



Balancing Environmental Conservation and Economic Development in Mountain Regions: An MCDM Analysis of Türkiye's Eastern Black Sea

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Abstract. Mountainous regions often face geographical constraints, limited economic diversity, infrastructure deficiencies, and unequal access to markets and public services. In this context, policies aimed at promoting regional development are crucial. Türkiye's Eastern Black Sea region is well-suited for examining such a challenge. This study assumes that alternative regional development pathways can produce significantly different economic benefits and environmental costs. The aim of the study is to find the best sustainable development path using Multi-Criteria Decision Making (MCDM) techniques. Four alternative pathways are considered: conventional growth-oriented development, green economic transformation, nature-based regional development, and integrated climate-resilient development. Their performance was tested against twelve criteria grouped into four dimensions: economic and regional development, biodiversity and natural capital, climate and environmental sustainability, and landscape, cultural and social sustainability. The Logarithmic Additive Weighting Coefficient Estimation (LAAW) method was used to evaluate the criteria. The four sustainable development pathways identified using weighted criteria were ranked using the Q-rung Orthopair Fuzzy Set (q-ROFS)-based Complex Proportional Assessment (COPRAS) method. To test the validity and structural stability of the proposed decision support system, the findings were comparatively analyzed using q-ROFS-based Weighted Aggregated Sum Product Assessment (WASPAS) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods. The results were obtained as $A_4 > A_3 > A_2 > A_1$. Integrated Climate-Resilient Development was determined to be the most effective sustainable development strategy for Türkiye.

Keywords: Sustainability, Climate change, MCDM, q-ROFS, LAAW, Economic development

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1. Introduction

Mountain regions are socio-ecological systems in which economic development is particularly related to the availability and quality of natural resources (Booth, 1999). Existing forests, freshwater systems, and biodiversity affect the local livelihoods, land use, and culture while contributing to broader economic and social welfare (Fang and Ying, 2016). At the same time, mountainous regions are often challenged by geographical constraints, limited economic diversification, infrastructure deficiencies, and unequal access to markets and public services. In that respect, policies aimed at stimulating regional development have direct and indirect impacts on biodiversity, landscape, and social life. When economic growth policies put excessive pressure on ecosystems and natural resources, short-term development gains cost the loss of natural capital on which long-term prosperity depends (England, 2000; Jean et al., 2025).



This trade-off has become increasingly apparent under climate change. Mountain ecosystems are particularly sensitive to natural degradation caused by climate change (Bastien-Olvera et al., 2024). Economic activities, together with land-use transformations, exacerbate habitat fragmentation, deforestation, water-resource pressure, pollution, and landscape degradation. Consequently, sustainable development in mountainous regions requires development policies that reconcile economic, ecological, climatic, and social objectives (Miao et al., 2025).

Türkiye's Eastern Black Sea presents a highly relevant setting for examining such a challenge. The region is characterized by mountainous terrain, extensive forests, rich biodiversity, dense river networks, highlands, and traditional “yayla” culture (Somuncu, 2010). These environmental and cultural features shape the local livelihoods and economic activities. At the same time, the region has been experiencing a structural transformation with industrial and infrastructure investments, hydropower development, and rapidly growing tourism activities (Koçak and Şarkgüneşi, 2017). While contributing to economic growth with renewable energy production and income generation, inadequate environmental flows and associated construction in urban expansion adversely affect ecosystems, biodiversity, and landscapes (Capik et al., 2012; Somuncu, 2016).

Economic growth of the region interacts with significant environmental and climatic vulnerabilities. The Eastern Black Sea is Türkiye's wettest basin (Aksu, 2025). It is particularly subject to extreme floods, and climate projections reveal substantial changes in temperature and precipitation conditions in the near future (Nacar et al., 2024). Evidence indicates that anthropogenic land-use changes can increase landslide occurrence (Glade, 2003; Li et al., 2020), demonstrating that development policy choices and natural hazards cannot be considered independently (Hoang and Liou, 2024; Kelman, 2020; Klomp and Valckx, 2014). As a result, economic growth needs to be planned alongside biodiversity conservation, freshwater ecosystem protection, climate resilience, landscape integrity, and the preservation of traditional livelihoods (Mitra and Paul, 2025; Aşıcı, 2013; Dietz and Adger, 2003).

This study premises that alternative regional development pathways can generate significantly different economic benefits and environmental costs. Accordingly, the study hypothesizes that development strategies integrate economic transformation with biodiversity conservation and natural-capital protection. Moreover, climate resilience should be taken into account to balance regional development and environmental conservation rather than conventional growth-oriented approaches (Goswami et al., 2026). Formulating such a problem requires a framework capable of assessing alternative development pathways across multiple and conflicting constraints.

The aim of this study is therefore to evaluate alternative sustainable development pathways for Türkiye's Eastern Black Sea region through a multi-criteria decision-making (MCDM) framework. Four alternative pathways are considered: conventional growth-oriented development, green economic transformation, nature-based regional development, and integrated climate-resilient development. Their performance is tested for twelve criteria grouped under four dimensions: economic and regional development, biodiversity and natural capital, climate and environmental sustainability, and landscape, cultural and social sustainability. The objective of the study is to identify the economic and environmental trade-offs associated with development pathways, determine their relative performance across multiple criteria, and eventually identify the one that most balance contradicting environmental, social, and economic dimensions for long-term mountain development.

In this study, the Logarithmic Additive Estimation of Weight Coefficients (LAAW) method is used to evaluate the criteria. Four sustainable development paths, determined using weighted criteria, are ranked using the Q-Rung Orthopair Fuzzy Sets (q-ROFS)-based Complex Proportional Assessment (COPRAS) method.



The study aims to contribute to the design of development policies for environmentally sensitive mountain regions by bringing economic development and environmental conservation together within a decision framework. The Eastern Black Sea case illustrates this policy challenge confronted by mountain economies: economic growth is necessary for improving regional welfare, yet activities that deteriorate natural capital weaken the basis of sustainable economic prosperity.

The rest of the paper is organized as follows: Section 2 provides a detailed account of the literature studies conducted in this field. Section 3 defines the problem, identifies the criteria and alternatives. The criterion weighting and alternative ranking methods used in the study are explained in detail. Section 4 presents the application results step-by-step in tables. Section 5 is the discussion section. Finally, Section 6 presents the conclusions.

2. Literature Review

The relationship between economic development and environmental conservation has long been the focus of the sustainability literature. The issue becomes especially critical in mountain regions. Economic opportunities in these regions are constrained by geographical conditions, so economic development depends heavily on natural resources, ecosystems, and landscapes. The literature relevant to this problem can be organized around four topics: the growth and environment relationship, natural capital and biodiversity, the specific vulnerabilities of mountain economies, and the interaction of development pressures with climate and environmental risks.

2.1. Economic Growth, Natural Capital and Environmental Conservation

The relationship between economic growth and the environment has an extensive literature. Using cross-country panel data, Aşıcı (2013) demonstrates that economic growth can cause significant environmental pressures depending on the structure and characteristics of the growth process. Therefore, the major policy question is about how economic growth is achieved. In a more recent work, Goswami et al. (2026) similarly emphasize the multidimensional relationship between economic growth and climate change, showing that sustainability outcomes cannot be understood through income growth.

England (2000) argues that traditional economic growth theories may underestimate the role of natural capital in development and questions the substitutability of natural assets by produced capital. More recently, Jean et al. (2025) have revisited the relationship between natural capital and economic growth. They point to the importance of considering natural capital as a component of long-term economic capacity instead of treating environmental concerns as just a constraint to growth policies. Furthermore, climate change complicates this relationship because its effects on natural capital are uneven across countries and ecosystems. Bastien-Olvera et al. (2024) show that climate change has a significant role in the global value of natural capital, that are distributed unequally.

Biodiversity is an important component of natural capital. Dietz and Adger (2003) examine the relation between economic growth and biodiversity and demonstrate that economic growth does not necessarily generate sufficient incentives for biodiversity protection. The result is important especially for environmentally sensitive regions. While economic growth can provide resources for environmental protection, it also increases the stress on biodiversity.

2.2. Development Challenges Specific to Mountain Regions

Mountain economies differ from low-land regions due to accessibility constraints, dispersed settlements, vulnerable ecosystems, higher infrastructure costs, and strong dependence on locally available environmental resources. Booth (1999) examines economic development in the Mountain West. The study highlights the heterogeneous economic development within mountain territories caused by spatial characteristics of the regions. Similarly, Fang and Ying (2016) demonstrate variable levels and structures of economic development across mountainous regions in China. These studies suggest that economic



development in mountain regions cannot be approached through standard growth strategies. Geographical and ecological characteristics of the region should be incorporated into policies.

Miao et al. (2025) examine the priority implementation of Sustainable Development Goals in underdeveloped mountain regions. They emphasize the need to balance multiple development objectives rather than targeting economic, environmental, or social targets independently. Their perspective is closely related to the current study.

The Eastern Black Sea Mountains of Türkiye constitute a relevant case. Somuncu (2010) identifies sustainable development challenges in the region that result from the impacts of changing economic activities on distinctive ecological characteristics of the region. The region possesses environmental and cultural assets. However, expanding transportation networks, energy investments, tourism, settlement, and other economic activities have eroded natural capital.

Tourism illustrates this tension particularly clearly. There is a lot of evidence in the literature that mountain tourism can diversify regional economies, create employment, and provide markets for local goods and services (Gherdan et al., 2025). At the same time, rapid tourism development may result in rapid construction and landscape transformation, increased resource consumption, and the commercialization of cultural assets (Mouhou, 2025; Ali, 2023). Somuncu (2016) specifically examines the commercialization of cultural heritage associated with tourism in the Eastern Black Sea Mountains. Tourism-led development may harm the preservation of traditional mountain culture. More broadly, Mitra and Paul (2025) emphasize the need to balance tourism growth with cultural heritage conservation and environmental stability in mountain regions. Indeed, nature and culture may function as economic resources supporting tourism.

2.3. Energy, Water Resources and Environmental Externalities

Energy production represents another major component of the environment–growth dilemma in the Eastern Black Sea. Hydropower has a significant role in Türkiye's renewable energy strategy. The steep topography and dense river systems of the Eastern Black Sea provide a strong potential for hydropower development. Capik et al. (2012) demonstrate the economic and energy significance of small hydropower in the region. At a broader geographical scale, Koçak and Şarkgüneşi (2017) find an important relationship between renewable energy use and economic growth in Black Sea and Balkan countries.

However, hydropower comes with its local environmental costs. It contributes positively to low-carbon energy production while altering river flows, freshwater habitats, landscapes, and other ecosystem functions (Botelho, 2017). Industrial expansion, transport infrastructure, and intensive tourism may improve income, employment, and accessibility. However, they impose environmental costs through pollution, habitat fragmentation, land-use change, and pressure on water resources. The cumulative effects of such activities can be dramatic in mountain ecosystems because environmental disturbances can interact with existing physical vulnerabilities.

2.4. Climate Change, Land-Use Pressure and Disaster Resilience

Climate change adds a further dimension to this tension. Nacar et al. (2024) project changes in temperature and precipitation in the Eastern Black Sea. The future climatic conditions of Türkiye's wettest basin may shift the environmental constraints on development decisions. Therefore, development strategies need to be evaluated in terms of their capacity to remain consistent under changing climatic conditions.

Mountain regions are highly vulnerable to hydro-meteorological hazards such as floods and landslides. The literature increasingly shows that these hazards are not determined solely by natural conditions. Kelman (2020) emphasizes that disasters may emerge with human choices. Glade (2003) reveals the relationship between land-use change and landslide occurrence. Li et al. (2020) show how human activities influence the development of landslide susceptibility. Comparable evidence from mountainous regions indicates that anthropogenic activities can also increase flash-flood susceptibility (Hoang and Liou, 2024). At the



macroeconomic level, natural disasters also have direct economic consequences, although their magnitude and direction vary substantially across contexts and disaster types (Klomp and Valckx, 2014). Economic development and disaster resilience should not be treated as distinct policy areas. The form of development process can influence environmental risks.

2.5. Research Gap and Positioning of the Study

The existing literature provides evidence regarding individual dimensions of sustainable development in mountain regions. One strand examines the relationship between economic growth, environmental pressure, biodiversity, and natural capital (Aşıcı, 2013; Dietz and Adger, 2003; England, 2000). Another emphasizes the particular development conditions and sustainability challenges of mountainous regions (Booth, 1999; Fang and Ying, 2016; Miao et al., 2025). Meanwhile, the disaster and land-use literature demonstrates that development decisions can alter vulnerability to floods and landslides (Glade, 2003; Hoang and Liou, 2024; Li et al., 2020).

Economic growth, energy demand, tourism, biodiversity, climate change, landscape, and disaster resilience represent interconnected components of the same regional development problem. Yet, to the best of our knowledge, no previous study has evaluated these dimensions simultaneously within a common framework in order to compare alternative development pathways. Nevertheless, a development strategy performing favorably according to one objective may generate substantial costs under another. Hydropower may contribute to renewable energy production while affecting river ecosystems. Tourism activities may increase local income while increasing stress on landscape and cultural heritage. Industrial and infrastructure development may increase output and employment while generating pollution and habitat fragmentation.

The present study addresses this gap by conceptualizing sustainable development in the Eastern Black Sea as a multi-criteria regional decision problem. It compares four alternative development pathways: conventional growth-oriented development, green economic transformation, nature-based regional development, and integrated climate-resilient development. These alternative pathways are tested across economic, biodiversity and natural-capital, climate and environmental, and landscape, cultural and social dimensions. Such an integrated approach allows the trade-offs identified across the literature to be incorporated into a common analytical framework and provides a basis for identifying development strategies capable of balancing environmental conservation with long-term regional economic development.

3. The Method

3.1. Problem Definition

The decision problem is defined as the selection of a regional development pathway that balances economic development and environmental protection while keeping climate resilience and socio-cultural sustainability in Türkiye's Eastern Black Sea Mountain region. To address this problem, four alternative development pathways are evaluated using twelve criteria representing four sustainability dimensions.

The q-ROFS-based COPRAS method is used to effectively evaluate four sustainability dimensions: Conventional Growth-Oriented Development, Green Economic Transformation, Nature-Based Regional Development, and Integrated Climate-Resilient Development. The main objective of the study is to select the most effective development path in Türkiye in terms of sustainability dimensions.

3.2. Definition of Alternatives

The alternatives represent different development focuses rather than projects. In this way, industrial development, energy production, tourism, infrastructure, and nature-based activities are considered as



components of broader development pathways. Then, their economic and environmental trade-offs are assessed within a decision framework.

A₁ – Conventional Growth-Oriented Development: This pathway prioritizes economic output, industrial expansion, infrastructure investment, energy production, and tourism growth. Environmental protection is addressed through existing regulatory mechanisms rather than acting as a central focus on development. Such a strategy may generate substantial short-term economic benefits. However, economic expansion can also increase stress on environmental pressures (Aşıcı, 2013; Dietz and Adger, 2003).

A₂ – Green Economic Transformation: This pathway still takes economic development as a major regional objective while seeking to reduce its environmental intensity. It emphasizes cleaner industrial production, resource and energy efficiency, pollution control, environmentally responsible renewable energy development, greener infrastructure, and improved environmental standards. Environmental impacts are expected to be associated with investment and production decisions. It focuses on natural capital as a productive asset supporting long-term economic development (England, 2000; Jean et al., 2025).

A₃ – Nature-Based Regional Development: This pathway gives priority to economic activities that provide incentives for preserving the region's natural and cultural assets, such as sustainable agriculture and forestry. While restricting industrial, infrastructure, and energy development, local products, ecosystem-compatible livelihoods, ecotourism, and small-scale cultural and nature-based tourism is prioritized. (Mitra and Paul, 2025; Somuncu, 2016).

A₄ – Integrated Climate-Resilient Development: This pathway combines economic transformation, biodiversity and ecosystem conservation, sustainable tourism, and energy and climate-resilient infrastructure within an integrated regional strategy. This approach reflects the increasing emphasis on integrated sustainability priorities in underdeveloped mountain regions (Miao et al., 2025). It also recognizes the effects of climate change on natural capital (Bastien-Olvera et al., 2024).

3.3. Evaluation Criteria

The evaluation criteria are derived from the major challenges identified in the literature. To maintain a solid framework suitable for the regional decision problem, twelve criteria were organized under four dimensions: Economic and Regional Development; Biodiversity and Natural Capital; Climate and Environmental Sustainability; and Landscape, Cultural and Social Sustainability. The table below summarizes the criteria:

MC₁: Economic and Regional Development Dimension:

C₁ – Regional Economic Value Creation (max): Contribution to regional output and economic activity.

C₂ – Local Employment and Income Generation (max): Capacity to create local employment and generate income.

C₃ – Economic Diversification and Resilience (max): Capacity to diversify regional economic activities and reduce dependence on a limited number of sectors.

MC₂: Biodiversity and Natural Capital

C₄ – Biodiversity Conservation (max): Protection of species diversity and ecologically sensitive areas.

C₅ – Terrestrial Habitat and Ecosystem Integrity (max): Preservation of forests, mountain habitats, and ecological connectivity.

C₆ – Freshwater Ecosystem and Water Resource Protection (max): Protection of rivers and ecosystems.

MC₃: Climate and Environmental Sustainability



C₇ – Climate Change Mitigation (max): Contribution to low-carbon development and reduction of greenhouse-gas emissions.

C₈ – Climate and Disaster Resilience (max): Capacity to reduce vulnerability and increase resilience to climate change, floods, landslides, erosion, and extreme weather.

C₉ – Pollution and Environmental Pressure (min): Air, water, and soil pollution, waste generation, and other environmental burdens.

MC₄: Landscape, Cultural and Social Sustainability

C₁₀ – Landscape Integrity (max): Preservation of mountain landscapes and avoidance of physical and visual degradation.

C₁₁ – Cultural Heritage and Traditional Livelihood Preservation (max): Preservation of local cultural heritage, yayla culture, traditional practices, and livelihoods.

C₁₂ – Community Well-being and Social Acceptance (max): Contribution to local quality of life and compatibility with community interests and preferences.

These twelve criteria provide a multidimensional representation of the trade-off examined in this study. Sustainable development of mountainous regions requires simultaneous consideration of economic benefits, natural-capital preservation, climate and environmental resilience, and landscape and socio-cultural sustainability. The resulting four-alternative, twelve-criterion decision structure forms the basis for the subsequent MCDM analysis.

3.4. Analysis

Fuzzy set concepts were first introduced to the literature by Zadeh (1965). Some situations cannot be clearly expressed as 0 or 1, leading to the creation of fuzzy expressions (Mokhtarian, 2011). The application area of fuzzy logic is quite broad. In this study, it was used in the selection of Sustainable Development Plans. Twelve predetermined criteria were weighted using the Fuzzy LAAW algorithm. Four alternatives were ranked using the q-ROFS-based COPRAS method.

3.4.1. Logarithmic Additive Estimation of Weight Coefficients (LAAW)

LAAW is a novel methodology based on the logarithmic evaluation of the relationship between the criterion priority vector and the absolute anti-ideal point (Pamucar et al., 2021). One of the most important advantages of the LAAW method is that it does not become more complex as the number of criteria increases. It eliminates uncertainties arising from expert preferences (Deveci et al., 2021).

In this study, the Fuzzy LAAW algorithm was used to determine the criterion weights. The terms in Table 1 were used as fuzzy linguistic terms.

Table 1. Fuzzy linguistic scale for criteria evaluation.

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

Step 1. Determining the fuzzy priority vector.

The study includes k experts ($\Omega = \{\Omega_1, \Omega_2, \dots, \Omega_k\}$) who evaluate n criteria ($C = \{C_1, C_2, \dots, C_n\}$).

Experts evaluate the criteria by assigning Triangular Fuzzy Numbers (TFNs). The fuzzy priority vector assigned by the t . expert ($1 \leq t \leq k$) to the n . criterion is obtained as $\Upsilon^t = (\tilde{\theta}_1^t, \tilde{\theta}_2^t, \dots, \tilde{\theta}_n^t)$. An element in this vector is shown as $\tilde{\theta}_j^t = (\theta_j^{(l)t}, \theta_j^{(m)t}, \theta_j^{(u)t})$.

Step 2. Defining the Absolute Anti-Ideal Point ($\tilde{\xi}_{AIP}$)

Absolute Anti-Ideal Point is explained by Eq. (1).

$$\tilde{\xi}_{AIP} < \min(\tilde{\theta}_j^t, \tilde{\theta}_j^t, \dots, \tilde{\theta}_j^t) \quad (1)$$

Step 3. Calculation of the combined fuzzy relation vector.

To bring together the assessments of all experts under a single framework, a combined fuzzy priority vector $\Upsilon = (\tilde{\theta}_1, \tilde{\theta}_2, \dots, \tilde{\theta}_n)$ was calculated using the Bonferroni function in Eq. (2).

$$\tilde{\theta}_j = (\theta_j^{(l)}, \theta_j^{(m)}, \theta_j^{(u)}) = \left(\left(\frac{1}{k(k-1)} \sum_{x=1}^k (\theta_j^{(l)(x)})^{\alpha_1} \sum_{y=1, y \neq x}^k (\theta_j^{(l)(y)})^{\alpha_2} \right)^{\frac{1}{\alpha_1 + \alpha_2}}, \left(\frac{1}{k(k-1)} \sum_{x=1}^k (\theta_j^{(m)(x)})^{\alpha_1} \sum_{y=1, y \neq x}^k (\theta_j^{(m)(y)})^{\alpha_2} \right)^{\frac{1}{\alpha_1 + \alpha_2}}, \left(\frac{1}{k(k-1)} \sum_{x=1}^k (\theta_j^{(u)(x)})^{\alpha_1} \sum_{y=1, y \neq x}^k (\theta_j^{(u)(y)})^{\alpha_2} \right)^{\frac{1}{\alpha_1 + \alpha_2}} \right) \quad (2)$$

Here, $\alpha_1, \alpha_2 \geq 0$ represent the stabilization parameters of the Bonferroni function, and k represents the total number of experts. Using the $\tilde{\xi}_{AIP}$ values, the fuzzy relation vector $A = (\tilde{\gamma}_1, \tilde{\gamma}_2, \dots, \tilde{\gamma}_j)$ is obtained as Eq. (3).

$$\tilde{\gamma}_j = \frac{\tilde{\theta}_j}{\tilde{\xi}_{AIP}} = \left(\frac{\theta_j^{(l)}}{\xi_{AIP}^{(l)}}, \frac{\theta_j^{(m)}}{\xi_{AIP}^{(m)}}, \frac{\theta_j^{(u)}}{\xi_{AIP}^{(u)}} \right) \quad (3)$$

This process calculates the fuzzy relation vector $A = (\tilde{\gamma}_1, \tilde{\gamma}_2, \dots, \tilde{\gamma}_j)$

Step 4. Determining the Weighting Coefficient Vectors ($\tilde{w}_j$)

Eq. (4) is used to find the final weighting coefficients of the criteria.



$$\tilde{w}_j = \frac{\ln(\tilde{\gamma}_j)}{\ln(\tilde{b})} = \left(\frac{\ln(\gamma_j^{(l)})}{\ln(b^{(u)})}, \frac{\ln(\gamma_j^{(m)})}{\ln(b^{(m)})}, \frac{\ln(\gamma_j^{(u)})}{\ln(b^{(l)})} \right) \quad (4)$$

Here, the value of $\tilde{b}$ is calculated by multiplying all the calculated $\tilde{\gamma}_j$ elements in Eq. (5).

$$\tilde{b} = \prod_{j=1}^n \tilde{\gamma}_j = \left(\prod_{j=1}^n \gamma_j^{(l)}, \prod_{j=1}^n \gamma_j^{(m)}, \prod_{j=1}^n \gamma_j^{(u)} \right) \quad (5)$$

The resulting weighting coefficients must satisfy the condition $\sum_{j=1}^n w_j = 1$. Finally, the fuzzy values were defuzzified so that the criteria could be ranked as Eq. (6).

$$def(w_j) = \left(w_j^{(l)} + 4 \cdot w_j^{(m)} + w_j^{(u)} \right) / 6 \quad (6)$$

3.4.2. Q-Rung Orthopair Fuzzy Set-based COPRAS Method

In 2017, Yager defined q-ROFS by extending Pythagorean fuzzy numbers (PFS) with intuitionistic fuzzy numbers (IFS). IFS's, PFS's, and q-ROFS methods are advantageous over classical fuzzy sets because they examine membership and non-membership cases together. Furthermore, q-level fuzzy numbers are considered superior to IFS and PFS numbers in modeling uncertainty because they define this relationship with the q -th parameter (Zhu et al., 2022).

In Eq. (7), x represents an element in the universal set, $\mu_A(x)$ indicates the degree to which the element is a member of the set, and $\nu_A(x)$ indicates the degree to which it is not a member. The values of $\mu_A(x)$ and $\nu_A(x)$ must be in the range of 0-1 (Yager, 2017).

$$A = \{x, \mu_A(x), \nu_A(x) | x \in X\} \quad (7)$$

In Eq. (8), the sum of the q degrees of membership and non-membership is 1 or less than 1. This reveals the uncertainty value in Eq. (9). If it is not equal to 1, an uncertainty condition arises (Yager, 2017).

$$(\mu_A(x))^q + (\nu_A(x))^q \leq 1 \quad (8)$$

$$\pi_A(x) = \left(1 - (\mu_A(x))^q - (\nu_A(x))^q \right)^{1/q} \quad (9)$$

q-ROFS, an effective method for modeling uncertain data, offer a much larger uncertainty definition space compared to intuitionistic fuzzy number (IFS) and Pythagorean fuzzy number (PFS) fuzzy sets as the q parameter increases (Zhu et al., 2022).

In this study, the q-ROFS-based COPRAS method was used to rank the alternatives.

Step 1. Selection of experts and determination of their importance weights.

The set of alternatives in the solution space is defined as $X = \{X_1, X_2, \dots, X_n\}$ and the set of criteria is defined as $Z = \{Z_1, Z_2, \dots, Z_n\}$. q-ROFS numbers $M_g = [m_g(a), \gamma_g(a), \tau_g(a)]$ are used to calculate the importance weights of the decision-makers as. Eq. (10) is used to determine the importance weights of the decision-makers.

$$\Omega_g = \frac{1 + m_g^q - \gamma_g^q}{\sum_{g=1}^p (1 + m_g^q - \gamma_g^q)} \quad (10)$$



Table 2 presents the linguistic terms used.

Table 2. Linguistic terms (Pinar, 2022).

Linguistic terms	Abbreviations	η	γ
Extremely high	EH	0.95	0.15
Very high	VH	0.85	0.25
High	H	0.75	0.35
Medium high	MH	0.65	0.45
Medium	M	0.55	0.55
Medium low	ML	0.45	0.65
Low	L	0.35	0.75
Very low	VL	0.25	0.85
Extremely low	EL	0.15	0.95

Step 2. Creating a combined decision matrix and weighting the criteria.

The importance weights of the criteria (φ_j) Eq. (11) is obtained.

$$\varphi_j = \frac{\sum_{g=1}^p \Omega_g (1 + m_{jg}^q - \gamma_{jg}^q)}{\sum_{j=1}^s \sum_{g=1}^p \Omega_g (1 + m_{jg}^q - \gamma_{jg}^q)} \quad (11)$$

Step 3. Weighted decision matrix.

The combined decision matrix is multiplied by the criterion weights in Eq. (12) to obtain the weighted decision matrix.

$$\varphi_g \theta_1 = \left\langle \left(1 - \left(1 - m_{ij}^q\right)^{\varphi_g}\right)^{\frac{1}{q}}, \gamma_{Ai}^{\varphi_g} \right\rangle, \tau_{Ai}(a_j) = \left(1 - m_{Ai}^q(a_j) - \gamma_{Ai}^q(a_j)\right)^{1/q} \quad (12)$$

The elements of the newly obtained matrix are q-ROFS numbers in the format $r'_{ij} = [m_{Ai\varphi}(a_j), \gamma_{Ai\varphi}(a_j), \tau_{Ai\varphi}(a_j)]$.

Step 4. Calculating Maximization and Minimization Indices.

The utility criteria are summed to obtain the P_i values Eq. (13):

$$P_i = \sum_{j=1}^g r'_{ij}^+, \quad i = 1, 2, 3, \dots, z \quad (13)$$

The cost criteria are then summed to form the R_i values Eq (14):

$$R_i = \sum_{j=g+1}^s r'_{ij}^-, \quad i = 1, 2, 3, \dots, z \quad (14)$$

These collected q-ROFS values were defuzzified with the score function in Eq. (15) to convert them into comparable net numbers.

$$S(A) = \frac{1 + m(a)^q - \gamma(a)^q}{2} \quad (15)$$

Step 5. Calculating the relative importance of the alternatives and finally ranking them.

The relative importance (Q_i) of each alternative is formulated by Eq. (16) using the defuzzified benefit and cost indices.



$$Q_i = P_i + \frac{R_{min} \sum_{j=1}^Z R_i}{R_i \sum_{j=1}^Z \frac{R_{min}}{R_i}} \quad (16)$$

Finally, these relative importance values are ratioed to the maximum Q value, and the utility values of the alternatives (N_i) are calculated as percentages via Eq. (17).

$$N_i = \left(\frac{Q_j}{Q_{max}} \right) * 100 \quad (17)$$

They are ranked according to their N_i values (Guliyev et al., 2025).

4. Experimental Results

4.1. Application of the Fuzzy LAAW method

As the first step of the application, the criteria were evaluated by 3 experts of equal importance. The evaluation results are given in Table 3.

Table 3. Expert evaluations.

Type	Criteria List		Expert 1	Expert 2	Expert 3
-	MC ₁	Economic and Regional Development Dimension	H	MH	VH
-	MC ₂	Biodiversity and Natural Capital	VH	VH	H
-	MC ₃	Climate and Environmental Sustainability	VH	H	VH
-	MC ₄	Landscape, Cultural and Social Sustainability	H	VH	H
Benefit	C ₁₁	Regional Economic Value Creation	H	MH	H
Benefit	C ₁₂	Local Employment and Income Generation	H	H	MH
Benefit	C ₁₃	Economic Diversification and Resilience	MH	H	H
Benefit	C ₂₁	Biodiversity Conservation	VH	VH	H
Benefit	C ₂₂	Terrestrial Habitat and Ecosystem Integrity	VH	H	VH
Benefit	C ₂₃	Freshwater Ecosystem and Water Resource Protection	VH	VH	VH
Benefit	C ₃₁	Climate Change Mitigation	H	H	VH
Benefit	C ₃₂	Climate and Disaster Resilience	VH	VH	VH
Cost	C ₃₃	Pollution and Environmental Pressure	H	VH	H
Benefit	C ₄₁	Landscape Integrity	H	H	MH
Benefit	C ₄₂	Cultural Heritage and Traditional Livelihood Preservation	MH	VH	H
Benefit	C ₄₃	Community Well-being and Social Acceptance	H	H	MH

Table 4 presents these converted to fuzzy numbers

Table 4. Blurred expert assessments.



Type	Criteria List	Expert 1	Expert 2	Expert 3
	MC ₁ Economic and Regional Development Dimension	(6,7,8)	(5,6,7)	(7,8,9)
	MC ₂ Biodiversity and Natural Capital	(7,8,9)	(7,8,9)	(6,7,8)
	MC ₃ Climate and Environmental Sustainability	(7,8,9)	(6,7,8)	(7,8,9)
	MC ₄ Landscape, Cultural and Social Sustainability	(6,7,8)	(7,8,9)	(6,7,8)
Benefit	C ₁₁ Regional Economic Value Creation	(6,7,8)	(5,6,7)	(6,7,8)
Benefit	C ₁₂ Local Employment and Income Generation	(6,7,8)	(6,7,8)	(5,6,7)
Benefit	C ₁₃ Economic Diversification and Resilience	(5,6,7)	(6,7,8)	(6,7,8)
Benefit	C ₂₁ Biodiversity Conservation	(7,8,9)	(7,8,9)	(6,7,8)
Benefit	C ₂₂ Terrestrial Habitat and Ecosystem Integrity	(7,8,9)	(6,7,8)	(7,8,9)
Benefit	C ₂₃ Freshwater Ecosystem and Water Resource Protection	(7,8,9)	(7,8,9)	(7,8,9)
Benefit	C ₃₁ Climate Change Mitigation	(6,7,8)	(6,7,8)	(7,8,9)
Benefit	C ₃₂ Climate and Disaster Resilience	(7,8,9)	(7,8,9)	(7,8,9)
Cost	C ₃₃ Pollution and Environmental Pressure	(6,7,8)	(7,8,9)	(6,7,8)
Benefit	C ₄₁ Landscape Integrity	(6,7,8)	(6,7,8)	(5,6,7)
Benefit	C ₄₂ Cultural Heritage and Traditional Livelihood Preservation	(5,6,7)	(7,8,9)	(6,7,8)
Benefit	C ₄₃ Community Well-being and Social Acceptance	(6,7,8)	(6,7,8)	(5,6,7)

The average of the criteria evaluated by three experts was taken and combined. The combined expert scores are given in Table 5.

Table 5. Combined expert assessments

Criteria	L	M	U
MC ₁	6	7	8
MC ₂	6.666667	7.666667	8.666667
MC ₃	6.666667	7.666667	8.666667
MC ₄	6.333333	7.333333	8.333333
C ₁₁	5.666667	6.666667	7.666667
C ₁₂	5.666667	6.666667	7.666667
C ₁₃	5.666667	6.666667	7.666667
C ₂₁	6.666667	7.666667	8.666667
C ₂₂	6.666667	7.666667	8.666667
C ₂₃	7	8	9
C ₃₁	6.333333	7.333333	8.333333
C ₃₂	7	8	9
C ₃₃	6.333333	7.333333	8.333333
C ₄₁	5.666667	6.666667	7.666667
C ₄₂	6	7	8
C ₄₃	5.666667	6.666667	7.666667

The absolute anti-ideal point values were determined as 4.7, 4.8, and 4.9, respectively. The expert evaluations were divided by the ξ_{AIP} values, and the combined relationship vector was calculated in Table 6.



Table 6. Combined relation vector.

Criteria	L	M	U
MC ₁	1.224490	1.458333	1.702128
MC ₂	1.360544	1.597222	1.843972
MC ₃	1.360544	1.597222	1.843972
MC ₄	1.292517	1.527778	1.773050
C ₁₁	1.156463	1.388889	1.631206
C ₁₂	1.156463	1.388889	1.631206
C ₁₃	1.156463	1.388889	1.631206
C ₂₁	1.360544	1.597222	1.843972
C ₂₂	1.360544	1.597222	1.843972
C ₂₃	1.428571	1.666667	1.914894
C ₃₁	1.292517	1.527778	1.773050
C ₃₂	1.428571	1.666667	1.914894
C ₃₃	1.292517	1.527778	1.773050
C ₄₁	1.156463	1.388889	1.631206
C ₄₂	1.224490	1.458333	1.702128
C ₄₃	1.156463	1.388889	1.631206

The final weighting coefficients for the criteria have been calculated and are presented in Table 7.

Table 7. Final weighting coefficients.

Criteria	L	M	U	Def local	L	M	U	Def global
MC ₁	0.086979	0.21713	0.494824	0.041828				
MC ₂	0.132229	0.269484	0.56929	0.05132				
MC ₃	0.132229	0.269484	0.56929	0.05132				
MC ₄	0.1102	0.243902	0.532802	0.046681				
C ₁₁	0.099026	0.333333	1.122041	0.073669	0.008613	0.072377	0.555213	0.087401
C ₁₂	0.099026	0.333333	1.122041	0.073669	0.008613	0.072377	0.555213	0.087401
C ₁₃	0.099026	0.333333	1.122041	0.073669	0.008613	0.072377	0.555213	0.087401
C ₂₁	0.164336	0.323532	0.629261	0.06021	0.02173	0.087187	0.358232	0.074637
C ₂₂	0.164336	0.323532	0.629261	0.06021	0.02173	0.087187	0.358232	0.074637
C ₂₃	0.190378	0.352937	0.668071	0.065473	0.025174	0.095111	0.380326	0.080499
C ₃₁	0.142943	0.311983	0.658385	0.059101	0.018901	0.084074	0.374812	0.07477
C ₃₂	0.198698	0.376035	0.74686	0.07065	0.026274	0.101335	0.42518	0.087756
C ₃₃	0.142943	0.311983	0.658385	0.059101	0.018901	0.084074	0.374812	0.07477
C ₄₁	0.096236	0.317609	0.992019	0.068025	0.010605	0.077466	0.52855	0.086959
C ₄₂	0.134076	0.364781	1.078302	0.077047	0.014775	0.088971	0.574522	0.096809
C ₄₃	0.096236	0.317609	0.992019	0.068025	0.010605	0.077466	0.52855	0.086959

The weights of the last 12 criteria are provided in Table 8.

Table 8. Weights of the criteria.

Type	Criteria	Weight
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Benefit	C ₁₁	0.087401
Benefit	C ₁₂	0.087401
Benefit	C ₁₃	0.087401
Benefit	C ₂₁	0.074637
Benefit	C ₂₂	0.074637
Benefit	C ₂₃	0.080499
Benefit	C ₃₁	0.074770
Benefit	C ₃₂	0.087756
Cost	C ₃₃	0.074770
Benefit	C ₄₁	0.086959
Benefit	C ₄₂	0.096809
Benefit	C ₄₃	0.086959

4.2. Application of the q-ROFS Based COPRAS Method

The experts' alternative assessments are reported in Table 9.

Table 9. Evaluation of alternatives.

Exper t 1	Alternative List	C ₁₁	C ₁	C ₁₃	C ₂	C ₂	C ₂	C ₃₁	C ₃₂	C ₃₃	C ₄	C ₄₂	C ₄₃
			2		1	2	3				1		
A ₁	Conventional Growth-Oriented Development	VH	V	H	L	L	V	M	L	EH	L	M	M
A ₂	Green Economic Transformation	H	H	VH	H	H	H	VH	H	M	H	H	H
A ₃	Nature-Based Regional Development	M	H	H	E	E	E	H	H	VL	E	EH	V
A ₄	Integrated Climate-Resilient Development	VH	V	EH	V	V	V	EH	EH	L	V	V	EH
			H		H	H	H				H	H	

Exper t 2	Alternative List	C ₁₁	C ₁	C ₁₃	C ₂	C ₂	C ₂	C ₃₁	C ₃₂	C ₃₃	C ₄	C ₄₂	C ₄₃
			1		1	2	3				1		
A ₁	Conventional Growth-Oriented Development	EH	V	H	V	L	L	M	M	EH	V	L	M
A ₂	Green Economic Transformation	VH	H	VH	H	V	H	EH	V	M	H	H	V
A ₃	Nature-Based Regional Development	M	V	H	E	E	V	M	V	VL	E	EH	EH
A ₄	Integrated Climate-Resilient Development	VH	E	EH	V	E	E	VH	EH	L	V	V	EH
			H		H	H	H				H	H	

Exper t 3	Alternative List	C ₁₁	C ₁	C ₁₃	C ₂	C ₂	C ₂	C ₃₁	C ₃₂	C ₃₃	C ₄	C ₄₂	C ₄₃
			2		1	2	3				1		
A ₁	Conventional Growth-Oriented Development	VH	H	M	L	V	V	M	L	V	L	M	M
A ₂	Green Economic Transformation	H	V	H	V	H	V	VH	H	L	H	V	H
A ₃	Nature-Based Regional Development	M	H	VH	E	V	E	H	V	EL	E	EH	V
A ₄	Integrated Climate-Resilient Development	EH	V	VH	V	E	V	EH	EH	VL	V	EH	EH
			H		H	H	H				H		

The q parameter was determined as in Eq. (3). The combined decision matrix is given in Table 10.



Table 10. Combined decision matrix.

Criteria	A ₁ η	A ₁ γ	A ₂ η	A ₂ γ	A ₃ η	A ₃ γ	A ₄ η	A ₄ γ
C ₁₁	0.897555	0.210858	0.790919	0.312866	0.588815	0.514414	0.897555	0.210858
C ₁₂	0.8235	0.279672	0.790919	0.312866	0.790919	0.312866	0.897555	0.210858
C ₁₃	0.722055	0.380583	0.8235	0.279672	0.790919	0.312866	0.928806	0.177845
C ₂₁	0.323569	0.781953	0.790919	0.312866	0.95	0.15	0.85	0.25
C ₂₂	0.323569	0.781953	0.790919	0.312866	0.928806	0.177845	0.928806	0.177845
C ₂₃	0.291594	0.815267	0.790919	0.312866	0.928806	0.177845	0.897555	0.210858
C ₃₁	0.489006	0.614794	0.897555	0.210858	0.722055	0.380583	0.928806	0.177845
C ₃₂	0.389819	0.715065	0.790919	0.312866	0.8235	0.279672	0.95	0.15
C ₃₃	0.928806	0.177845	0.422312	0.681757	0.2261	0.882105	0.323569	0.781953
C ₄₁	0.323569	0.781953	0.75	0.35	0.95	0.15	0.85	0.25
C ₄₂	0.422312	0.681757	0.790919	0.312866	0.95	0.15	0.897555	0.210858
C ₄₃	0.521723	0.581495	0.790919	0.312866	0.897555	0.210858	0.95	0.15

The weighted decision matrix is presented in Table 11.

Table 11. Weighted decision matrix.

Criteria	A ₁ η	A ₁ γ	A ₂ η	A ₂ γ	A ₃ η	A ₃ γ	A ₄ η	A ₄ γ
C ₁₁	0.473494	0.872803	0.386922	0.903429	0.270347	0.943558	0.473494	0.872803
C ₁₂	0.41007	0.894616	0.386922	0.903429	0.386922	0.903429	0.473494	0.872803
C ₁₃	0.34325	0.919033	0.41007	0.894616	0.386922	0.903429	0.508781	0.85991
C ₂₁	0.136957	0.98181	0.367615	0.916928	0.513357	0.867972	0.409374	0.901704
C ₂₂	0.136957	0.98181	0.367615	0.916928	0.484325	0.879074	0.484325	0.879074
C ₂₃	0.126389	0.983693	0.376749	0.910703	0.495919	0.87022	0.461355	0.88223
C ₃₁	0.209954	0.96428	0.450683	0.890133	0.326169	0.930315	0.484595	0.878872
C ₃₂	0.174836	0.970997	0.387429	0.903056	0.410604	0.894211	0.539585	0.846637
C ₃₃	0.484595	0.878872	0.18006	0.971763	0.095423	0.990664	0.137039	0.981778
C ₄₁	0.144104	0.978839	0.359683	0.912752	0.538081	0.847918	0.429934	0.886432
C ₄₂	0.196195	0.963593	0.39991	0.893606	0.555948	0.83222	0.488941	0.860114
C ₄₃	0.236516	0.953949	0.386287	0.903893	0.472738	0.873403	0.538081	0.847918

Table 12 reports the calculated maximization and minimization indices. The relative importance levels and final ranking values are given in Table 13.

Table 12. Max-Min index.

Alternative	P_i	R_i
A ₁	0.873240329	0.21747217

A ₂	1.75668224	0.044089331
A ₃	2.18209237	0.014307485
A ₄	2.477265901	0.028125353

Table 13. Relative importance levels and final ranking.

Alternative	Q_i	N_i	Rank
A ₁	0.88377204	34.53988936	4
A ₂	1.80863027	70.68552365	3
A ₃	2.342173186	91.53763535	2
A ₄	2.558699684	100	1

4.3. Comparative Analysis

The q-ROFS-based COPRAS method was compared with the q-ROFS-based WASPAS and q-ROFS-based TOPSIS methods. A comparison table is presented in Table 14. The ranking of the alternatives in all methods was found to be A₄, A₃, A₂, and A₁.

Table 14. Comparative analysis.

Alternatives/Methods	q-ROF COPRAS		q-ROF WASPAS		q-ROF TOPSIS	
	N_i	Rank	CC	Rank	WASPAS Score	Rank
A ₁	34.53989	4	0.167048651	4	0.10093465	4
A ₂	70.68552	3	0.609882471	3	0.46123916	3
A ₃	91.53764	2	0.737378153	2	0.57266237	2
A ₄	100	1	0.844240689	1	0.71104371	1

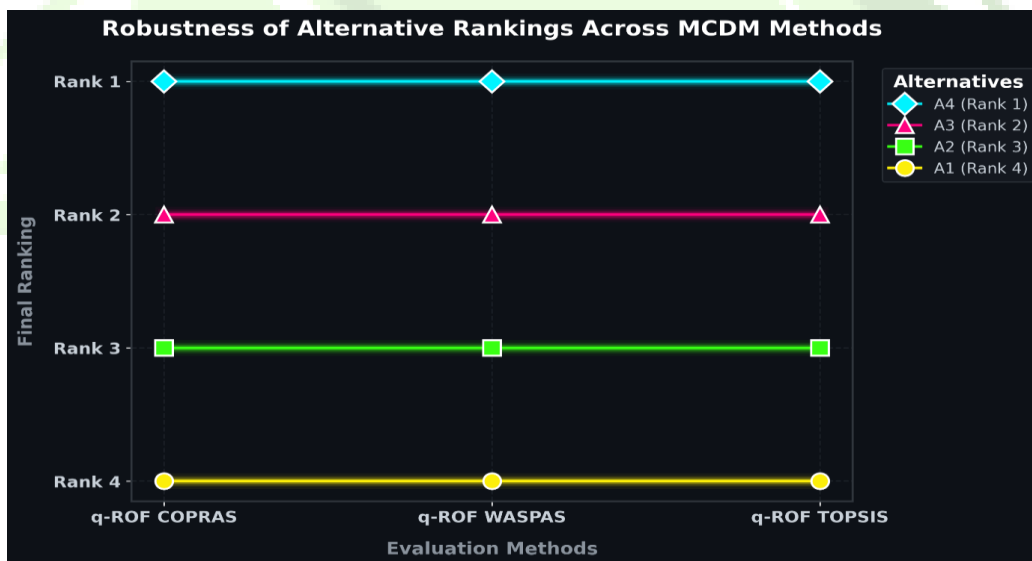


Figure 1. Robustness of alternative rankings.

When the methods are compared, the change in ranking for all methods is shown in Figure 1.

5. Discussion



The findings of this study highlight the advantages of the proposed q-ROFS-based method in addressing complex decision-making problems under uncertainty. As a generalization of IFS and PFS, q-ROFSs provide a flexible structure for representing uncertainty by simultaneously considering membership and non-membership degrees. The Fuzzy LAAW method, employed for criterion weighting, is particularly advantageous in problems involving a large number of criteria, as it requires relatively few comparisons. In addition, its fuzzy structure enables variations in expert judgments to be represented more effectively.

A comparative analysis was conducted to assess the stability of the proposed method based on the alternative rankings obtained using the q-ROFS-based COPRAS method. The q-ROFS-based WASPAS and q-ROFS-based TOPSIS methods were employed for comparison. The identical rankings obtained across these methods supported the stability and robustness of the proposed approach.

The ranking of the alternatives was obtained as $A_4 > A_3 > A_2 > A_1$. Accordingly, Integrated Climate-Resilient Development (A_4) was identified as the most effective sustainable development strategy for the Eastern Black Sea Region of Türkiye.

6. Conclusion

This study aimed to identify the most suitable sustainable development pathway for the Eastern Black Sea Region of Türkiye. The alternatives were defined as conventional growth-oriented development, green economic transformation, nature-based regional development, and integrated climate-resilient development. The Fuzzy LAAW method was employed to determine the criterion weights due to its relatively simple structure and limited comparison requirements. To account for uncertainty in expert evaluations, q-ROFS were integrated with the COPRAS method to rank the alternatives.

First, four main criteria and twelve sub-criteria identified through a literature review were evaluated by three experts. The ranking obtained using the q-ROFS-based COPRAS method was $A_4 > A_3 > A_2 > A_1$. Accordingly, integrated climate-resilient development was identified as the most suitable sustainable development strategy among the considered alternatives.

The results were further compared with those obtained using q-ROFS-based WASPAS and q-ROFS-based TOPSIS, and the same ranking was observed across all methods. Future studies may address the same decision problem using different fuzzy set extensions and MCDM methods to examine the consistency of the results. In addition, the proposed framework may be applied to other regions to evaluate its broader applicability.

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