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A Fuzzy Multi-Criteria Decision-Making Model Based on F-Entropy and F-MABAC for Assessing Sustainability Strategies

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ABSTRACT

Assessing sustainability strategies constitutes a complex decision-making problem that requires the simultaneous consideration of environmental, economic, and social dimensions. This study proposes an integrated fuzzy multi-criteria decision-making (MCDM) model to support sustainability-oriented evaluations under uncertainty. The proposed framework combines the Fuzzy Entropy (F-Entropy) method for determining criteria weights with the Fuzzy MABAC technique for ranking alternatives. By representing expert judgments through linguistic variables, the model effectively captures uncertainty inherent in real-world decision environments. The results indicate that the ninth alternative, Industry, Innovation and Infrastructure, achieves the highest overall performance, whereas the third alternative, Good Health and Well-Being, is ranked last. The findings demonstrate that the proposed approach provides a robust and reliable decision-support tool for assessing sustainability strategies.

1. Introduction

The concept of sustainability has come to the fore as one of the most pressing global agendas of our time. It is defined by a holistic development approach that necessitates the balanced consideration of environmental, economic, and social dimensions [1]. The increasing complexity of contemporary decision-making processes is evidenced by the need to evaluate multiple, often conflicting criteria in the face of growing challenges. These challenges include population increase, rising energy demand, depletion of natural resources, and climate change, which require decision-makers to operate in conditions of uncertainty. In this context, Multi-Criteria Decision-Making (MCDM) methods are distinguished as effective tools that facilitate the systematic, transparent, and analytically robust resolution of sustainability-oriented problems.

Despite the wide range of applications of traditional MCDM methods such as AHP (Analytic Hierarchy Process), TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution), VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje) and ELECTRE (ELimination Et Choix

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Traduisant La Realite), the growing prominence of uncertainty and the frequent inability of experts to express their judgments with precise numerical values has heightened the relevance of fuzzy logic–based approaches. Consequently, advanced representations, including fuzzy sets, multi-fuzzy expressions, intuitionistic fuzzy structures, and spherical or triangular fuzzy models, contribute to the more realistic and nuanced capture of decision-makers' preferences under uncertainty.

The scope of MCDM methodologies in sustainability research has been steadily expanding, with intensive applications in diverse domains such as the selection of renewable energy technology, the assessment of environmental impact, the design of sustainable supply chains, the development of green buildings, the decision-making process regarding grid topologies, the prioritization of blue-green infrastructure strategies, and the selection of materials. In particular, methods such as AHP, TOPSIS, and related techniques integrated with Geographic Information Systems (GIS) considerably enhance the capacity for spatial multi-criteria evaluation in energy and land-use planning. Furthermore, the integration of optimization-based approaches, including NSGA-II (Non-dominated Sorting Genetic Algorithm II), MARCOS (Measurement of alternatives and ranking according to COmpromise solution), and COMET (Characteristic Objects Method), with weighting techniques such as entropy, CRITIC (Criteria Importance Through Intercriteria Correlation) and BWM (Best-Worst Method), serves to enhance the analytical robustness of decision-making frameworks.

New-generation fuzzy logic–based MCDM methods have become particularly prominent in real-world problems where expert judgments inherently involve uncertainty. In this regard, the Fuzzy MABAC approach has been demonstrated to provide more balanced and reliable decision outcomes by assessing alternatives' distances to ideal and anti-ideal solutions through a region-based evaluation scheme. The model's fuzzy-extended formulation integrates qualitative expert assessments via fuzzy membership functions, thereby offering an appropriate means of handling the uncertainty commonly encountered in sustainability-focused analyses.

In a similar manner, the Fuzzy CoCoSo (Fuzzy Combined Compromise Solution) method provides a comprehensive and balanced decision-making mechanism by integrating the weighted sum model with a proportional assessment approach. In instances where criterion weights or alternative evaluations are expressed through the utilization of fuzzy terms, the Fuzzy CoCoSo methodology provides a flexible and robust analytical framework [2].

Consequently, it has emerged as a leading contemporary MCDM method in domains such as the ranking of energy technologies, the evaluation of infrastructure strategies, and the selection of sustainable materials.

The analytical value of MCDM methods in sustainability-oriented research has grown substantially in recent years, with fuzzy logic–based models in particular enabling more flexible, realistic, and multidimensional evaluations within complex decision environments. In this study, the Fuzzy MABAC and Fuzzy CoCoSo techniques will be employed to support the decision-making process from a sustainability perspective. The proposed methodological framework aims to contribute meaningfully to both theoretical advances and practical applications.

2. Review of literature

The term 'sustainability' is a multidimensional concept, encompassing environmental, economic, and social dimensions. The primary aim of sustainability is to optimize resource use, mitigate environmental impacts, and ensure long-term balance. In this context, MCDM methods offer a valuable methodological framework for addressing complex and multidimensional decision problems, particularly in sustainability-oriented domains such as renewable energy, water management, transportation, and material selection. Existing literature indicates a growing prevalence of fuzzy logic–based models, spatial analysis techniques, and hybrid MCDM approaches in enhancing decision-making processes under uncertainty.

Sohani *et al.,* [3] utilized the 4E framework to enhance the energy, exergy, environmental, and economic performance of solar-assisted distillation systems. The integration of the DMOOA (Discrete Mycorrhiza Optimization Algorithm) and TOPSIS methodologies resulted in enhancements to system efficiency, reductions in carbon emissions, and optimized cost effectiveness.

Krishankumar *et al.,* [4] integrated multi-hesitant fuzzy linguistic expressions with a Choquet-integral-based MCDM framework to support decision-making processes for renewable energy supply in smart cities. The model effectively captured the uncertainty inherent in expert judgments and identified solar energy as the most suitable alternative. Asante *et al.,* [5] conducted an examination of the technical, economic and institutional barriers affecting renewable energy deployment in Ghana. The CRITIC and fuzzy TOPSIS methods were utilized in this study. The findings of the study indicate that financial constraints and deficiencies in technical infrastructure represent the most significant obstacles to energy transition. Shah and Longsheng [6] employed fuzzy Delphi and grey AHP approaches to assess the factors impeding renewable energy development in Pakistan. Their findings indicated that solar energy exhibited the least substantial barrier profile. The analysis emphasizes the critical importance of policy-driven interventions in advancing a sustainable energy transition.

Dehghan *et al.,* [7] applied a GIS–AHP based framework to identify suitable installation zones for wind energy and evaluated the technical and economic feasibility of a hybrid energy system. The study emphasizes the pivotal role of spatial criteria in the realm of energy investment planning. Nasrollahi *et al.,* [8] conducted an extensive examination of wave energy technologies, utilizing a comprehensive set of 52 criteria through the FDM (Finite Difference Method) and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) methods. This study concluded that the Pelamis system emerges as the most optimal choice for sustainable energy generation. The findings of the present study underscore the necessity of multi-criteria analyses in the context of marine energy investments. Vasiljević *et al.,* [9] made a significant contribution to the field of sustainable transportation planning through the utilization of the SWARA (Stepwise Weight Assessment Ratio Analysis) method, which enabled the weighting of environmental, economic and accessibility criteria. This study was conducted within the context of airport–railway system integration, marking a notable advancement in the realm of sustainable urban planning. The findings of this study serve to underscore the necessity for a multidimensional evaluation approach in the context of transportation projects. Islam *et al.,* [10] employed an AHP–MCDA and GIS-based approach to identify suitable locations for solar power plant installations in Bangladesh, determining that extensive regions possess high suitability. The study demonstrates the strategic value of spatial analyses in shaping energy policies.

Erdogan *et al.,* [11] employed the AHP method to select optimal feedstocks for biofuel production, thereby revealing that third-generation algal biomass offers the most advantageous sustainability profile. The researchers emphasized the importance of environmental and economic compatibility in biofuel technologies. Tran [12] integrated methods such as MAIRCA (Multi Attributive Ideal-Real Comparative. Analysis), SPOTIS (The Stable Preference Ordering Toward Ideal Solution), and COMET (Characteristic Objects Method) with CRITIC weighting to evaluate sustainable electricity generation technologies, finding that water-based and solar thermal systems exhibit superior performance. Le [13] assessed the sustainability performance of e-commerce enterprises in Vietnam using fuzzy DEMATEL and neutrosophic axiomatic design, demonstrating that technological capacity and financial resilience play a decisive role in securing competitive advantage. Depczyński [14] analyzed raw material efficiency and waste management in industrial production using VIKOR and TOPSIS, indicating that sustainable manufacturing strategies must priorities resource efficiency and waste reduction.

Medrán *et al.,* [15] employed the MIVES method to compare traditional, modular concrete, and timber housing systems, thereby demonstrating that timber and modular designs exhibit superior performance with regard to environmental and economic criteria. Zhou *et al.,* [16] proposed a novel integration of triangular fuzzy QFD, BWM, and TOPSIS to facilitate a comprehensive evaluation of green building design alternatives. This approach enables a systematic alignment of customer requirements with technical design specifications. Akusta *et al.,* [17] utilized the fuzzy AHP method to analyse the barriers affecting renewable energy investments in Türkiye, thereby revealing that uncertainties in regulatory processes significantly hinder the investment climate.

Al-Awadhi *et al.,* [18] conducted a GIS–AHP-based analysis of solar energy investment suitability in Oman, identifying extensive areas with high potential across the region. Ur Rehman [19] developed a bipolar fuzzy BWM–EDAS (Evaluation Based on Distance from Average Solution) model that enables a comprehensive assessment of clean energy technologies based on both positive and negative criteria, demonstrating that solar energy is the most promising alternative. Tatar *et al.,* [20] evaluated the risks associated with renewable energy investment in the Belt and Road Initiative (BRI) Middle Corridor countries using the spherical fuzzy AHP method. Their findings indicated that Türkiye and Romania offer the most favorable investment environments.

Kaur *et al.,* [21] conducted an assessment of photovoltaic (PV) panels, batteries, and converters utilizing a combination of five objective weighting techniques in conjunction with the MARCOS method. The study concluded that thin-film PV modules emerge as the most sustainable component.

Turk *et al.,* [22] developed an MCDM framework integrating Fuzzy AHP and Best-Worst Method (BWM) to systematically determine the selection criteria for unmanned surface vehicles (USVs) to be used in port security. In the study, nine criteria were evaluated based on expert opinions, and the results of both methods showed high consistency. The findings revealed that endurance was the most critical criterion, while maintenance cost and investment cost were of least importance. These results represent a significant contribution to the literature by demonstrating that operational continuity and reliability are prioritized over cost-oriented parameters in high-risk operational areas such as port security. Ouria *et al.,* [23] proposed a plus-energy microgrid architecture for university campuses and demonstrated that MCDM-based optimization enhances both the technical and economic feasibility of such systems.

A survey of the extant literature reveals a preponderance of studies in the field of sustainability that rely on multi-criteria decision-making methods. The capacity of these methodologies to engender rational and coherent resolutions, even in circumstances of uncertainty, renders them strategically pivotal in domains such as sustainable energy, environmental management, transportation planning, and material selection. Recent research findings indicate a growing adoption of hybrid MCDM frameworks, with spatial analysis and fuzzy-logic-based models increasingly contributing to more realistic and practically applicable decision processes. It is evident that MCDM methods are of paramount importance as both analytical and operational decision-support tools for achieving sustainable development goals.

3. Methodology

3.1 Problem definition and structuring of criteria and alternatives

Sustainable development has three main pillars: Economic, social and environmental. For the economic dimension, we identified four criteria, and these are economic growth, unemployment, income inequality and production quality, respectively. Economic growth and income per capita are directly related to most of the development goals, since economic growth is the most powerful instrument in improving the quality of life. As Rodrik [24] states, *"Historically nothing has worked better than economic growth in enabling societies to improve the life chances of their members, including those at the very bottom."* The second criterion, which is the unemployment rate, is probably the best measure in evaluating the labor market performance. Considering that production needs capital as well as labor, we introduced unemployment rate to evaluate labor market performance [25]. The third criterion is the income inequality, which measures the distribution of income among a population. According to the World Inequality Report (2022) richest 10% increased their income and wealth in almost every country between 1980 and 2021. Panizza [26] demonstrated that, in addition to reducing economic growth, inequality also hampers university education and, consequently, human capital formation. Furthermore, Polacko [27] showed that inequality negatively affects economic indicators such as growth, investment, and innovation, while also worsening education, health, social outcomes, and even contributing to higher rates of violence and crime. Last but not least, we also introduce quality of production as a criterion. This can be proxied by high tech exports and/or economic complexity, and it is argued that quality of production strongly associated with development related goals such as inequalities, economic growth and co2 emissions [28]. The Fig. 1. shows the performance of Türkiye for the selected criteria for economic pillar for the period between 2000 and 2023.

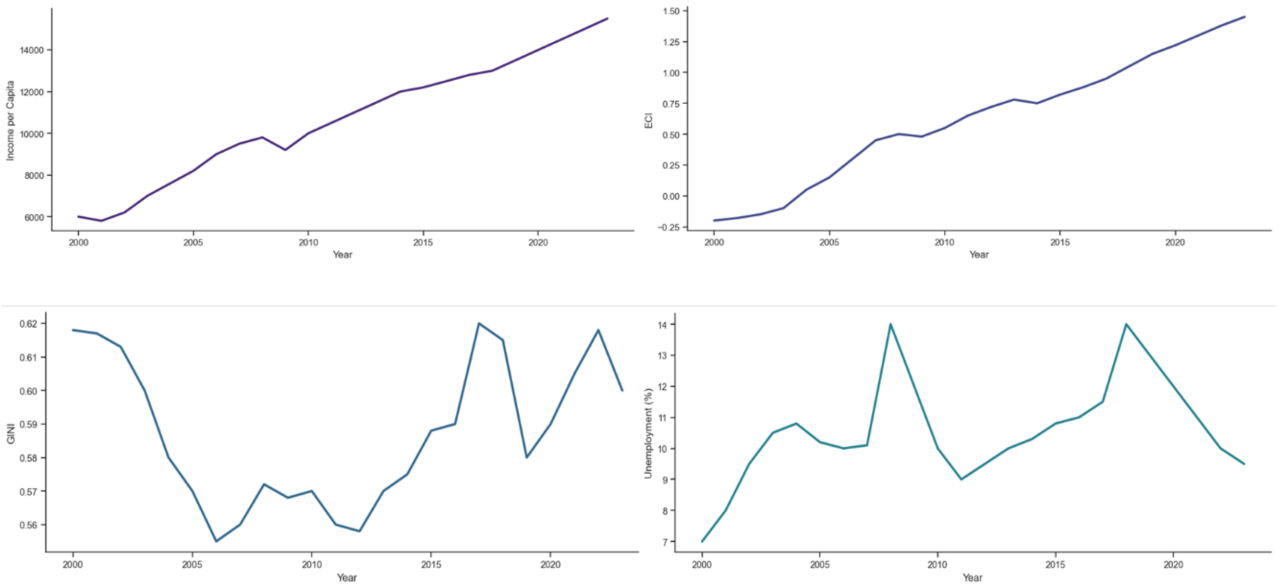

Fig. 1. The performance of Türkiye for the selected criteria for economic pillar for the period between 2000 and 2023 [29-31]

As a proxy for production quality, we use Economic Complexity Index, which is a holistic measure of a country's productive structure [32]. According to the data, Türkiye showed a decent performance in per capita growth as well as production quality. However, Türkiye has not been able to demonstrate a strong performance in the Gini index and the unemployment rate. Both of them showed a considerable volatility over the period.

The second pillar of sustainable development is social inclusion. In terms of this dimension, we identified 4 different criteria, and they are urbanization, rule of law, human capital, and health expenditures, respectively. We included rule of law as a proxy for institutional quality, which is widely recognized as an important determinant of growth and development. Institutions are considered as the main structure of social as well as economic activity [33]. Furthermore, it is proved that institutions are the main reason for income differences across the globe today [34]. The second criterion is the urbanization rate. Urbanization is mainly a shift of population from rural areas to cities/city centers, and it is directly linked to economic development as well as environmental quality [35]. The third criterion, human capital, can be defined as all abilities, knowledge and skills gained through the lifetime of a person [36] and influences various economic, social and environmental aspects, such as growth, technology, social innovation environmental degradation and public policy. Finally, we also introduce health expenditures as a proxy for determining the general health condition of a community. Health has a strong influence on development goals, such as healthier workers are more productive, healthier children express a higher cognitive ability and thus human capital, and healthier workers tend to save more for future [37]. Consequently, WHO [38] showed a positive link between development levels and health expenditures. Fig. 2. shows the performance of Türkiye for the selected social criteria.

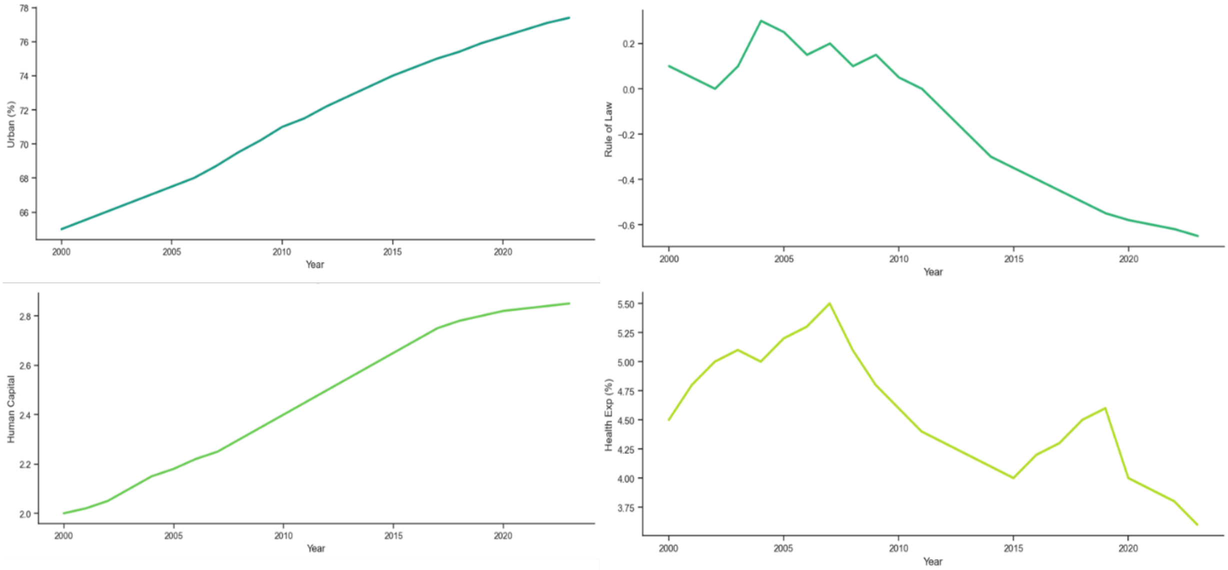

Fig. 2. The performance of Türkiye for social criteria [29, 39]

In terms of urbanization and human capital, the performance of Türkiye between the years 2000 and 2023 has risen steadily. On the other hand, rule of law index dropped significantly in these years, which indicates a deterioration in institutional quality. Regarding health expenditures, Türkiye experienced a rise between 2000 and 2010, then it also exhibited a significant drop.

The last pillar of sustainable development is the environment. For this pillar, we determined four criteria, namely, CO2 Emissions, renewable energy use, deforestation and recycling rate. Especially in recent years, a wide range of studies have been conducted on the relationship between growth/development and environmental degradation, and many of these studies have used carbon emissions or greenhouse gas emissions data as measures of environmental degradation [40, 41] since CO2 emissions warm the atmosphere and is regarded as the primary driver of climate change. The second criterion is renewable energy use. Energy is one of the most essential inputs of economic production, together with labor and capital, and it has a critical importance for almost all economic activities Stern [42]. However, the use of non-renewable energy sources, particularly oil and coal, for the sake of industrialization and growth has significantly harmed the environment and, consequently, sustainability. The third criterion, deforestation, undermines sustainability by reducing carbon removal capacity, accelerating erosion, increasing flood risk, and contributing to biodiversity loss [43]. In addition, the reason behind deforestation is to gain short term economic benefits such as lowering unemployment or increasing income, but long-term costs such as environmental and climate damage and reduced agricultural resilience outweighs benefits [44]. Lastly, the recycling rate is included due to its multiple contributions to sustainability. Recycling has various effects on sustainability, such as reducing emissions as well as energy use [45] preserving natural resources and thus reducing resource depletion [46] and supporting sustainable development via circular economy. Fig. 3. shows Turkiye’s performance on environmental pillars.

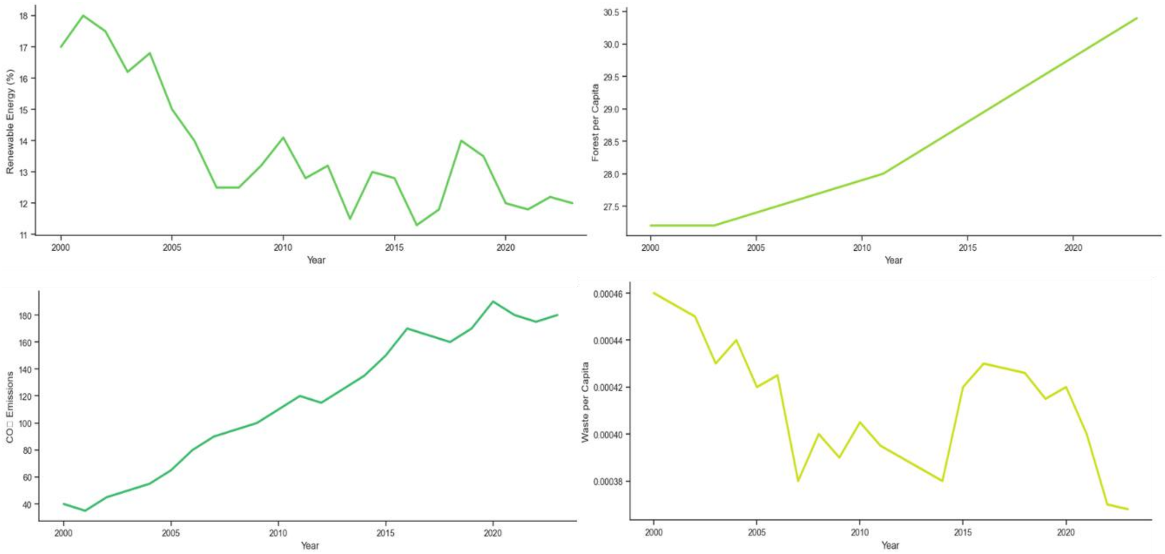

Fig. 3. Türkiye’s performance on environmental pillars [29, 47, 48]

Unfortunately, data for deforestation and recycling rate do not exist for all the years, thus, we proxied deforestation with forest per capita. For recycling rate, we use waste per capita data, which shows the average waste of a person in tonnes. During the relevant years, Türkiye did not show a good performance in terms of carbon emissions and renewable energy, continuously increasing its carbon emissions while steadily reducing its use of renewable energy. In terms of municipal waste per capita, Türkiye showed a modest improvement. According to OECD [47] data, Türkiye managed to slightly increase the total amount of recycled waste between 2016 and 2021—the years for which data are available. With regard to forest area per capita, Türkiye experienced an increase in this indicator over the period 2005–2020.

3.3 Shannon fuzzy Entropy

Recognizing that many real-world decision-making problems involve uncertain and imprecise data, Hosseinzadeh Lotfi and Fallahnejad adapted and enhanced the Shannon Entropy method for fuzzy and interval-valued information by incorporating α-cuts into the formulation [49-51]. The steps of the Fuzzy Shannon Entropy method based on α-cut sets are described in five stages [50].

Step 1. Conversion of Fuzzy Data into Interval Data Using α-Cut Sets

$$(X) = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix}$$

A fuzzy variable x_{ij}in the fuzzy decision matrix is represented by an α-cut set, which is defined as a classical set consisting of all elements whose membership degrees are greater than or equal to α ($\alpha \in (0,1]$). This concept is expressed as shown in Eq. (1).

$$(x_{ij})_a = \{x_{ij} \in R \mid \mu_{x_{ij}}(x_{ij}) \geq \alpha\} \tag{1}$$

The α-cut set of the variable $x_{ij}$is represented as an interval, as shown in Eq. (2).

$$\left[\left(x_{ij}\right)_{\alpha}^{L},\left(x_{ij}\right)_{\alpha}^{U}\right]=\left[min_{x_{ij}}\left\{x_{ij}\in R:\mu_{xij}(x_{ij})\geq\alpha\right\},max_{x_{ij}}\left\{x_{ij}\in R:\mu_{xij}(x_{ij})\geq\alpha\right\}\right],\tag{2}$$

where $0<\alpha\leq 1$. Following this procedure, the fuzzy data are adjusted according to different confidence levels $(1-\alpha)$and transformed into interval values. The resulting matrix is presented below.

$$(B)=\begin{bmatrix}[x_{11}^{L},x_{11}^{U}] & [x_{12}^{L},x_{12}^{U}] & \cdots & [x_{1n}^{L},x_{1n}^{U}]\\ [x_{21}^{L},x_{21}^{U}] & [x_{22}^{L},x_{22}^{U}] & \cdots & [x_{2n}^{L},x_{2n}^{U}]\\ \cdots & \cdots & \cdots & \cdots\\ [x_{m1}^{L},x_{m1}^{U}] & [x_{m2}^{L},x_{m2}^{U}] & \cdots & [x_{mn}^{L},x_{mn}^{U}]\end{bmatrix}$$

Step 2. The normalized values $P_{ij}^{L}$and $P_{ij}^{U}$are obtained using the Eq. (3) and Eq. (4) provided below.

$$P_{ij}^{L}=\frac{x_{ij}^{L}}{\sum_{i=1}^{m}x_{ij}^{U}}\ where\ j=1,2,\dots,n\ and\ i=1,2,\dots,m\tag{3}$$

$$P_{ij}^{R}=\frac{x_{ij}^{U}}{\sum_{i=1}^{m}x_{ij}^{U}}\ where\ \ i=1,2,\dots,m\ and\ j=1,2,\dots,n\tag{4}$$

Step 3. Calculation of the Lower (e_{j}^{L}) Eq. (5) and Upper (e_{j}^{U}) Eq. (6) Bounds of the Interval Entropy Values for the Criteria

$$\left(e_{j}^{L}\right)=min\left\{-e_{0}.\sum_{i=1}^{m}p_{ij}^{L}.\ln\left(p_{ij}^{L}\right)-e_{0}\sum_{i=1}^{m}p_{ij}^{U}.\ln\left(p_{ij}^{U}\right)\right\},\ i=1,2,\dots,m\ and\ j=1,2,\dots,n\tag{5}$$

$$\left(e_{j}^{U}\right)=max\left\{-e_{0}.\sum_{i=1}^{m}p_{ij}^{L}.\ln\left(p_{ij}^{L}\right)-e_{0}\sum_{i=1}^{m}p_{ij}^{U}.\ln\left(p_{ij}^{U}\right)\right\},\ i=1,2,\dots,m\ and\ j=1,2,\dots,n\tag{6}$$

Step 4. Calculation of the Lower (d_{j}^{L}) Eq. (7) and Upper (d_{j}^{U}) Eq. (8) Bounds of the Variation Interval

$$d_{j}^{L}=1-e_{j}^{U}where\ j=1,2,\dots,n\tag{7}$$

$$d_{j}^{U}=1-e_{j}^{L}where\ j=1,2,\dots,n\tag{8}$$

Step 5. Calculation of the Lower (w_{j}^{L})Eq. (9) and Upper (w_{j}^{U}) Eq. (10)-(11) Bounds of the Interval Weights of the Criteria

$$w_{j}^{L}=\frac{d_{j}^{L}}{\sum_{j=1}^{n}d_{j}^{L}}\ where\ j=1,2,\dots,n\tag{9}$$

$$w_{j}^{U}=\frac{d_{j}^{U}}{\sum_{j=1}^{n}d_{j}^{U}}\ where\ j=1,2,\dots,n\tag{10}$$

$$\sum_{j=1}^{n}w_{j}=1\ where\ j=,1,2,\dots,n\tag{11}$$

The interval $[w_{j}^{L},w_{j}^{U}]_{\alpha}$represents the entropy weight of the j-th fuzzy criterion at the α-cut level.

3.3 Multi-Attributive Border Approximation Area Comparison (MABAC)

The MABAC method was introduced into the literature in 2015 by Pamucar and Cirovic [52]. In their study, they presented the application of a new model to be used in investment decision-making. In addition, it has been observed that in recent years the MABAC method has been frequently used in solving multi-criteria decision-making (MCDM) problems. Naz *et al.,* [53] employed a new MABAC model integrated with power-weighted Hamy mean operators to select the most appropriate blockchain system for secure transaction environments. Torkayesh *et al.,* [54] conducted a comprehensive literature review of 117 studies to examine the recent developments, application areas, and future research directions of the MABAC method. Üçler [55] analyzed the 2018–2022 macroeconomic performance of G7 countries using SD and MABAC methods, highlighting the most influential criteria each year and the top-performing countries according to MABAC. Orhan and Mutlu [56] evaluated and ranked the COVID-19 response performance of 30 countries, using the CRITIC and MABAC methods. Pamucar and Ćirovic [52] utilized also MABAC in the selection of transportation and handling resources in logistics centers. The fuzzy MABAC approach addresses the problem through a seven-step procedure [57, 58].

Step 1. First create the initial decision matrix (X), alternatives are represented as vectors $A_i = (X_{i1}, X_{i2}, \ldots, X_{in})$, where x_{ij}denotes the value of the ith alternative with respect to the jth criterion $(i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n)$ as shown in Eq. (12).

$$(X) = \begin{array}{c} \\ A_1 \\ A_2 \\ \ldots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1, & C_2, & \ldots, & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & \ldots & x_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ x_{m1} & x_{m2} & \ldots & x_{mn} \end{bmatrix} \end{array} \tag{12}$$

Here m represents the total number of alternatives, while n shows the total number of criteria.

Step 2. Transforming the initial decision matrix (X) elements into a normalized form, as shown in Eq. (13).

$$(N) = \begin{array}{c} \\ A_1 \\ A_2 \\ \ldots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1, & C_2, & \ldots, & C_n \end{array} \\ \begin{bmatrix} t_{11} & t_{12} & \ldots & t_{1n} \\ t_{21} & t_{22} & \ldots & t_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ t_{m1} & t_{m2} & \ldots & t_{mn} \end{bmatrix} \end{array} \tag{13}$$

The values of the normalized matrix (N) are calculated using the following formulas, as shown in Eq. (14) for benefit-type criteria and Eq. (15) for cost-type criteria.

$$t_{ij} = \frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \tag{14}$$

$$t_{ij} = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \tag{15}$$

Here, $x_{ij}, x_i^+ and\ x_i^-$ denote the elements of the initial decision matrix (X). $x_i^+ and\ x_i^-$ defined as follows:

$x_i^+ = \max(x_{1r}, x_{2r}, \ldots, x_{mr})$ and correspond to the maximum values in the right-hand spread of the fuzzy numbers for the evaluated criterion across the alternatives,

$x_i^- = \min(x_{1l}, x_{2l}, \ldots, x_{ml})$ and correspond to the minimum values in the left-hand spread of the fuzzy numbers for the evaluated criterion across the alternatives.

Step 3. Determination of the weighted matrix (V) values as shown in Eq. (16) .

$$(V) = \begin{bmatrix} v_{11} & v_{12} & \ldots & v_{1n} \\ v_{21} & v_{22} & \ldots & v_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ v_{m1} & v_{m2} & \ldots & v_{mn} \end{bmatrix} \tag{16}$$

The elements of matrix (V) are derived based on Eq. (17);

$$v_{ij} = w_i t_{ij} + w_i \tag{17}$$

Here, t_{ij} denote the elements of normalized matrix (N), while w_i indicates the weights coefficient of the corresponding criterion.

Step 4. Construction of the approximate border area matrix (G). The border approximation area for each criterion is calculated using Eq. (18).

$$g_i = \left(\prod_{j=1}^{m} v_{ij}\right)^{1/m} \tag{18}$$

Here, v_{ij} denostes the elements of the weighted matrix (V), and m indicates the total number of alternatives. By calculating the g_i values for all criteria, the Border Approximation Area matrix (G) shown in Eq. (19) is obtained.

$$C_1, C_2, \ldots, C_n$$

$$(G) = [g_1, g_2, \dots, g_n] \tag{19}$$

Step 5. At this stage, the distances of each value in the decision matrix from the border approximation area are calculated, resulting in the Q matrix as presented in Eq. (20).

$$(Q) = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1n} \\ q_{21} & q_{22} & \cdots & q_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix} \tag{20}$$

The q_{ij}values in Eq. (9) are obtained by calculating the difference between the elements of the weighted decision matrix and the border approximation matrix, as shown in Eq. (21).

$$(Q) = (V) - (G) \tag{21}$$

The values of alternative A_i may belong to the border approximate area (G), to the upper approximate area G^+, or to the lower approximate area G^-, $(A_i \in G \vee G^+ \vee G^-)$.

Based on the values from the previous step, the performance of each decision alternative A_i relative to the border approximation area $(G, G^+ \ or \ G^-$ is determined using Eq. (22).

$$A_i \in \begin{cases} G^+ if \ q_{ij} > 0 \\ G \ if \ q_{ij} = 0 \\ G^- if \ q_{ij} < 0 \end{cases} \tag{22}$$

As indicated in Eq. (22), a decision alternative can be located in the upper G^+, border G, or lower G^-approximation area. For an alternative to be considered the best, the majority of its criterion values should fall within the upper approximation area. A $q_{ij} > 0$ indicates that the alternative $A_i$is close to the positive ideal, whereas $q_{ij} < 0$ signifies its proximity to the negative ideal.

Step 6. Ranking of alternatives. The final criteria function values for each alternative are obtained by summing the row elements of the Q matrix, representing their distances from the border approximation areas, which are then used for ranking, as shown in Eq. (23).

$$S_i = \sum_{j=1}^{n} q_{ij}, j = 1,2, \dots, n, \quad i = 1,2, \dots, m \tag{23}$$

where n denotes the number of criteria, and m is number of alternatives.

Step 7. The final ranking of alternatives is determined by de-fuzzifying the obtained S_i values, which can be carried out [55] using the following Eq. (24) and Eq. (25);

$$Defuzzifying \ S = [(t_3 - t_1) + (t_2 - t_1)]3^{-1} + t_1 \tag{24}$$

$$Defuzzifying \ S = [\lambda t_3 + t_2 + (1 - \lambda) t_1]2^{-1} \tag{25}$$

4. Case study

Fifteen alternatives were utilized in the present study. The following alternatives are posited:

A_1: No poverty (EC)
A_2: Zero hunger (S)
A_3: Good health and well-being (S)
A_4: Quality education (S)
A_5: Gender equality (S)
A_6: Clean water and sanitation (ENV)
A_7: Affordable and clean energy (ENV)
A_8: Decent work and economic growth (EC)
A_9: Industry, innovation and infrastructure (EC)
A_{10}: Reduced inequalities (S)
A_{11}: Sustainable cities and communities (S)
A_{12}: Responsible consumption and production (EC)
A_{13}: Climate action (ENV)

A_{14}: Life below water (ENV)
A_{15}: Life on land (ENV)
(EC = Economic, S = Social, ENV = Environmental)

The evaluation of these alternatives was conducted by means of a multifaceted assessment, encompassing a total of 12 distinct criteria. The criteria were divided into benefits and costs in terms of economic, social, and environmental aspects.

C_1: Income per capita
C_2: Unemployment rate
C_3: Income inequality
C_4: Production Quality/High tech exports
C_5: Urbanization
C_6: Rule of Law
C_7: Human capital
C_8: Health expenditures
C_9: CO_2 Emissions
C_{10}: Renewable energy
C_{11}: Deforestation
C_{12}: Recycling rate

A total of five distinct expert opinions were obtained with the purpose of evaluating the alternatives in terms of the specified criteria. The linguistic expressions documented in Table 1 were utilized to ascertain the expert opinions.

Table 1
Linguistic terms

Linguistic terms	Membership function
Absolutely low (AL)	(1, 1, 1)
Very low (VL)	(1, 2, 3)
Low (L)	(2, 3, 4)
Medium low (ML)	(3, 4, 5)
Equal (E)	(4, 5, 6)
Medium high (MH)	(5, 6, 7)
High (H)	(6, 7, 8)
Very high (VH)	(7, 8, 9)
Absolutely high (AH)	(8, 9, 9)

The criteria C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8, C_9, C_{10}, C_{11} and C_{12} can be categorized as follows: C_1, C_2, C_3 and C_4 are economic; C_5, C_6, C_7 and C_8 are social; and C_9, C_{10}, C_{11} and C_{12} are environmental. It is evident that criteria C_2, C_3, C_9, and C_{11} are classified as cost criteria, while the remaining criteria are designated as benefit criteria. Table 2 presents an alternative/criteria matrix, which has been prepared according to the opinions of experts in the field.

Table 2
Alternative criteria matrix

Alternatives/Criteria	Income per capita	Unemployment rate	Income inequality
A_1: No poverty (EC)	(7.6, 8.6, 8.8)	(7.4, 8.4, 9.0)	(7.0, 8.0, 8.8)
A_2: Zero hunger (S)	(6.6, 7.6, 8.4)	(7.4, 8.4, 9.0)	(6.8, 7.8, 8.8)
A_3: Good health and well-being (S)	(6.8, 7.8, 8.6)	(7.0, 8.0, 8.8)	(6.8, 7.8, 8.8)
A_4: Quality education (S)	(6.4, 7.4, 8.4)	(6.2, 7.2, 8.2)	(6.8, 7.8, 8.8)
A_5: Gender equality (S)	(5.0, 6.0, 7.0)	(6.2, 7.2, 8.2)	(5.8, 6.8, 7.6)
A_6: Clean water and sanitation (ENV)	(6.2, 7.2, 8.2)	(4.8, 5.8, 6.8)	(5.6, 6.6, 7.4)
A_7: Affordable and clean energy (ENV)	(6.2, 7.2, 8.2)	(4.0, 5.0, 6.0)	(5.6, 6.6, 7.4)
A_8: Decent work and economic growth (EC)	(7.4, 8.4, 8.8)	(7.4, 8.4, 9.0)	(7.0, 8.0, 8.8)
A_9: Industry, innovation and infrastructure (EC)	(7.4, 8.4, 8.8)	(6.4, 7.4, 8.2)	(6.2, 7.2, 7.8)
A_{10}: Reduced inequalities (S)	(6.4, 7.4, 7.8)	(6.4, 7.4, 8.2)	(7.6, 8.6, 8.8)
A_{11}: Sustainable cities and communities (S)	(6.6, 7.6, 8.6)	(5.6, 6.6, 7.6)	(6.6, 7.6, 8.6)
A_{12}: Responsible consumption and production (EC)	(5.4, 6.4, 7.2)	(5.0, 6.0, 7.0)	(6.2, 7.2, 8.2)
A_{13}: Climate action (ENV)	(5.8, 6.8, 7.6)	(4.2, 5.2, 6.2)	(4.8, 5.8, 6.6)
A_{14}: Life below water (ENV)	(5.4, 6.4, 7.4)	(3.6, 4.6, 5.4)	(3.8, 4.8, 5.8)
A_{15}: Life on land (ENV)	(5.6, 6.6, 7.4)	(4.0, 5.0, 5.8)	(4.8, 5.8, 6.6)

Alternatives/Criteria	Production Quality/ High tech exports	Urbanization	Rule of Law
A_1: No poverty (EC)	(5.4, 6.4, 7.4)	(4.6, 5.6, 6.6)	(6.6, 7.6, 8.4)
A_2: Zero hunger (S)	(5.2, 6.2, 7.2)	(4.2, 5.2, 6.2)	(7.0, 8.0, 8.6)
A_3: Good health and well-being (S)	(4.4, 5.4, 6.4)	(5.2, 6.2, 7.2)	(6.6, 7.6, 8.4)
A_4: Quality education (S)	(5.8, 6.8, 7.6)	(6.2, 7.2, 8.0)	(7.2, 8.2, 8.8)
A_5: Gender equality (S)	(4.6, 5.6, 6.6)	(4.6, 5.6, 6.6)	(7.4, 8.4, 9.0)
A_6: Clean water and sanitation (ENV)	(5.2, 6.2, 7.0)	(4.6, 5.6, 6.6)	(6.8, 7.8, 8.6)
A_7: Affordable and clean energy (ENV)	(5.8, 6.8, 7.4)	(5.4, 6.4, 7.4)	(6.0, 7.0, 8.0)
A_8: Decent work and economic growth (EC)	(6.8, 7.8, 8.0)	(5.0, 6.0, 6.8)	(7.4, 8.4, 9.0)
A_9: Industry, innovation and infrastructure (EC)	(7.6, 8.6, 9.0)	(6.4, 7.4, 8.4)	(7.0, 8.0, 8.8)
A_{10}: Reduced inequalities (S)	(5.0, 6.0, 7.0)	(4.0, 5.0, 6.0)	(6.8, 7.8, 8.6)
A_{11}: Sustainable cities and communities (S)	(5.6, 6.6, 7.4)	(6.2, 7.2, 7.8)	(6.6, 7.6, 8.6)
A_{12}: Responsible consumption and production (EC)	(5.8, 6.8, 7.6)	(4.2, 5.2, 6.2)	(6.2, 7.2, 8.2)
A_{13}: Climate action (ENV)	(5.2, 6.2, 7.2)	(4.8, 5.8, 6.8)	(7.2, 8.2, 8.8)
A_{14}: Life below water (ENV)	(5.0, 6.0, 6.8)	(4.8, 5.8, 6.6)	(6.2, 7.2, 8.0)
A_{15}: Life on land (ENV)	(5.2, 6.2, 7.0)	(5.6, 6.6, 7.4)	(6.2, 7.2, 8.0)

Table 2
Continued

Alternatives/Criteria	Human capital	Health expenditures	CO2 Emissions
A_1: No poverty (EC)	(7.4, 8.4, 8.8)	(7.0, 8.0, 8.6)	(3.4, 4.4, 5.4)
A_2: Zero hunger (S)	(7.0, 8.0, 8.8)	(6.2, 7.2, 8.2)	(3.0, 4.0, 5.0)
A_3: Good health and well-being (S)	(6.4, 7.4, 8.4)	(7.8, 8.8, 9.0)	(7.6, 8.6, 9.0)
A_4: Quality education (S)	(7.4, 8.4, 8.8)	(5.2, 6.2, 7.2)	(3.4, 4.4, 5.4)
A_5: Gender equality (S)	(7.0, 8.0, 8.6)	(5.4, 6.4, 7.4)	(1.8, 2.8, 3.8)
A_6: Clean water and sanitation (ENV)	(6.0, 7.0, 8.0)	(7.2, 8.2, 9.0)	(6.6, 7.6, 8.2)
A_7: Affordable and clean energy (ENV)	(6.2, 7.2, 8.2)	(6.2, 7.2, 8.0)	(7.2, 8.2, 8.6)
A_8: Decent work and economic growth (EC)	(7.2, 8.2, 8.8)	(6.4, 7.4, 8.4)	(5.0, 6.0, 7.0)
A_9: Industry, innovation and infrastructure (EC)	(6.4, 7.4, 8.2)	(6.0, 7.0, 7.8)	(4.2, 5.2, 6.2)
A_{10}: Reduced inequalities (S)	(7.0, 8.0, 8.8)	(5.6, 6.6, 7.6)	(2.6, 3.6, 4.6)
A_{11}: Sustainable cities and communities (S)	(6.4, 7.4, 8.4)	(6.6, 7.6, 8.4)	(6.4, 7.4, 8.0)
A_{12}: Responsible consumption and production (EC)	(7.2, 8.2, 8.8)	(6.4, 7.4, 8.4)	(5.6, 6.6, 7.6)
A_{13}: Climate action (ENV)	(6.8, 7.8, 8.6)	(4.8, 5.8, 6.8)	(7.6, 8.6, 9.0)
A_{14}: Life below water (ENV)	(6.0, 7.0, 7.8)	(4.4, 5.4, 6.4)	(6.0, 7.0, 7.8)
A_{15}: Life on land (ENV)	(6.2, 7.2, 8.0)	(4.8, 5.8, 6.6)	(7.4, 8.4, 8.8)

Alternatives/Criteria	Renewable energy	Deforestation	Recycling rate
A_1: No poverty (EC)	(3.2, 4.2, 5.2)	(3.0, 4.0, 5.0)	(2.6, 3.6, 4.6)
A_2: Zero hunger (S)	(3.2, 4.2, 5.2)	(3.0, 4.0, 5.0)	(2.6, 3.6, 4.6)
A_3: Good health and well-being (S)	(7.0, 8.0, 8.6)	(6.0, 7.0, 7.8)	(4.6, 5.6, 6.6)
A_4: Quality education (S)	(3.4, 4.4, 5.4)	(2.0, 2.8, 3.6)	(4.4, 5.4, 6.4)
A_5: Gender equality (S)	(2.6, 3.6, 4.6)	(1.6, 2.0, 2.4)	(1.6, 2.4, 3.2)
A_6: Clean water and sanitation (ENV)	(7.2, 8.2, 8.8)	(6.6, 7.6, 8.6)	(7.0, 8.0, 8.6)
A_7: Affordable and clean energy (ENV)	(7.8, 8.8, 9.0)	(6.6, 7.6, 8.6)	(6.4, 7.4, 8.2)
A_8: Decent work and economic growth (EC)	(5.8, 6.8, 7.6)	(3.6, 4.6, 5.6)	(5.2, 6.2, 7.2)
A_9: Industry, innovation and infrastructure (EC)	(6.2, 7.2, 8.0)	(3.2, 4.2, 5.2)	(5.2, 6.0, 6.8)
A_{10}: Reduced inequalities (S)	(3.2, 4.2, 5.2)	(1.8, 2.6, 3.4)	(2.2, 3.2, 4.2)
A_{11}: Sustainable cities and communities (S)	(7.2, 8.2, 8.8)	(6.6, 7.6, 8.6)	(5.6, 6.6, 7.4)
A_{12}: Responsible consumption and production (EC)	(6.4, 7.4, 8.4)	(4.6, 5.6, 6.6)	(6.4, 7.4, 8.2)
A_{13}: Climate action (ENV)	(7.8, 8.8, 9.0)	(7.4, 8.4, 9.0)	(7.0, 8.0, 8.8)
A_{14}: Life below water (ENV)	(7.8, 8.8, 9.0)	(7.0, 8.0, 8.8)	(7.2, 8.2, 9.0)
A_{15}: Life on land (ENV)	(7.8, 8.8, 9.0)	(7.4, 8.4, 9.0)	(7.2, 8.2, 8.8)

As illustrated in Table 3, the mean of the l, m and u values are demonstrated.

Table 3
Average alternative criteria matrix

Alternatives/Criteria	C_1	C_2	C_3	C_4	C_5	C_6
A_1: No poverty (EC)	8.34	8.27	7.94	6.4	5.6	7.54
A_2: Zero hunger (S)	7.54	8.27	7.8	6.2	5.2	7.87
A_3: Good health and well-being (S)	7.74	7.94	7.8	5.4	6.2	7.54
A_4: Quality education (S)	7.4	7.2	7.8	6.74	7.14	8.07
A_5: Gender equality (S)	6	7.2	6.74	5.6	5.6	8.27
A_6: Clean water and sanitation (ENV)	7.2	5.8	6.54	6.14	5.6	7.74
A_7: Affordable and clean energy (ENV)	7.2	5	6.54	6.7	6.4	7
A_8: Decent work and economic growth (EC)	8.2	8.27	7.94	7.54	5.94	8.27
A_9: Industry, innovation and infrastructure (EC)	8.2	7.34	7.07	8.4	7.4	7.94
A_{10}: Reduced inequalities (S)	7.2	7.4	8.4	6	5	7.74
A_{11}: Sustainable cities and communities (S)	7.6	6.6	7.6	6.54	7.07	7.6
A_{12}: Responsible consumption and production (EC)	6.4	6	7.2	6.74	5.2	7.2
A_{13}: Climate action (ENV)	6.74	5.2	5.74	6.2	5.8	8.07
A_{14}: Life below water (ENV)	6.4	4.54	4.8	5.94	5.74	7.14
A_{15}: Life on land (ENV)	6.54	4.94	5.74	6.14	6.54	7.14

Table 3
Continued

Alternatives/Criteria	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1: No poverty (EC)	8.2	7.87	4.4	4.2	4	3.6
A_2: Zero hunger (S)	7.94	7.2	4	4.2	4	3.6
A_3: Good health and well-being (S)	7.4	8.54	8.4	7.87	6.94	5.6
A_4: Quality education (S)	8.2	6.2	4.4	4.4	2.8	5.4
A_5: Gender equality (S)	7.87	6.4	2.8	3.6	2	2.4
A_6: Clean water and sanitation (ENV)	7	8.14	7.47	8.07	7.6	7.87
A_7: Affordable and clean energy (ENV)	7.2	7.14	8	8.54	7.6	7.4
A_8: Decent work and economic growth (EC)	8.07	7.4	6	6.74	4.6	6.2
A_9: Industry. innovation and infrastructure (EC)	7.4	6.94	5.2	7.14	4.2	6
A_{10}: Reduced inequalities (S)	7.94	6.6	3.6	4.2	2.6	3.2
A_{11}: Sustainable cities and communities (S)	7.4	7.54	7.27	8.07	7.6	6.54
A_{12}: Responsible consumption and production (EC)	8.07	7.4	6.6	7.4	5.6	7.4
A_{13}: Climate action (ENV)	7.74	5.8	8.4	8.54	8.27	7.94
A_{14}: Life below water (ENV)	6.94	5.4	6.94	8.54	7.94	8.14
A_{15}: Life on land (ENV)	7.14	5.74	8.2	8.54	8.27	8.07

In the initial phase of the study, criterion weighting was executed through the utilization of Fuzzy Entropy. The matrix created in Table 3 was subjected to normalization for the Fuzzy Entropy steps. The normalized matrix is presented in Table 4.

Table 4
Normalized matrix

Alternatives/Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	0.077	0.051	0.058	0.066	0.062	0.065	0.072	0.075	0.083	0.042	0.076	0.040
A_2	0.069	0.051	0.059	0.064	0.058	0.068	0.069	0.069	0.091	0.042	0.076	0.040
A_3	0.071	0.054	0.059	0.056	0.069	0.065	0.065	0.082	0.043	0.079	0.044	0.063
A_4	0.068	0.059	0.059	0.070	0.079	0.070	0.072	0.059	0.083	0.044	0.109	0.061
A_5	0.055	0.059	0.068	0.058	0.062	0.072	0.069	0.061	0.130	0.036	0.152	0.027
A_6	0.066	0.074	0.070	0.063	0.062	0.067	0.061	0.078	0.049	0.081	0.040	0.088
A_7	0.066	0.085	0.070	0.069	0.071	0.061	0.063	0.068	0.045	0.085	0.040	0.082
A_8	0.076	0.052	0.058	0.078	0.066	0.072	0.071	0.071	0.061	0.067	0.066	0.070
A_9	0.076	0.058	0.065	0.087	0.082	0.069	0.064	0.066	0.070	0.071	0.073	0.067
A_{10}	0.066	0.058	0.055	0.062	0.055	0.067	0.069	0.063	0.101	0.042	0.117	0.036
A_{11}	0.070	0.065	0.060	0.068	0.078	0.066	0.065	0.072	0.050	0.081	0.040	0.073
A_{12}	0.058	0.071	0.064	0.070	0.058	0.063	0.071	0.071	0.055	0.074	0.054	0.082
A_{13}	0.062	0.082	0.080	0.064	0.064	0.070	0.068	0.056	0.043	0.085	0.037	0.089
A_{14}	0.059	0.094	0.096	0.061	0.063	0.062	0.061	0.052	0.052	0.085	0.038	0.091
A_{15}	0.060	0.086	0.080	0.063	0.072	0.062	0.062	0.055	0.044	0.085	0.037	0.090

As illustrated in Table 5, the criterion weights were calculated using the fuzzy entropy method.

Table 5
Criterion weights

Criterion	Entropy	Weight
Income per capita	0.998	0.014
Unemployment rate	0.992	0.062
Income inequality	0.995	0.036
Production Quality/High tech exports	0.998	0.018
Urbanization	0.997	0.021
Rule of Law	0.999	0.004
Human capital	0.999	0.005
Health expenditures	0.997	0.024
CO2 Emissions	0.976	0.189
Renewable energy	0.984	0.126
Deforestation	0.957	0.341
Recycling rate	0.980	0.161

The criterion that was assigned the highest weight was that of renewable energy. In the subsequent phase, the evaluation of alternatives was conducted through the utilization of Fuzzy MABAC, with the assigned criterion weights serving as the foundation for the assessment. The normalized decision matrix is represented in Table 6.

Table 6
Normalized decision matrix

Alternatives/Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	1.000	0.000	0.113	0.333	0.250	0.421	1.000	0.787	0.714	0.122	0.681	0.209
A_2	0.657	0.000	0.151	0.267	0.083	0.684	0.789	0.574	0.786	0.122	0.681	0.209
A_3	0.743	0.089	0.151	0.000	0.500	0.421	0.368	1.000	0.000	0.865	0.213	0.558
A_4	0.600	0.286	0.151	0.444	0.889	0.842	1.000	0.255	0.714	0.162	0.872	0.523
A_5	0.000	0.286	0.453	0.067	0.250	1.000	0.737	0.319	1.000	0.000	1.000	0.000
A_6	0.514	0.661	0.509	0.244	0.250	0.579	0.053	0.872	0.167	0.905	0.106	0.953
A_7	0.514	0.875	0.509	0.422	0.583	0.000	0.211	0.553	0.071	1.000	0.106	0.860
A_8	0.943	0.000	0.113	0.711	0.389	1.000	0.895	0.638	0.429	0.635	0.585	0.663
A_9	0.943	0.250	0.358	1.000	1.000	0.737	0.316	0.489	0.571	0.716	0.649	0.628
A_{10}	0.514	0.250	0.000	0.200	0.000	0.579	0.789	0.383	0.857	0.122	0.904	0.140
A_{11}	0.686	0.446	0.208	0.378	0.861	0.474	0.368	0.681	0.202	0.905	0.106	0.721
A_{12}	0.143	0.607	0.321	0.444	0.083	0.158	0.895	0.638	0.321	0.770	0.426	0.860
A_{13}	0.314	0.821	0.736	0.267	0.333	0.842	0.632	0.128	0.000	1.000	0.000	0.965
A_{14}	0.171	1.000	1.000	0.178	0.306	0.105	0.000	0.000	0.262	1.000	0.053	1.000
A_{15}	0.229	0.893	0.736	0.244	0.639	0.105	0.158	0.106	0.036	1.000	0.000	0.988

The creation of a weighted normalized matrix was achieved by multiplying the normalized decision matrix with the weights. As illustrated in Table 7, the weighted matrix is presented.

Table 7
Weighted normalized matrix

Alternative	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	0.014	0.000	0.004	0.006	0.005	0.002	0.005	0.019	0.135	0.015	0.232	0.034
A_2	0.009	0.000	0.006	0.005	0.002	0.003	0.004	0.014	0.148	0.015	0.232	0.034
A_3	0.010	0.006	0.006	0.000	0.010	0.002	0.002	0.024	0.000	0.109	0.073	0.090
A_4	0.008	0.018	0.006	0.008	0.018	0.003	0.005	0.006	0.135	0.020	0.298	0.084
A_5	0.000	0.018	0.017	0.001	0.005	0.004	0.003	0.008	0.189	0.000	0.341	0.000
A_6	0.007	0.041	0.019	0.004	0.005	0.002	0.000	0.021	0.031	0.114	0.036	0.153
A_7	0.007	0.054	0.019	0.008	0.012	0.000	0.001	0.013	0.013	0.126	0.036	0.138
A_8	0.013	0.000	0.004	0.013	0.008	0.004	0.004	0.015	0.081	0.080	0.200	0.107
A_9	0.013	0.016	0.013	0.018	0.021	0.003	0.001	0.012	0.108	0.090	0.221	0.101
A_{10}	0.007	0.016	0.000	0.004	0.000	0.002	0.004	0.009	0.162	0.015	0.308	0.022
A_{11}	0.010	0.028	0.008	0.007	0.018	0.002	0.002	0.016	0.038	0.114	0.036	0.116
A_{12}	0.002	0.038	0.012	0.008	0.002	0.001	0.004	0.015	0.061	0.097	0.145	0.138
A_{13}	0.004	0.051	0.027	0.005	0.007	0.003	0.003	0.003	0.000	0.126	0.000	0.155
A_{14}	0.002	0.062	0.036	0.003	0.006	0.000	0.000	0.000	0.049	0.126	0.018	0.161
A_{15}	0.003	0.056	0.027	0.004	0.013	0.000	0.001	0.003	0.007	0.126	0.000	0.159

The Fuzzy MABAC steps performed on the weighted matrix are shown in Table 8.

Table 8
Fuzzy MABAC

Alternative	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	*Sum*	*Rank*
A_1	0.006	-0.027	-0.009	0.000	-0.004	0.000	0.002	0.007	0.058	-0.063	0.087	-0.066	-0.009	8
A_2	0.002	-0.027	-0.008	-0.001	-0.007	0.001	0.001	0.002	0.071	-0.063	0.087	-0.066	-0.008	7
A_3	0.003	-0.021	-0.008	-0.006	0.001	0.000	-0.001	0.012	-0.077	0.031	-0.073	-0.010	-0.149	15
A_4	0.001	-0.009	-0.008	0.002	0.010	0.001	0.002	-0.006	0.058	-0.058	0.152	-0.015	0.130	2
A_5	-0.007	-0.009	0.003	-0.005	-0.004	0.002	0.001	-0.004	0.111	-0.078	0.196	-0.099	0.107	3
A_6	0.000	0.014	0.005	-0.002	-0.004	0.000	-0.002	0.009	-0.046	0.036	-0.109	0.054	-0.044	10
A_7	0.000	0.028	0.005	0.001	0.003	-0.002	-0.002	0.001	-0.064	0.048	-0.109	0.039	-0.051	11
A_8	0.006	-0.027	-0.009	0.006	-0.001	0.002	0.002	0.003	0.004	0.002	0.054	0.007	0.049	5
A_9	0.006	-0.011	0.000	0.012	0.012	0.001	-0.001	0.000	0.031	0.012	0.076	0.001	0.137	1
A_{10}	0.000	-0.011	-0.013	-0.003	-0.009	0.000	0.001	-0.003	0.085	-0.063	0.163	-0.077	0.070	4
A_{11}	0.002	0.001	-0.006	0.001	0.009	0.000	-0.001	0.004	-0.039	0.036	-0.109	0.016	-0.086	13
A_{12}	-0.005	0.011	-0.002	0.002	-0.007	-0.002	0.002	0.003	-0.016	0.019	0.000	0.039	0.043	6
A_{13}	-0.003	0.024	0.013	-0.001	-0.002	0.001	0.000	-0.009	-0.077	0.048	-0.145	0.056	-0.095	14
A_{14}	-0.005	0.035	0.023	-0.003	-0.003	-0.002	-0.003	-0.012	-0.028	0.048	-0.127	0.061	-0.014	9
A_{15}	-0.004	0.029	0.013	-0.002	0.004	-0.002	-0.002	-0.009	-0.070	0.048	-0.145	0.059	-0.081	12

The alternative ranking is shown in Table 9.

Table 9
Rank of alternatives

Alternatives	Rank
A_9: Industry, innovation and infrastructure	1
A_4: Quality education	2
A_5: Gender equality	3
A_{10}: Reduced inequalities	4
A_8: Decent work and economic growth	5
A_{12}: Responsible consumption and production	6
A_2: Zero hunger	7
A_1: No poverty	8
A_{14}: Life below water	9
A_6: Clean water and sanitation	10
A_7: Affordable and clean energy	11
A_{15}: Life on land	12
A_{11}: Sustainable cities and communities	13
A_{13}: Climate action	14
A_3: Good health and well-being	15

In the Fuzzy MABAC results, A_9 (Industry, innovation and infrastructure) was ranked first. The alternatives of A_4 (Quality education) and A_5 (Gender equality) emerged as significant contenders, ranking second and third respectively.

5. Results and conclusion

The concept of sustainable development emerged gradually as a result of growing concerns about the environmental and social consequences of economic growth. The negative environmental effects of economic growth, such as resource depletion, air pollution and loss of biodiversity; as well as the anti-social impacts of growth, such as increasing inequalities and health hazards, attracted increasing attention and ultimately led to the emergence of the concept of sustainable development. The concept was formally created in 1987 by the World Commission on

Environment and Development (WCED), commonly known as the Brundtland Report. The report defined sustainable development as: *"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* [59].

In 2015, a total of 17 goals to achieve all three dimensions (economic, social and environmental) of sustainable development have been identified by United Nations [60]. Achieving these goals requires complex decision-making processes that accounts for multiple criteria. Therefore, this paper uses Fuzzy MABAC and Fuzzy CoCoSo techniques to evaluate the importance of sustainable development goals for Türkiye. To this end, twelve criteria were identified to assess the relative importance of fifteen sustainable development goals in Türkiye. Although all SDG's are interconnected and achieving them all has a significant importance, especially for developing countries economic constraints such as lack of fiscal space or structural shocks emerges as significant barriers. Therefore, expert opinions were obtained to elaborate on which criteria should be prioritized. Afterwards, five independent expert assessments were collected to evaluate the SDG's against the specified criteria in linguistic terms. Next, the rank of alternatives, or SDG's, are obtained through Fuzzy MABAC technique. According to the results, A_9 (Industry, innovation and infrastructure), A_4 (Quality education) and A_5 (Gender equality) are emerged as top three goals to prioritize in Türkiye.

The first alternative to prioritize is industry, innovation and infrastructure. In economic development theory, industrialization and structural transformation are tightly interconnected concepts, often discussed together. Structural transformation refers to the long-term reallocation of economic activity from low-productivity sectors (typically agriculture and informal activities) toward higher-productivity sectors such as manufacturing and modern services. Industrialization is one of the central engines of this process. Innovation plays an essential role in achieving structural transformation by raising productivity, facilitating industrial upgrading, and improving institutional quality as well as human capital. Similarly, infrastructure also has a fundamental role in structural transformation, by reducing transaction costs, supporting technological advancement, and improving economic resilience and sustainability. When these three concepts (industry, innovation and infrastructure) are considered together, it is not surprising that this alternative ranks first in terms of sustainable development.

The second most important alternative is quality education. It is evident in the literature that investment to improve the education quality promotes growth and contributes to social well-being [61]. In addition, it is also shown that human capital also significantly improves environmental performance. Thus, education and human capital have a crucial role in reaching sustainable development goals.

The third-ranked alternative, gender equality, is closely linked to sustainable development goals. According to the findings of Dugarova [62] gender equality plays a fundamental role in the attainment of multiple sustainable development goals. Specifically, it is shown to be essential for fostering economic growth, improving labor productivity, diminishing poverty and strengthening human capital through better health and educational outcomes. Moreover, gender equality contributes to food security, enhances the capacity to cope with climate change–related challenges, and supports the development of more peaceful and inclusive societies.

This study ranked the Sustainable Development Goals in terms of their relative importance by incorporating expert opinions and applying various MCDM methods. While the findings suggest that certain goals, such as industry, innovation and infrastructure, quality education and gender equality, emerge as relatively more important within the adopted analytical framework, it is crucial to emphasize that all Sustainable Development Goals are significant and interdependent. The prioritization presented in this paper should therefore be interpreted as a reflection of expert-based assessments and methodological choices.

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Conflicts of Interest

The authors declare no conflicts of interest.

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