convolutional neural networks, and support vector machines have significantly improved waste prediction and management efficiency. Additionally, growing research focuses on utilizing C&D waste as precursors for manufacturing alkali-activated materials (AAMs), offering an eco-friendly alternative to conventional binders like cement and lime. AAMs derived from C&D waste possess high silica and alumina content, reducing energy consumption, carbon emissions, and resource depletion, making them a sustainable construction material [3].

In terms of waste recovery and recycling, Caro *et al.*, [4] compared the environmental performance of recycling twelve material fractions of C&D waste, such as concrete, bricks, gypsum, and ceramics. Their study highlighted that recycling concrete and bricks yielded the highest environmental benefits, potentially reducing 33 million tons of CO_2 equivalent emissions annually, despite higher processing costs. Similarly, Yi *et al.*, [5] introduced a new C&D waste management framework in Lombardy, Italy, integrating life cycle assessment (LCA) and life cycle costing (LCC) within a multi-criteria decision-making (MCDM) model to optimize recycling in road construction and concrete production.

Several studies have emphasized the role of multi-criteria decision-making (MCDM) techniques in optimizing C&D waste management strategies. For instance, Rayhan *et al.*, [6] proposed an MCDM-based approach to improve C&D waste management efficiency in Dhaka City, Bangladesh, focusing on reuse, recovery, and hybridization of decision-making models. Further, Rayhan & Bhuiyan [7] provided a comprehensive review covering C&D waste definitions, sources, impacts, management hierarchies, circular economy models, and the 3R principles (Reduce, Reuse, Recycle). These studies collectively emphasize that effective waste management requires well-structured and optimized decision-making approaches that balance economic, environmental, and technical considerations.

Multi-criteria decision-making (MCDM) techniques are widely employed in various domains to evaluate multiple conflicting criteria and derive optimal solutions. MCDM approaches are particularly useful in C&D waste management, where decision-makers must consider diverse factors such as cost, resource recovery, energy consumption, and environmental impact [8]. Various MCDM methods have been applied in the construction sector, including robot selection [9], supplier selection [10], and renewable energy selection [11]. These techniques enable structured decision-making by systematically evaluating alternatives based on quantitative and qualitative criteria, thus improving decision accuracy [12].

Among various MCDM methods, the Step-wise Weight Assessment Ratio Analysis (SWARA) is widely used for subjective weighting of criteria based on expert judgment, making it ideal for situations where domain expertise is crucial [13]. The most recent review of SWARA using several different MCDM techniques is shown in Table 1.

On the other hand, WASPAS is a ranking method that uses additive and multiplicative approaches to improve decision accuracy [20]. Ghorbani *et al.*, [21] used multi-index DM strategies such as Co-

Table 1
 Recent review on integration of SWARA with existing methods

AUTHOR	YEAR	SET	MCDM	APPLICATION
Milinković <i>et al.</i> , [14]	2025	Fuzzy	FUCOM-OPARA	Assessment of the possibilities for urban planning
Mehdiabadi <i>et al.</i> , [15]	2025	Fuzzy	MABAC	Oil and gas industry sustainability service chain capabilities
Rani & Mishra [16]	2025	Single Valued Neutrosophic	TOPSIS	Renewable energy systems
Naz <i>et al.</i> , [17]	2025	Probabilistic uncertain linguistic term	ELECTRE-I	Choosing features for image recognition
Pajić <i>et al.</i> , [18]	2024	Fuzzy	MARCOS	Choosing a strategic warehouse site for business logistics
Seikh & Chatterjee [19]	2024	Interval-valued Fermatean fuzzy	ARAS	Identifying India's top renewable energy sources

CoSo, PROMETHEE II, and WASPAS models to assess the most hazardous portion of the Kerman water conveyance tunnel. Arivendan *et al.*, [22] used the new WASPAS and CRITIC techniques to evaluate the structural, mechanical, and thermal properties of Linum usitatissimum/carbon fibre composites. Rasheed [23] used molecular graphs to compute degree-based topological indices for drugs used to treat migraines. After gathering information on biological activities and molecular structures, descriptors were calculated using vertex degree, edge division, and counting degree approaches. Each topological indicator was analysed using curvilinear regression models, and the WASPAS approach was utilised to evaluate the drug's qualities in-depth. Jiang & Wang [24] combined the WASPAS method with IFS to present a new integrated methodology for supplier selection in the shipbuilding sector. After obtaining indicator data using an intuitionistic fuzzy number methodology, the method assessed indicator weights using both subjective and objective weights. Alternative suppliers were prioritised using the WASPAS technique, and sensitivity tests demonstrated the method's stability under different attribute weights. With an emphasis on metal materials, Kumar & Rajak [25] evaluated the materials utilised in bio-implant applications and suggested a framework for choosing the optimal material using an integrated WASPAS technique.

Lotfi A. Zadeh developed fuzzy sets, which extend traditional set theory by allowing elements to have membership degrees as opposed to binary membership. Fuzzy sets are especially well-suited to deal with imprecision and ambiguity in real-world DM situations [26]. Extensions to fuzzy sets have been developed over time to help manage various forms of uncertainty. PFS was developed by Cuong & Kreinovich [27] in the year 2013. Luo *et al.*, [28] introduced two new approaches to building similarity measurements on PFS. The first approach creates new measures by combining membership differences that are favourable, neutral, non-favourable, and refusal using a monotonically declining function. The second approach uses a strictly decreasing binary function to aggregate distance measures between two sets. These metrics exhibit excellent reliability and appropriate results. For real-world performance evaluation challenges, Mahmoodirad *et al.*, [29] presented a novel BCC DEA model with picture fuzzy type data. Two-dimensional PFS, a novel framework that employs probability to assess expert opinions, was presented by Wu *et al.*, [30]. The framework's theoretical value and applicability were demonstrated when it was used to choose carbon emission reduction strategies for China's iron and steel sector. The Picture Hesitant Fuzzy Soft Set concept was established by Ashraf *et al.*, [31], who concentrated on improving energy management in businesses to cut expenses and increase revenues. The picture fuzzy SWARA-CRITIC-COPRAS approach was introduced by Razzaq *et al.*, [32] to aid decision-makers assess and choose dynamic digital marketing technology.

1.1 Motivation and contributions

The motivation for this study arises from growing complexity in construction and demolition (C&D) waste management, particularly with the increasing volumes of waste due to fast-paced urbanization and infrastructure development. Traditional methods of waste management do not consider that DM is a multi-faceted process, say environmental, economic, and social factors, which must be traded off carefully when selecting an optimal waste management strategy. In addition, uncertainty and vagueness in expert judgments typically complicate DM processes. The major contributions of the study include,

- The study proposes a new hybrid approach through integrating Picture Fuzzy Numbers (PFNs) with the SWARA and WASPAS approaches to enable decision-makers to handle uncertainty and vagueness in expert judgments.
- By incorporating fuzzy logic into DM, the study enhances the dependability and accuracy of rankings of various C&D waste management alternatives even in the presence of uncertainty or dynamic conditions in the environment.
- The research applies MCDM techniques specific to the evaluation of C&D waste management plans based on many conflicting criteria such as environmental issues, cost, recovery of resources, and societal acceptability.
- The study provides a genuine, structured DM aid that can be used by stakeholders in the construction and demolition industry to make more sustainable and knowledgeable decisions regarding waste management practice.
- By emphasizing eco-friendly waste management practices, the strategy is part of a larger effort to encourage sustainability in demolition and construction.
- The use of MATLAB programming enhances computational efficiency, allowing for smooth data processing, weighting of factors, ranking, and visualization of outcomes, providing an easy-to-use interface for decision-makers.

2. Methodology

2.1 Definitions

Definition 1 [33] If \bar{U} is a Universal set, then the following is the definition of a picture fuzzy set (PFS) defined on \bar{U} :

$$\mathbb{P} = \left\langle x, (\zeta_{\mathbb{P}}(x), \lambda_{\mathbb{P}}(x), \delta_{\mathbb{P}}(x)) \mid x \in \bar{U} \right\rangle \tag{1}$$

where $\zeta_{\mathbb{P}}(x) : \bar{U} \rightarrow [0, 1]$, $\lambda_{\mathbb{P}}(x) : \bar{U} \rightarrow [0, 1]$ and $\delta_{\mathbb{P}}(x) : \bar{U} \rightarrow [0, 1]$ signifies the positive, neutral and negative membership grades of x to \mathbb{P} , respectively, with the condition $0 \leq \zeta_{\mathbb{P}}(x) + \lambda_{\mathbb{P}}(x) + \delta_{\mathbb{P}}(x) \leq 1$. For ease, take $\mathbb{P} = (\zeta_{\mathbb{P}}, \lambda_{\mathbb{P}}, \delta_{\mathbb{P}})$ to be considered as picture fuzzy number (PFN) with the grade of refusal defined as $\pi=1-(\zeta_{\mathbb{P}}+\lambda_{\mathbb{P}}+\delta_{\mathbb{P}})$.

Definition 2 [33] Let $\mathbb{P}_A = (\zeta_{\mathbb{P}_A}, \lambda_{\mathbb{P}_A}, \delta_{\mathbb{P}_A})$ and $\mathbb{P}_B = (\zeta_{\mathbb{P}_B}, \lambda_{\mathbb{P}_B}, \delta_{\mathbb{P}_B})$ then with $\Omega > 0$,

$$\mathbb{P}_A \oplus \mathbb{P}_B = \left\langle 1 - (1 - \zeta_{\mathbb{P}_A})(1 - \zeta_{\mathbb{P}_B}), \lambda_{\mathbb{P}_A} \lambda_{\mathbb{P}_B}, \delta_{\mathbb{P}_A} \delta_{\mathbb{P}_B} \right\rangle \tag{2}$$

$$\mathbb{P}_A \otimes \mathbb{P}_B = \left\langle \zeta_{\mathbb{P}_A} \zeta_{\mathbb{P}_B}, 1 - (1 - \lambda_{\mathbb{P}_A})(1 - \lambda_{\mathbb{P}_B}), 1 - (1 - \delta_{\mathbb{P}_A})(1 - \delta_{\mathbb{P}_B}) \right\rangle \quad (3)$$

$$\Omega \mathbb{P}_A = \left\langle 1 - (1 - \zeta_{\mathbb{P}_A})^\Omega, (\lambda_{\mathbb{P}_B})^\Omega, (\delta_{\mathbb{P}_A})^\Omega \right\rangle \quad (4)$$

$$(\mathbb{P}_A)^\Omega = \left\langle (\zeta_{\mathbb{P}_A})^\Omega, 1 - (1 - \lambda_{\mathbb{P}_A})^\Omega, 1 - (1 - \delta_{\mathbb{P}_A})^\Omega \right\rangle \quad (5)$$

$$(\mathbb{P}_A)^C = \left\langle (\delta_{\mathbb{P}_A}), (\lambda_{\mathbb{P}_A}), (\zeta_{\mathbb{P}_A}) \right\rangle \quad (6)$$

Definition 3 [33] Let $\mathbb{P}=(\zeta_{\mathbb{P}}, \lambda_{\mathbb{P}}, \delta_{\mathbb{P}})$ be a PFS on \bar{U} . The score and accuracy function of the PFS \mathbb{P} is defined as follows,

$$S(\mathbb{P}) = \zeta_{\mathbb{P}} - \lambda_{\mathbb{P}} - \delta_{\mathbb{P}} \quad (7)$$

where $S(\mathbb{P}) \in [-1,1]$.

$$A(\mathbb{P}) = \zeta_{\mathbb{P}} + \lambda_{\mathbb{P}} - \delta_{\mathbb{P}} \quad (8)$$

where $A(\mathbb{P}) \in [0,1]$.

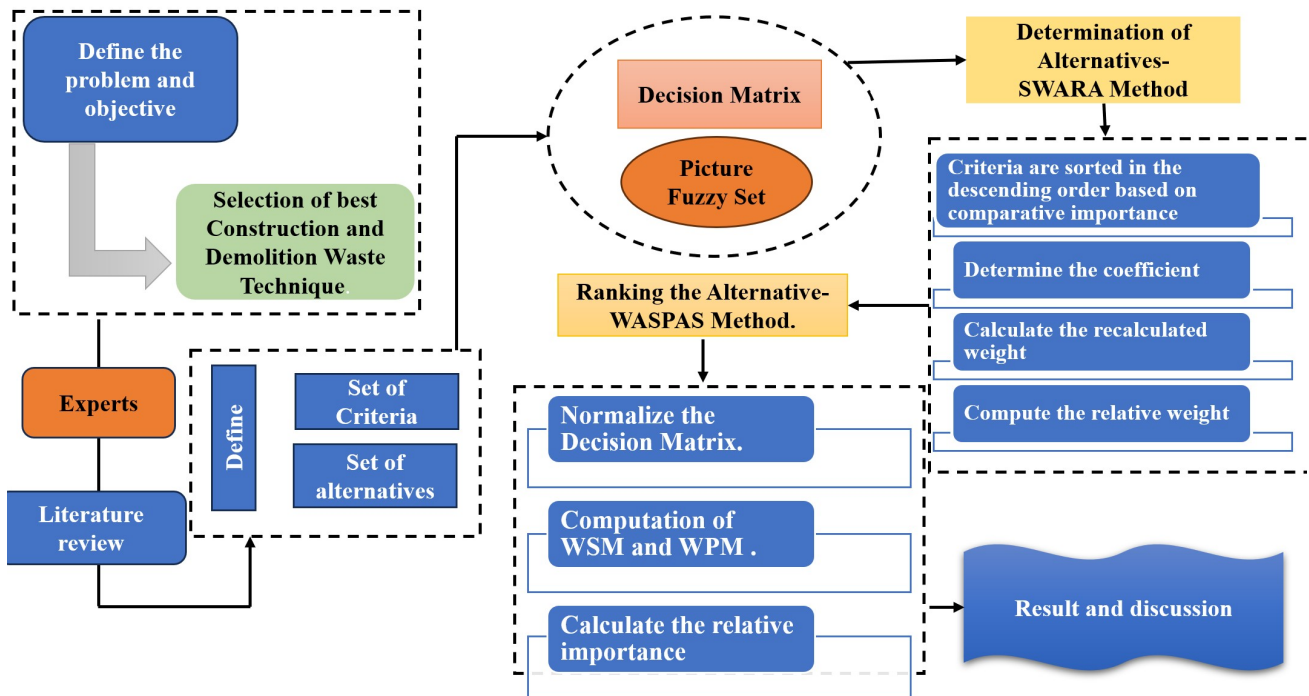


Fig. 1. Overall proposed framework

2.2 Stepwise weight assessment ratio analysis

In MCDM, SWARA is a useful technique for figuring out the subjective weights of various criteria while assessing alternatives. It entails giving factors in DM processes weights using a methodical way. This approach is very helpful when a number of criteria must be considered in order to reach a well-informed conclusion. The overall framework for the proposed methodology is given in Figure 1. The proportional value of the criteria is decided by expert opinions. The SWARA method's algorithm is shown as follows:

Step 1: The criteria are arranged according to their expected significance in descending order.

Step 2: The response states the relative importance of criterion j in respect to the preceding $(j-1)$ criterion, beginning with the second criterion and continuing for each individual criterion. This ratio is known as γ_j , or the comparative importance of the average value.

Step 3: Compute the coefficient μ_j as follows:

$$\mu_j = \begin{cases} 1, & j = 1 \\ \gamma_j + 1, & j > 1 \end{cases} \quad (9)$$

Step 4: Compute the recalculated weight ν_j as follows:

$$\nu_j = \begin{cases} 1, & j = 1 \\ \frac{\nu_{j-1}}{\mu_j}, & j > 1 \end{cases} \quad (10)$$

Step 5: The following formula determines the relative weight of the evaluation criteria:

$$\omega_j = \frac{\nu_j}{\sum_{k=1}^n \nu_k} \quad (11)$$

where n indicates the number of criteria, and ω_j indicates the relative weight of the j^{th} criterion.

2.3 Weighted aggregated sum product assessment method

The Weighted Aggregated Sum Product Assessment (WASPAS) approach is an MCDM strategy for evaluating and selecting the best option from a set of alternatives based on a variety of criteria. It provides a more thorough analysis than utilising either model alone by combining the advantages of two well-known approaches: the Weighted Sum Model (WSM) and the Weighted Product Model (WPM); in other words, it provides a hybrid approach by combining the advantages of both WSM and WPM methodologies. The algorithm of the WASPAS method is presented as follows:

Step 1: Development of evaluation Matrix

The basic structure of the decision matrix used in WASPAS method is represented by the following flalign :

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \quad (12)$$

where, m is the number of alternatives, n is the number of criteria and \tilde{x}_{ij} is the performance of i^{th} alternative with respect to j^{th} criterion.

Step 2: Normalization of the decision matrix

Normalized value of decision matrix can be computed using two flaligns which is given below:
 For beneficial criteria,

$$\bar{r}_{ij} = \frac{\tilde{x}_{ij}}{\max \tilde{x}_{ij}} \tag{13}$$

For non-beneficial criteria,

$$\bar{r}_{ij} = \frac{\min \tilde{x}_{ij}}{x_{ij}} \tag{14}$$

Step 3: Computation of WSM and WPM

Total relative importance of i^{th} alternative is computed using the two flaligns given below:

$$WS = Q_i^{(1)} = \sum_{j=1}^n \bar{r}_{ij} \omega_j \tag{15}$$

$$WP = Q_j^{(2)} = \prod_{j=1}^n (\bar{r}_{ij})^{\omega_j} \tag{16}$$

where w_j is the weightage of criteria and $Q_i^{(1)}$ and $Q_j^{(2)}$ indicate the relative importance of the i^{th} alternative with respect to the j^{th} criterion, which are based on the WS and WP methods, respectively. The weights assigned to each criterion by each expert are then averaged.

Step 4: Calculation of total relative importance Joint generalized criterion of weighted aggregation of additive and multiplicative methods is calculated on the basis of the following flalign:

$$Q_i = \kappa Q_i^{(1)} + (1 - \kappa) Q_i^{(2)} \tag{17}$$

where κ lies between 0 to 1.

3. Case study

In assessing the viability and efficiency of sustainable construction and demolition (C&D) waste management, this case study emphasises the importance of a hybrid approach. Adequate treatment techniques are required to combat the negative effects of C&D waste, which include pollution, resource loss, and land degradation. Reducing environmental degradation and fostering long-term sustainability need the efficient application of waste management techniques. Finding the best and most appropriate waste treatment methods can be aided by expert advice from the relevant professions. A DM framework is constructed to help determine the best methods for managing waste, making choices that are both economically and environmentally sound. A brief description of the criteria and alternatives is provided in the subsequent subsections.

3.1 Alternatives

The six different types of chosen alternatives are explained as follows:

- **Carbonation** (\mathcal{A}_1)

Carbonation is the process in which carbon dioxide from atmosphere reacts with calcium hydroxide in concrete or cement-based materials, leading to the formation of calcium carbonate (CaCO_3). The main advantage is that it leads to CO_2 sequestration and the main disadvantage of this process is it causes the risk of corrosion of reinforcement steel due to lower pH.

- **Upcycling recycled concrete (\mathcal{A}_2)**
Upcycling recycled concrete involves transforming concrete waste from demolished buildings or construction sites into higher-value products or materials.
- **Crushing and screening (\mathcal{A}_3)**
Crushing breaks down large materials into smaller, more manageable pieces, increasing their potential for reuse. Screening sorts those materials by size, ensuring they are appropriate for specific applications.
- **Plasma gasification (\mathcal{A}_4)**
Plasma gasification is an extreme thermal process using plasma arc torch which converts organic matter into a syngas (synthesis gas) which is primarily made up of hydrogen and carbon monoxide. This arc breaks down waste primarily into elemental gas and solid waste (slag), in a device called a plasma converter. The process is intended to be a net generator of electricity, depending upon composition input wastes, and to reduce the volumes of waste to being sent to landfill sites.
- **Vitrification (\mathcal{A}_5)**
Vitrification is an effective method that involves the process of converting waste materials into a glass-like solid through high-temperature treatment. It significantly reduces the overall volume of waste.
- **Bioreactor landfills (\mathcal{A}_6)**
A bioreactor landfill is an engineered landfill developed to speed up the process of waste degradation and gas production by controlling with moisture and air supply and promote environmental protection.

3.2 Criteria

Eight relevant criteria have been selected for this problem where

- **Cost (\mathcal{C}_1)**
Cost refers to the financial expenditures associated with the various stages of managing and disposing of the waste generated during construction, renovation, or demolition projects.
- **Environmental impact (\mathcal{C}_2)**
Environmental impact refers to the change in the environment, whether adverse or beneficial, resulting from activities, products, or services of a facility.
- **Revenue generation (\mathcal{C}_3)**
Revenue generation refers to the income generated from the management, recycling, and disposal of waste materials generated during construction, renovation, or demolition projects.
- **Waste reduction (\mathcal{C}_4)**
Waste reduction refers to the process of eliminating the waste material at the source .
- **Pollution prevention (\mathcal{C}_5)**
Pollution prevention refers to strategies and practices aimed at minimizing or eliminating the generation of waste and pollutants such as optimizing materials orders.

- **Resource recovery potential (\mathcal{C}_6)**
Resource recovery potential refers to the estimation of the potential for recovering valuable material, promoting recycling of materials, and reducing new raw material use.
- **Community acceptance (\mathcal{C}_7)**
Community acceptance refers to the science and practice of protecting and improving the health of a population by preventing disease, promoting healthy lifestyles, and ensuring safe environments, including individual and community well-being.
- **Quality of recycled product (\mathcal{C}_8)**
Quality of the recycled product refers to the degree to which the recycled material retains its properties and functionality compared to the original material.

3.3 Adaptation to the problem using Matlab-programming

% Weight evaluation by SWARA

The following is the calculation of the criterion weights by the SWARA method using the Matlab programming language.

Criteria = {'Cost', 'Environmental impact', 'Revenue generation', 'Waste reduction', 'Pollution prevention', 'Resource recovery potential', 'Community acceptance', 'Quality of recycled product'};

% Example expert evaluations.

```
S = [0, 0.89, 0.81, 0.76, 0.70, 0.53, 0.45, 0.32;]
```

% Number of criteria.

```
n = length(criteria);
```

% Initialize vectors

```
K = zeros(1, n); % Coefficient (K)
```

```
Q = zeros(1, n); % Weight (Q)
```

```
W = zeros(1, n); % Normalized weight (W)
```

% Step 1: Set the first Q value to 1.

```
Q(1) = 1;
```

```
k(1) = 1;
```

% Step 2: Calculate K and Q for the rest of the criteria

```
for i = 2:n
```

```
    K(i) = 1 + S(i);
```

```
    Q(i) = Q(i-1) / K(i);
```

```
end
```

% Step 3: Normalize the weights (W)

```
total_Q = sum(Q);
```

```
for i = 1:n
```

```
    W(i) = Q(i) / total_Q;
```

```
end
```

% Display the results

```
disp('Criteria Weights using SWARA Method:');
```

```
for i = 1:n
```

```
    fprintf('%s: %.4f', criteria{i}, W(i));
```

```
end
```

% Weighted Sum Model and Weighted Product Model (WSM and WPM).

The following is the ranking of the alternatives as determined by the WASPAS technique with the Matlab programming language.

Here, X represents the decision matrix, Xval is the number of alternatives and Wcriteria is either beneficial or non beneficial criteria.

% Step 1: Define the Variable.

```
Xval = length(X(:,1));
```

% Step 2: Normalize the Decision Matrix. if, Wcriteria is 0 then it is non-beneficial and Wcriteria is 1 then it is beneficial

```
for i = 1:Xval
    for j = 1:length(W);
        if Wcriteria(1,j) == 0;
            Y(i,j) = min(X(:,j))/X(i,j);
        else
            Y(i,j) = X(i,j)/max(X(:,j));
        end
    end
end
```

```
end
```

% Step 3: Calculating the Preference Scores.

```
for i = 1:Xval
    PWSM(i,1) = sum(Y(i,:) .* W);
    PWPM(i,1) = prod(Y(i,:) .^W);
end
```

```
end
```

% Step 4: Output the Preference Scores .

```
Preference_Score_of_Weighted_Sum_Model = num2str([PWSM])
Preference_Score_of_Weighted_Product_Model = num2str([PWPM])
```

% Weighted Aggregated Sum Product Assessment(WASPAS).

% Step 5: Define the Variables.

```
Xval = length(X(:,1));
```

% Step 6: Normalize the Decision Matrix.

```
for i = 1:Xval ;
    for j = 1:length(W);
        if Wcriteria(1,j) == 0;
            Y(i,j) = min(X(:,j))/X(i,j);
        else
            Y(i,j) = X(i,j)/max(X(:,j));
        end
    end
end
```

```
end
```

```
end
```

% Step 7: Calculating the Preference Scores(same as WSM and WPM).

```
for i = 1:Xval
    PWSM(i,1) = sum(Y(i,:) .* W);
    PWPM(i,1) = prod(Y(i,:) .^W);
end
```

```
end
```

```
lambda = 0.5;
```

```
WASPAS SCORE = lamda * PWSM + (1 - lamda) * PWPM;
```

```
Joint_generalized_criterion = num2str([WASPAS SCORE]);
```

4. Results and discussion

In this study, we applied different waste management alternatives by means of the SWARA method to identify weights for different criteria and WASPAS method to rank alternatives with respect to these criteria. The criteria for this study included cost, environmental impact, revenue generation, waste reduction, pollution prevention, resource recovery potential, community acceptance, and quality of recycled product. The obtained weights by the SWARA method are presented in Table 2 and Figure 2.

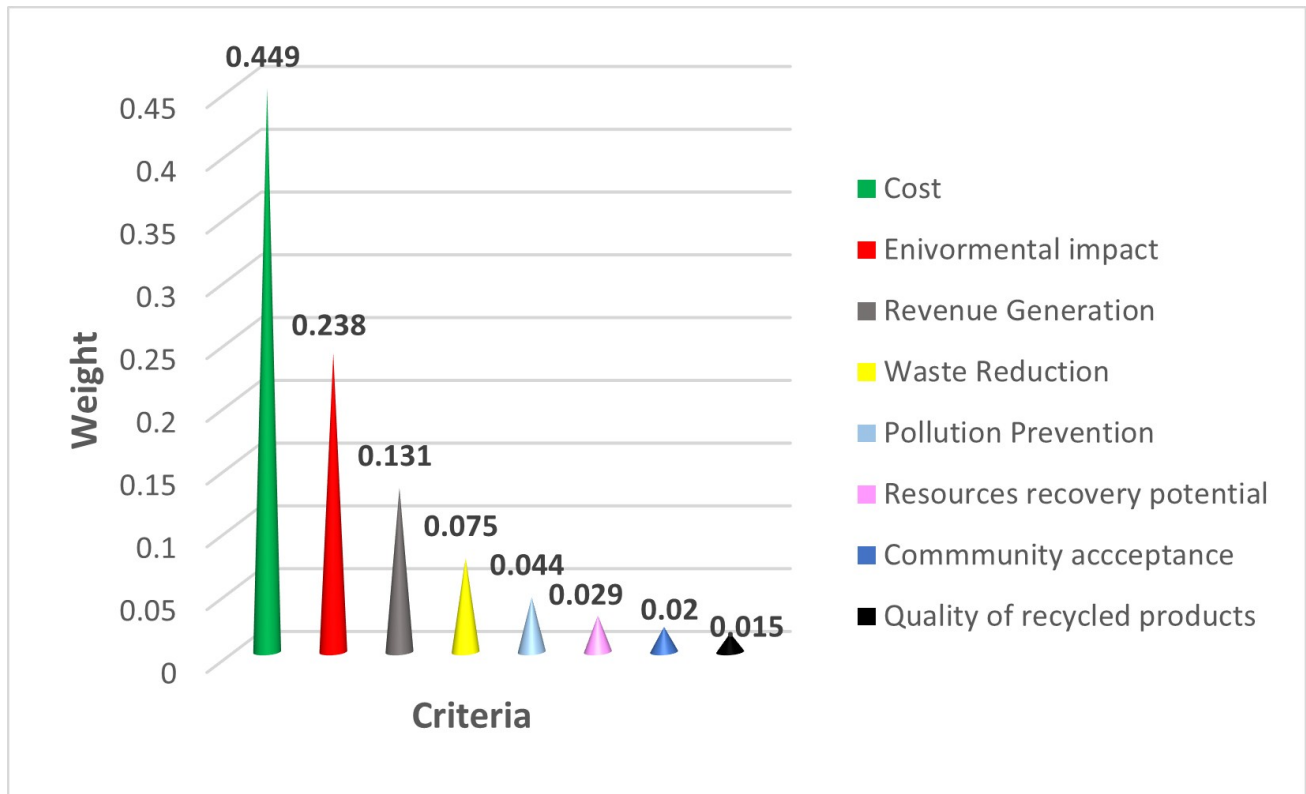


Fig. 2. Relative significance of each criterion

Table 2
 Weights of each criterion

	γ_j	μ_j	ν_j	ω_j
C_1		1.000	1.000	0.449
C_2	0.890	1.890	0.530	0.238
C_3	0.810	1.810	0.292	0.131
C_4	0.760	1.760	0.166	0.075
C_5	0.700	1.700	0.098	0.044
C_6	0.530	1.530	0.064	0.029
C_7	0.450	1.450	0.044	0.020
C_8	0.320	1.320	0.033	0.015
Total		2.226	1.000	1.000

These weights indicate that cost and environmental impact are the two most significant in the DM process, with cost being the most weighted. Revenue generation is also considered, but with a lower weight than environmental considerations. Pollution prevention and resource recovery potential are

other considerations with relatively lower weights, showing their lower significance on the overall ranking.

Table 3
 Evaluation matrix constructed using PFS

	\mathcal{C}_1	\mathcal{C}_2	\mathcal{C}_3	\mathcal{C}_4	\mathcal{C}_5	\mathcal{C}_6
\mathcal{A}_1	(0.5,0.3,0.1)	(0.4,0.2,0.1)	(0.5,0.2,0.1)	(0.6,0.3,0.1)	(0.5,0.2,0.1)	(0.7,0.2,0.1)
\mathcal{A}_2	(0.6,0.3,0.1)	(0.5,0.2,0.1)	(0.6,0.3,0.1)	(0.6,0.2,0.1)	(0.7,0.2,0.1)	(0.6,0.3,0.1)
\mathcal{A}_3	(0.7,0.2,0.1)	(0.6,0.3,0.1)	(0.5,0.3,0.1)	(0.6,0.3,0.1)	(0.5,0.3,0.1)	(0.6,0.2,0.1)
\mathcal{A}_4	(0.6,0.2,0.1)	(0.6,0.2,0.1)	(0.7,0.2,0.1)	(0.5,0.3,0.1)	(0.7,0.2,0.1)	(0.6,0.3,0.1)
\mathcal{A}_5	(0.5,0.3,0.1)	(0.5,0.3,0.1)	(0.5,0.3,0.1)	(0.7,0.2,0.1)	(0.6,0.3,0.1)	(0.5,0.3,0.1)
\mathcal{A}_6	(0.4,0.2,0.1)	(0.6,0.2,0.1)	(0.5,0.2,0.1)	(0.5,0.3,0.1)	(0.5,0.2,0.1)	(0.5,0.2,0.1)

\mathcal{C}_7	\mathcal{C}_8
(0.6,0.2,0.1)	(0.6,0.3,0.1)
(0.5,0.3,0.1)	(0.6,0.3,0.1)
(0.5,0.2,0.1)	(0.5,0.3,0.1)
(0.6,0.3,0.1)	(0.4,0.2,0.1)
(0.5,0.2,0.1)	(0.7,0.2,0.1)
(0.6,0.3,0.1)	(0.6,0.2,0.1)

The following alternatives were then ranked using the WASPAS approach according to how well they performed across these weighted criteria. The decision matrix was first built using the PFS definition found in definition 1, and it was subsequently defuzzified using the score function found in definition 3. The expert-constructed performance matrix and the defuzzified matrix are shown in Tables 3 and 4, respectively. This matrix is then normalised using the Eqs. (13) and (14) for the beneficial

Table 4
 Score function matrix

	\mathcal{C}_1	\mathcal{C}_2	\mathcal{C}_3	\mathcal{C}_4	\mathcal{C}_5	\mathcal{C}_6	\mathcal{C}_7	\mathcal{C}_8
\mathcal{A}_1	0.1	0.1	0.2	0.2	0.2	0.4	0.3	0.2
\mathcal{A}_2	0.2	0.2	0.2	0.3	0.4	0.2	0.1	0.2
\mathcal{A}_3	0.4	0.2	0.1	0.2	0.1	0.3	0.2	0.1
\mathcal{A}_4	0.3	0.3	0.4	0.1	0.4	0.2	0.2	0.1
\mathcal{A}_5	0.1	0.1	0.1	0.4	0.2	0.1	0.2	0.4
\mathcal{A}_6	0.1	0.3	0.2	0.1	0.2	0.2	0.2	0.3

and cost criterion respectively. The normalised values are subsequently given in Table 5. Eqs. (15) and (16) are used to calculate the WSM and WPM values. The final ranking of the alternatives are computed using Eq. (17) and shown in Table 6 and Figure 3.

The WASPAS ranking indicates carbonation as the top-ranked alternative with a value of 0.850, closely followed by vitrification at 0.813. Both of these alternatives scored well on all of the criteria, particularly cost and environmental impact, which are the most heavily weighted criteria. Carbonation, aside from being eco-friendly in its capacity to displace CO_2 and improve the quality of concrete, is the best of the rest for employing resources efficiently and having a lower environmental footprint. Vitrification, while scoring lower than carbonation, also possesses tremendous environmental advantages, especially in waste treatment and pollution control.

On the other hand, bioreactor landfills scored 0.634, indicating moderate performance. Upcycling recycled concrete and plasma gasification occupy fourth and fifth positions with 0.532 and 0.429

Table 5
 Normalized decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
A_1	1.000	1.000	0.500	0.500	0.500	1.000	1.000	0.500
A_2	0.500	0.500	0.500	0.750	1.000	0.500	0.333	0.500
A_3	0.250	0.500	0.250	0.500	0.250	0.750	0.667	0.250
A_4	0.333	0.333	1.000	0.250	1.000	0.500	0.667	0.250
A_5	1.000	1.000	0.250	1.000	0.500	0.250	0.667	1.000
A_6	1.000	0.333	0.500	0.250	0.500	0.500	0.667	0.750
W_j	0.449	0.238	0.131	0.075	0.044	0.029	0.02	0.015

Table 6
 Final WASPAS ranking values

	WSM	WPM	WASPAS SCORE	Rank
A_1	0.869	0.832	0.850	1
A_2	0.538	0.527	0.532	4
A_3	0.351	0.327	0.339	6
A_4	0.454	0.403	0.429	5
A_5	0.852	0.771	0.813	2
A_6	0.674	0.595	0.634	3



Fig. 3. Ranking values of the different alternatives

scores, respectively. These alternatives are not as sustainable or profitable in terms of revenue generation as carbonation and vitrification but are still promising in waste and pollution reduction. The lowest ranked alternative was crushing and screening with a score of 0.339. This process, although beneficial in certain uses, fared poorly in environmental impact and resource recovery potential, which accounted for its low ranking.

Overall, the ranking indicates the significant position of cost and environmental impact in the DM process. Alternatives like carbonation and vitrification are more aligned with the sustainability goals of minimizing environmental harm and cost savings, while methods like bioreactor landfills and crushing and screening may be less effective in the long term from a sustainability perspective. Key findings necessitate consideration of both economic and environmental factors while framing waste management policies and indicate towards the need for innovations that recover maximum resources and cause minimum pollution.

5. Conclusion

This study demonstrated an effective and orderly approach to DM problems in construction and demolition activities using a combination of PFNs with the WASPAS and SWARA methods by MATLAB programming. Implementing the SWARA process to determine the weights of the criteria was a reliable and methodical approach to quantifying the priority of each of the factors in a way that presented a more equitable and informed evaluation of the decision process within C&D waste management. The systematic evaluation of the weights of the criteria in this process ensured that the decision process within construction and demolition operations was based on informed decision making and aligned with the needs of the projects.

The WASPAS method, which was applied for ranking alternatives in accordance with their performance, merged the advantages of the weighted sum and weighted product models. The hybrid model represented a robust and well-balanced DM model, which had the ability to efficiently aggregate multiplicative and additive values. The use of PFNs made up for the uncertainties and vagueness of experts' opinions and enhanced the accuracy of the assessment process. By allowing experts to express their doubt in their evaluations, PFNs assisted in a more realistic representation of the DM scenario.

MATLAB programming played a crucial role in this study, offering an efficient platform to process large volumes of data, calculate criteria weights, rank alternatives, and visualize results. Its computational power and flexibility significantly streamlined the DM process and made the implementation of this integrated approach more practical and efficient.

The study's findings strongly imply that carbonation and vitrification are the best choices, which is evidence of their high affordability and environmental advantages. In contrast, techniques including crushing, screening, and plasma gasification were placed lower because of their less favourable environmental impact and possibilities for resource recovery. This study's hybrid DM approach identified the technical, financial, and ecological compromises in addition to offering a broad assessment of the alternatives. The results highlight the importance of integrating sustainability and cost-effectiveness into the evaluation procedure, with significant ramifications for DM in C&D operations.

In practice, this study offers a practical MCDM solution for construction and demolition project management, where decision-makers can use this approach to identify the most suitable alternatives under uncertain conditions. The integration of advanced DM techniques with MATLAB's computational capabilities can help practitioners make more informed and reliable decisions. The results from this study contribute to improving the effectiveness of DM in the construction industry and provide a foundation for future research in similar applications, particularly in environments where uncertainty and complexity play a significant role.

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Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Wu, H., Zuo, J., Yuan, H., Zillante, G., & Wang, J. (2023). Investigation of the social and economic impacts of cross-regional mobility of construction and demolition waste in australia. *Resources, Conservation and Recycling*, 190, 106814. <https://doi.org/10.1016/j.resconrec.2023.106814>
- [2] Gao, Y., Wang, J., & Xu, X. (2024). Machine learning in construction and demolition waste management: Progress, challenges, and future directions. *Automation in Construction*, 162, 105380. <https://doi.org/10.1016/j.autcon.2024.105380>
- [3] Kravchenko, E., Lazorenko, G., Jiang, X., & Leng, Z. (2024). Alkali-activated materials made of construction and demolition waste as precursors: A review. *Sustainable Materials and Technologies*, 39, e00829. <https://doi.org/10.1016/j.susmat.2024.e00829>
- [4] Caro, D., Lodato, C., Damgaard, A., Cristóbal, J., Foster, G., Flachenecker, F., & Tonini, D. (2024). Environmental and socio-economic effects of construction and demolition waste recycling in the european union. *Science of the Total Environment*, 908, 168295. <https://doi.org/10.1016/j.scitotenv.2024.168295>
- [5] Yi, Y., Fei, X., Fedele, A., Lavagnolo, M. C., & Manzardo, A. (2024). Decision support model for selecting construction and demolition waste management alternatives: A life cycle-based approach. *Science of The Total Environment*, 951, 175408. <https://doi.org/10.1016/j.scitotenv.2024.175408>
- [6] Rayhan, D. S. A., & Bhuiyan, I. U. (2024a). A framework for evaluation of construction and demolition waste management alternatives using mcda techniques in the context of dhaka city. *International Journal of Construction Management*, 1–13. <https://doi.org/10.1080/15623599.2024.1234567>
- [7] Rayhan, D. S. A., & Bhuiyan, I. U. (2024b). Review of construction and demolition waste management tools and frameworks with the classification, causes, and impacts of the waste. *Waste Disposal & Sustainable Energy*, 6(1), 95–121. <https://doi.org/10.1007/s42768-024-00095-6>
- [8] Kang, D., Suvitha, K., Sandra, M., Pamucar, D., Simic, V., & Narayanamoorthy, S. (2024). Picture-hesitant fuzzy-based dual-normalized multiple aggregations for material selection in a lift-based converter. *Facta Universitatis, Series: Mechanical Engineering*. <https://doi.org/10.22190/FUME240213030K>
- [9] Kang, D., Sandra, M., Narayanamoorthy, S., Suvitha, K., Pamucar, D., & Simic, V. (2024). An enhanced decision making model for industrial robotic selection using three factors: Positive, abstained, and negative grades of membership. *Applied Soft Computing*, 155, 111447. <https://doi.org/10.1016/j.asoc.2024.111447>
- [10] Hesami, F. (2025). A hybrid anp-topsis method for strategic supplier selection in reverse logistics under rough uncertainty: A case study in the electronics industry. *Decision Making Advances*, 3(1), 70–95. <https://doi.org/10.31181/dma31202545>
- [11] Manirathinam, T., Narayanamoorthy, S., Geetha, S., Othman, M. F. I., Alotaibi, B. S., Ahmadian, A., & Kang, D. (2023). Sustainable renewable energy system selection for self-sufficient households using integrated fermatean neutrosophic fuzzy stratified ahp-marcos approach. *Renewable Energy*, 218, 119292. <https://doi.org/10.1016/j.renene.2023.119292>

- [12] Stević, Ž., Baydaş, M., Kavacak, M., Ayhan, E., & Marinković, D. (2024). Selection of data conversion technique via sensitivity-performance matching: Ranking of small e-vans with probid method. *Facta Universitatis, Series: Mechanical Engineering*, 643–671. <https://doi.org/10.22190/FUME240305023S>
- [13] Sarvari, H., Baghbaderani, A. B., Chan, D. W., & Beer, M. (2024). Determining the significant contributing factors to the occurrence of human errors in the urban construction projects: A delphi-swara study approach. *Technological Forecasting and Social Change*, 205, 123512. <https://doi.org/10.1016/j.techfore.2024.123512>
- [14] Milinković, A., Brkljač, D., Škorić, S., Stević, Ž., Danilevičius, A., & Das, D. K. (2025). Evaluation of potentials for urban planning using the fuzzy fucom-imf swara-fuzzy opara model. *Buildings*, 15(5), 803. <https://doi.org/10.3390/buildings15050803>
- [15] Mehdiabadi, A., Sadeghi, A., Yazdi, A. K., & Tan, Y. (2025). Sustainability service chain capabilities in the oil and gas industry: A fuzzy hybrid approach swara-mabac. *Spectrum of Operational Research*, 2(1), 92–112. <https://doi.org/10.31181/sor21202512>
- [16] Rani, P., & Mishra, A. R. (2025). Single-valued neutrosophic swara-topsis-based group decision-making for prioritizing renewable energy systems. *Computer and Decision Making: An International Journal*, 2, 425–439. <https://doi.org/10.59543/comdem.v2i.11227>
- [17] Naz, S., Butt, S. A., ul Hassan, M. M., Escorcía-Gutierrez, J., Fatima, A., & ul Ain, F. (2025). A hybrid novel swara-electre-i method using probabilistic uncertain linguistic information for feature selection in image recognition. *Neurocomputing*, 612, 128615. <https://doi.org/10.1016/j.neucom.2025.128615>
- [18] Pajić, V., Andrejić, M., Jolović, M., & Kilibarda, M. (2024). Strategic warehouse location selection in business logistics: A novel approach using imf swara–marcos—a case study of a serbian logistics service provider. *Mathematics*, 12(5), 776. <https://doi.org/10.3390/math12050776>
- [19] Seikh, M. R., & Chatterjee, P. (2024). Determination of best renewable energy sources in india using swara-aras in confidence level based interval-valued fermatean fuzzy environment. *Applied Soft Computing*, 155, 111495. <https://doi.org/10.1016/j.asoc.2024.111495>
- [20] Singh, T. (2024). Entropy weighted waspas and macbeth approaches for optimizing the performance of solar water heating system. *Case Studies in Thermal Engineering*, 53, 103922. <https://doi.org/10.1016/j.csite.2024.103922>
- [21] Ghorbani, S., Bour, K., & Javdan, R. (2025). Applying the promethee ii, waspas, and cocoso models for assessment of geotechnical hazards in tbm tunneling. *Scientific Reports*, 15(1), 491. <https://doi.org/10.1038/s41598-025-05199-4>
- [22] Arivendan, A., Chen, X., Zhang, Y. F., & Gao, W. (2025). Assessing the structural, mechanical, and thermal performance of linum usitatissimum/carbon fiber composites by using novel waspas and critic methods. *Industrial Crops and Products*, 224, 120378. <https://doi.org/10.1016/j.indcrop.2025.120378>
- [23] Rasheed, M. W. (2025). Curvilinear regression analysis and ranking of migraine treatment drugs using degree-based topological indices and the waspas method. *Computers in Biology and Medicine*, 186, 109657. <https://doi.org/10.1016/j.compbiomed.2025.109657>
- [24] Jiang, Q., & Wang, H. (2025). A hybrid intuitionistic fuzzy entropy–bwm–waspas approach for supplier selection in shipbuilding enterprises. *Sustainability*, 17(4), 1701. <https://doi.org/10.3390/su17041701>
- [25] Kumar, A., & Rajak, S. (2025). Selection of bio-implant materials based on metal additive manufacturing using integrated swara and waspas mcdm technique. *Journal of Materials Engineering and Performance*, 1–21. <https://doi.org/10.1007/s11665-025-07732-9>
- [26] Ramya, L., Thilagasree, C. S., Jayakumar, T., Peter, A. K., Akhira, E. A. P., Ferrara, M., & Ahmadian, A. (2024). An appropriate artificial intelligence technique for plastic materials recycling using

- bipolar dual hesitant fuzzy set. *Scientific Reports*, 14(1), 24817. <https://doi.org/10.1038/s41598-024-24817-9>
- [27] Cuong, B. C., & Kreinovich, V. (2013). Picture fuzzy sets-a new concept for computational intelligence problems. *2013 Third World Congress on Information and Communication Technologies (WICT 2013)*, 1–6. <https://doi.org/10.1109/WICT.2013.7113156>
- [28] Luo, M., Gao, J., & Li, W. (2025). Some new construction methods of similarity measure on picture fuzzy sets. *Soft Computing*, 1–15. <https://doi.org/10.1007/s00500-025-09045-7>
- [29] Mahmoodirad, A., Pamucar, D., Niroomand, S., & Simic, V. (2025). Data envelopment analysis based performance evaluation of hospitals–implementation of novel picture fuzzy bcc model. *Expert Systems with Applications*, 263, 125775. <https://doi.org/10.1016/j.eswa.2025.125775>
- [30] Wu, M., Ma, L., & Fan, J. (2025). A large-scale group decision-making framework based on two-dimensional picture fuzzy sets in the selection of optimal carbon emission reduction alternatives. *Expert Systems with Applications*, 261, 125488. <https://doi.org/10.1016/j.eswa.2025.125488>
- [31] Ashraf, S., Jana, C., Sohail, M., Choudhary, R., Ahmad, S., & Deveci, M. (2025). Multi-criteria decision-making model based on picture hesitant fuzzy soft set approach: An application of sustainable solar energy management. *Information Sciences*, 686, 121334. <https://doi.org/10.1016/j.ins.2025.121334>
- [32] Razzaq, A., Khan, Z. A., Naeem, K., & Riaz, M. (2025). Picture fuzzy complex proportional assessment approach with step-wise weight assessment ratio analysis and criteria importance through intercriteria correlation. *Engineering Applications of Artificial Intelligence*, 139, 109554. <https://doi.org/10.1016/j.engappai.2025.109554>
- [33] Alkan, N. (2024). Evaluation of sustainable development and utilization-oriented renewable energy systems based on critic-swara-codas method using interval valued picture fuzzy sets. *Sustainable Energy, Grids and Networks*, 38, 101263. <https://doi.org/10.1016/j.segan.2024.101263>