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Measuring environmental performance of turkic republics with multicriteria decision making methods

Türki cumhuriyetlerinin çevresel performansının çok kriterli karar verme yöntemleriyle ölçülmesi

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Measuring Environmental Performance of Turkic Republics With Multicriteria Decision Making Methods

Highlights

- *Multi-criteria methods reveal discrepancies in Turkic states' environmental rankings.*
- *Türkiye outperforms its EPI ranking using advanced decision-making techniques.*
- *Regional cooperation is key to improving environmental sustainability strategies.*

Graphical Abstract

In this study, the performance ranking of countries in environmental performance measurement was made by using multiple criteria weighting and ranking methods. The flowchart of the study is shown in Figure 1.

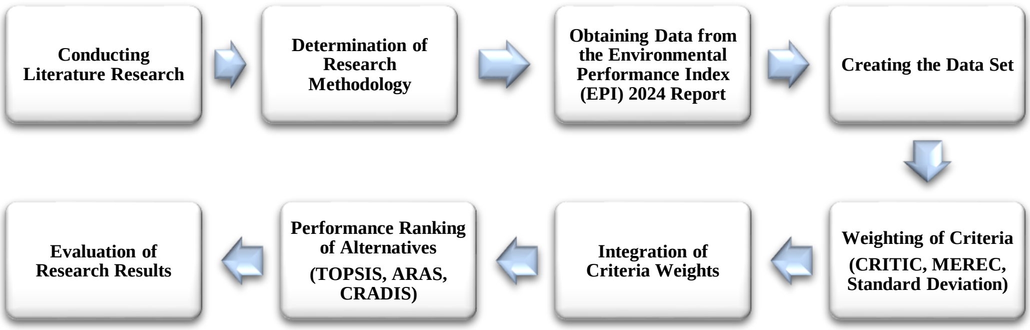

Figure. Application Flowchart

Aim

The aim of this study is to measure the environmental performance of the Turkic Republics in the EPI 2024 report with objective methods and to redo the ranking of the countries.

Design & Methodology

In the study, three different weighting methods (CRITIC, MEREC, STD) were used to weight the criteria. Then, the arithmetic means of the obtained criterion weights were taken, and the performance rankings of the countries were re-calculated using three different ranking methods (TOPSIS, ARAS, CRADIS) with the integrated weight values.

Originality

In this study, more comprehensive and consistent results are obtained by using more than one weighting and ranking method together.

Findings

As a result of the performance ranking, Turkey ranked 6th in the EPI 2024 report, 1st in the TOPSIS ranking, 4th in the ARAS ranking, and 4th in the CRADIS ranking.

Conclusion

As a result of the analysis, it was determined that the findings obtained from different ranking methods differed according to the rankings in the EPI 2024 report.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Measuring Environmental Performance of Turkic Republics With Multicriteria Decision Making Methods

Araştırma Makalesi / Research Article

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ABSTRACT

This study reassesses the environmental performance of the Turkic Republics using the 2024 Environmental Performance Index (EPI) data with Multi-Criteria Decision Making (MCDM) methods. CRITIC, Standard Deviation and MEREC methods are used to determine the criteria weights, followed by TOPSIS, ARAS and CRADIS methods to rank the countries. The results reveal certain deviations from the traditional EPI ranking, indicating that Türkiye performed better under the multi-criteria decision-making (MCDM) methods. While Kazakhstan and Uzbekistan generally exhibited the strongest overall performance, Azerbaijan and Kyrgyzstan ranked lower. Despite having the lowest performance in the EPI ranking, Türkiye secured the top position under the TOPSIS method. The study underscores the necessity for more comprehensive analyses to support countries in enhancing their environmental sustainability policies and highlights the potential significance of regional cooperation. Notably, water resources emerged as one of the most critical determinants of environmental performance. The findings suggest that traditional rankings may have certain limitations, whereas MCDM methods provide a more balanced and holistic framework for decision-making. In this context, it is recommended that regional structures such as the Organization of Turkic States enhance environmental cooperation to make sustainability policies more effective.

Keywords: Environment, Environmental Performance, EPI, MCDM

Türki Cumhuriyetlerinin Çevresel Performansının Çok Kriterli Karar Verme Yöntemleri ile Ölçülmesi

ÖZ

Bu çalışma, Türk Cumhuriyetlerinin çevresel performansını 2024 Çevresel Performans Endeksi (EPI) verileri kullanılarak Çok Kriterli Karar Verme (ÇKKV) yöntemleriyle yeniden değerlendirmektedir. Kriter ağırlıklarının belirlenmesinde CRITIC, Standart Sapma ve MEREC yöntemleri kullanılmış; ardından ülkelerin sıralanması için TOPSIS, ARAS ve CRADIS yöntemleri uygulanmıştır. Sonuçlar, geleneksel EPI sıralamasıyla bazı farklılıklar göstererek Türkiye'nin ÇKKV yöntemleri altında daha iyi bir performans sergilediğini ortaya koymaktadır. Kazakistan ve Özbekistan genel olarak en yüksek performansı gösterirken, Azerbaycan ve Kırgızistan daha düşük sıralarda yer almıştır. Türkiye, EPI sıralamasında en düşük performansa sahip olmasına rağmen, TOPSIS yöntemine göre birinci sırada yer almıştır. Çalışma, ülkelerin çevresel sürdürülebilirlik politikalarını geliştirmeleri için daha kapsamlı analizlere ihtiyaç duyduklarını ve bölgesel iş birliğinin potansiyel önemini vurgulamaktadır. Özellikle su kaynakları, çevresel performansın en kritik belirleyicilerinden biri olarak öne çıkmıştır. Bulgular, geleneksel sıralamaların belirli sınırlılıklar taşıyabileceğini, buna karşın ÇKKV yöntemlerinin karar alma süreçlerine daha dengeli ve bütüncül bir çerçeve sunduğunu göstermektedir. Bu bağlamda, Türk Devletleri Teşkilatı gibi bölgesel yapıların çevresel iş birliğini artırarak sürdürülebilirlik politikalarını daha etkin hale getirmeleri önerilmektedir.

Anahtar Kelimeler: Çevre, Çevresel Performans, EPI, ÇKKV

1. INTRODUCTION

The quality of life of societies is closely related to environmental structures. Accordingly, environmental quality has a significant impact on people's quality of life. Because uncontrolled and unconscious utilization of the environment can cause global warming and climate change, which can cause problems in many areas such as health, agriculture, water and sanitation [1]. Globalization has also caused many environmental problems. The depletion of natural resources, extinction of plant and animal species, deterioration of the ecological system and climate change are among the most important of these [2]. Moreover, increasingly visible evidence shows that environmental degradation poses challenges to human health and well-being, national and international security and political legitimacy, in short, to the stability of a country. The development of technology and the economic structure of countries, population growth and changes in people's lifestyles suggest that these challenges will only increase

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for future generations. Accordingly, countries' approaches and policies on the environment can affect both economic and vital factors globally [3].

With the increase in environmental problems, it has become necessary to take serious measures to prevent these problems. In this direction, studies have been carried out on the basis of states for the protection of the environment. It is accepted that the first important step taken to solve environmental problems globally was the United Nations Habitat 1 conference held in Sweden in 1972. Subsequently, conferences and studies on the causes of environmental problems, especially global warming, and how they can be prevented have been carried out until today [4-6].

Due to the rapid increase in environmental problems, many measurement tools and reports have emerged to evaluate these problems on a country basis. The Environmental Performance Index (EPI) is one of the most reliable and comprehensive reports measuring the environmental performance of countries. The first report was first published in 2000 under the leadership of Yale University. Later, reports analyzing the environmental performance of countries were published again in 2001, 2002 and 2005. Since 2006, it has been published regularly every two years [4].

The EPI is a comprehensive measure that assesses countries' achievements in environmental sustainability and ecosystem health. Yale University conducted an assessment covering 180 countries in 2024. The index is structured around three main policy goals: environmental health (25%), ecosystem vitality (45%) and climate change (30%). Under these goals, there are 11 categories and 40 performance indicators. The EPI rates countries' performance using a scale from 0 to 100, with higher scores indicating better environmental performance [7-8].

The aim of this research is to re-rank and evaluate the environmental performance of the Turkic Republics (Turkey, Azerbaijan, Kazakhstan, Uzbekistan, Kyrgyzstan, Turkmenistan, Turkmenistan, Uzbekistan and Kyrgyzstan) in terms of criteria superiority according to the international EPI data for the period 2024. The main motivation behind the selection of Turkic Republics in the research is to identify the reasons behind the low performance of Turkic States in terms of environmental performance in various reports, especially EPI. CRITIC, STD and MEREC methods from Multi-Criteria Decision Making (MCDM) methods were used for weighting the criteria and TOPSIS, ARAS and CRADIS techniques were used for ranking the performance of alternatives. Accordingly, the study analyzed 9 sub-criteria under 3 main criteria according to EPI. Since only Turkey's data is available for the Fisheries criterion and only Turkey and Azerbaijan's data is available for the Forestry criterion, these two criteria were excluded from the study. In the conclusion part of the study, the environmental performances of Turkey and other Turkic Republics are compared and country performances are evaluated in terms of criteria.

2. LITERATURE REVIEW

Environmental sustainability is one of the biggest challenges facing today's societies. Industrialization, rapid urbanization, depletion of natural resources and the increase in chemical wastes are factors that severely affect environmental performance and limit societies' access to reliable water, air, soil and food resources [9-12]. This situation makes it imperative to take important steps to protect the world's ecosystems and human health. Therefore, analyzing environmental performance is of great importance.

The Environmental Performance Index (EPI), as a basic tool for measuring environmental sustainability and performance, compares countries on indicators such as environmental health and ecosystem vitality. There are many academic studies in the literature on how the EPI assesses environmental performance and how this index is used [13-17]. These studies reveal the effects of different factors such as environmental sustainability, economic growth, globalization, governance and politics on the EPI.

Ünal and Polat emphasized that economic growth improves environmental performance in OECD countries, but foreign investments, urbanization, population growth and trade have negative effects [18]. On the other hand, Tunçarslan examined the differences in the environmental policies of BRICS countries and stated that these countries have achieved certain success in renewable energy and climate policies [19]. Karaman evaluated Türkiye 's environmental performance in the context of the EU harmonization process and discussed the impact of geographical location on environmental damage [4]. Savaş emphasized the need to increase environmental awareness in Türkiye [20], Adeel-Farooq et al. stated that economic growth and urbanization negatively affect environmental performance in ASEAN countries [21]. Fu et al. identified how international sanctions negatively affect environmental performance [22], while Wendling et al. identified the strong impact of good governance on environmental performance [8]. These studies reveal that multiple factors affecting environmental performance influence each other and that the strategies of each region and country towards environmental sustainability differ.

Savaş emphasized that environmental performance in Türkiye is particularly associated with consumption habits and the importance of raising environmental awareness and developing sustainable consumption habits [20]. Mortezazadeh et al. associate climate change performance in Iran with GHG production and GDP and state that Iran should take measures to reduce greenhouse gas emissions [23]. Boleti et al. examined the impact of economic complexity on environmental performance and stated that economic complexity improves environmental performance but has negative effects on air quality [24].

Rey and Ozymy investigated the impact of electoral rules on environmental performance in 20 democratic countries in Latin America and found that representation has a greater impact on ecosystem vitality than on public health [25]. Halkos and Zisiadou compare Greece's environmental performance with Mediterranean and Northern European countries and find that life expectancy has a strong impact on environmental performance, while population density has a lower impact [26]. Morse examined the relationship between environmental performance and income and income inequality, and found that income levels are associated with environmental health but not with ecosystem vitality [27]. Koziuk et al. classified countries by linking welfare levels with environmental indicators and emphasized the impact of environmental status criteria on this classification [28]. Bucher examined the relationship between the Environmental Performance Index (EPI) and two main criteria measuring environmental health and ecosystem vitality and found that independent variables such as health index, environmental sustainability, innovations and human development index have significant effects on the EPI [29]. Hsu and Zomer emphasized that the EPI aims to move environmental policies towards data and evidence-based action and advocated its use as a tool for comparing and monitoring environmental performance at the international level [30]. Shahabadi et al. examined the factors affecting environmental performance in OPEC countries and stated that governance index, internet users and abundance of natural resources have positive effects on environmental performance, while openness and per capita carbon dioxide emissions have negative effects [31]. Thomakos and Alexopoulos examined the relationship between carbon intensity and EPI, found that carbon intensity is an important explanatory factor in EPI rankings and stated that developed countries should take environmental measures [32]. De Leo and Miglietta examined the contributions of ecological footprint and water footprint to the environmental performance index, and stated that water resources are not sufficiently taken into account in environmental sustainability indices and that ecological footprint shows a positive relationship with EPI [33]. Hsu et al. examined the inequalities in environmental targets and the factors explaining these inequalities using 2012 Environmental Performance Index data and showed that progress on these targets is uneven across countries, regions and issues [34]. These studies reveal that the EPI is an important tool for assessing the combination of multifaceted factors affecting environmental performance and can play a fundamental role in the development of environmental policies.

Multi-Criteria Decision Making (MCDM) methods are widely used in environmental performance assessments and provide powerful tools for ranking alternatives based on multiple criteria. In this context, several studies have assessed the sustainability levels of countries and regions by applying different MCDM techniques in environmental performance analysis. For example, Marković et al. used the MOORA (Multi-Objective Optimization on the basis of Ratio Analysis) method to evaluate the agri-environmental performance of the European Union countries and determined the environmental ranking of the countries with this multi criteria decision-making technique. The MOORA method brings a comprehensive approach to environmental performance analysis by optimizing alternatives in line with different objectives [35]. Similarly, Gökgöz and Yalçın used a combination of three different CRITIC, TOPSIS and COPRAS methods to analyze the renewable energy performance of EU countries [36]. These methods aimed to obtain more reliable results by utilizing the combined power of different ranking methods when analyzing environmental impact performance. Eşiyok et al. used the EDAS (Evaluation based on Distance from Average Solution) ranking method together with Entropy and CRITIC weighting methods to evaluate the environmental performance of G7 countries and Türkiye, and also conducted sensitivity analysis and examined the effects of criteria weights on performance rankings [37]. This study emphasized the effects of changing criteria weights on ranking results and highlighted the sensitivity of methodologies used in environmental performance assessments. Örtlek et al. used the ARAS (Additive Ratio Assessment) method by calculating the criteria weights with the Entropy method to evaluate the environmental performance in the Level-2 Region and made the regional ranking [38]. In this study, the combination of Entropy and ARAS methods allowed for a more in-depth analysis of environmental performance. Another Türkiye-specific study was conducted by Öztürk who used the Gray Relational Analysis (GRA) method to assess Türkiye's green growth capacity. The GIA method evaluates the technological performance of Türkiye's industrial zones and examines the potential for achieving green growth targets [39]. Baležentis et al. examined the environmental performance of Lithuanian economic sectors using Data Envelopment Analysis (DEA) and the Hicks-Moorsteen index [40]. Ayçin and Çakın on the other hand, determined criterion weights with the Entropy method to measure environmental performance and then ranked environmental performance by combining Gray Relational Analysis (GRA) and MOORA methods [41]. This multiple approach provided more robust and accurate results by considering environmental factors from multiple perspectives. Pinar examined the sensitivity of subjective weights assigned to environmental performance indicators and conducted scenario analyses on EPI (Environmental Performance Index) data [42]. This study revealed that subjective variables can lead to significant changes in environmental performance rankings and demonstrated the sensitivity of environmental performance measurement. Finally, Khanova et al. included the EPI to measure environmental sustainability, using multiple indices to assess the sustainable development of EU countries and Ukraine [43].

Akandere analyzed the environmental performance of Belt and Road countries using Entropy and TOPSIS methods [44]. In this study, the identification of high-performing countries (Portugal, Italy) and low-performing countries (China, India) shows that indices such as EPI are a powerful tool for analyzing performance differences between countries. Altıntaş analyzed the environmental performance of G20 countries and identified water resources as the most important environmental performance criterion [45]. The evaluation of the environmental performance of Southeast Asian countries with the Fuzzy TOPSIS method by Abdullah reveals that the combination of EPI with different multi-criteria decision-making methods will allow for a more comprehensive analysis of environmental performance [46]. The selection of Malaysia as the country with the best environmental performance shows that EPI can increase the accuracy of the results with different methods in environmental performance rankings. It was observed that EPI was used to rank environmental performance in relation to CODAS and TOPSIS methods used by Altıntaş to evaluate the environmental performance of G7 countries. The TOPSIS method was found to have a higher explanatory power [45]. This further reinforces the use of EPI in environmental performance analysis based on multi-criteria decision-making (MCDM) methods. Özkan and Özcan [6] and Özkan Aksu and Temel Gencer [47] evaluated the environmental performance of OECD countries using Data Envelopment Analysis (DEA). Both studies revealed that Türkiye's environmental performance is low and needs to be improved. Such studies emphasize that EPI is an effective tool for environmental performance analysis, but further analysis is needed to identify improvement needs, especially in low-performing countries.

Senir determined the importance of the criteria with the Entropy method and evaluated the environmental sustainability performance of Eastern European countries using COPRAS and WASPAS methods. The study found that the WASPAS method yielded more consistent results and revealed that this method can be used as a powerful analysis tool for environmental sustainability [48]. Akandere and Zerenler found that ecosystem services were the highest valued criterion and ecosystem vitality was the lowest valued criterion in the evaluation made with the CRITIC method [49]. This study shows that the CRITIC method is a reliable tool in environmental performance analysis and Romania is the country with the highest performance. Doğan analyzed Türkiye's environmental performance using both CCPI and EPI indices and found that Türkiye's environmental performance is low [50]. This suggests that the EPI offers a more data-driven approach to assessing environmental performance, but may lead to underperformance in some countries.

The studies conducted in the literature within the scope of EPI with MCDM methods show how important a tool it is in environmental performance measurement and that combining different methods gives more accurate and comprehensive results. When the studies are examined, it is generally seen that only one method is used in criteria weighting and performance ranking is made based on this method. Unlike other studies, this study is a holistic study based on more than one criterion weighting method and more than one performance ranking technique.

3. MATERIAL and METHOD

In the methodology section of the study, firstly, information about the index used in the study is given. Then, the steps of the weighting methods used and the steps of the methods used for performance ranking are shown in tables. Finally, the dataset used in the study is presented in a table.

3.1. Environmental Performance Index (EPI-2024)

With the increase in efforts towards sustainable development, the concept of environmental performance has started to be emphasized by environmental experts and policy makers. Although quantitative methods for measuring environmental performance have developed relatively late, they have been increasingly used in recent years. Various indices have been developed to assess the environmental impact of academia, companies and governments. Among these, metrics such as Ecological Footprint, Green GDP, Environmental Sustainability Index and Environmental Performance Index (EPI) stand out [18], [51].

The EPI is one of the most comprehensive tools measuring environmental performance and was developed by Yale and Columbia Universities in the 2000s. The index allows countries to analyze and compare their environmental performance and environmental policies [7]. The EPI is calculated with data from international organizations and reliable scientific sources and helps identify areas for improvement in environmental policies [52]. The EPI allows countries to regularly monitor their environmental performance and identify their strengths and weaknesses. In this way, it becomes possible for them to make informed decisions on environmental policies and develop strategies towards sustainability goals. Environmental performance measurement helps countries to identify their ecological competencies and shortcomings, while at the same time contributing to more effective environmental policies by raising environmental awareness. Thus, countries can develop appropriate methods to strengthen environmental sustainability and address existing environmental problems [7]. Within the scope of the index, countries are evaluated according to certain criteria previously established. For each criterion, countries are ranked according to their performance. Since its inception, the criteria and indicators of the EPI have changed over the years [8].

EPI 2024 assesses countries' achievements in environmental sustainability under three main criteria: climate change, environmental health and ecosystem vitality. The climate change criterion covers the climate change mitigation sub-criterion, while the environmental health criterion includes sub-criteria that directly affect human health, such as air quality, sanitation and drinking water, heavy metals and solid waste. The ecosystem vitality criterion examines the protection of the natural environment under sub-criteria such as water resources, agriculture, fisheries, air pollution, forests and biodiversity & habitat. EPI measures the environmental performance of countries and comparatively reveals their progress towards sustainable development goals [7].

3.2. Methods Used for Weighting Criteria

Evaluating a decision problem with multiple criteria and alternatives requires multi-criteria decision-making methods [53]. Three different objective methods, namely CRITIC, Standard Deviation and MEREC, were used to determine the weight values of the 9 criteria used in the research. What is valid for all methods is to first create the decision matrix. Then, normalization is performed and different calculation stages start to occur. CRITIC method calculation stages can be explained in 4 steps [54], [55].

Table 1. Steps of the CRITIC method

Steps	Equations	Explanations
1	$r_{ij} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}}$	In the first step, the decision matrix is subjected to normalization to eliminate anomalies.
2	$p_{ik} = \frac{\sum_{i=1}^{m}(r_{ij}-r_j)(r_{ik}-r_k)}{\sqrt{\sum_{i=1}^{m}(r_{ij}-r_j)^2 \sum_{i=1}^{m}(r_{ij}-r_k)^2}}$	In this step, correlation analysis is applied to determine the relationship between the criteria.
3	$c_j = \sigma_j \sum_{k=1}^{n}(1 - p_{jk})$	In this step, the total amount of information contained in each criterion (c_j) is calculated. In this process, the standard deviation (σ_j) of the normalized decision matrix column values is used.
4	$w_j = c_j / \sum_{k}^{n} c_k$	In the last step of the CRITIC method, the weight value of each criterion is found according to the equation shown.

The MEREC method is a method based on the absolute value of the total performance within the scope of the criteria to remove the leverage effect. The MEREC method can be explained in 4 steps [56].

Table 2. Steps of the MEREC method

Steps	Equations	Explanations
1	$S_i = ln\left(1 + \left(\frac{1}{m}\sum_{j}\lvert ln(N_{ij})\rvert\right)\right)$	In the first step, a non-linear logarithmic function operation is applied to find the overall performance of the alternatives.
2	$S'_{ij} = ln\left(1 + \left(\frac{1}{m}\sum_{k,k\neq j}\lvert ln(N_{ij})\rvert\right)\right)$	Measuring performance by removing each criterion.
3	$E_j = \sum_{i}\lvert S'_{ij} - S_i\rvert$	Absolute value calculation is applied to find the removal effects of each criterion.
4	$w_j = \frac{E_j}{\sum k}$	Final weight values are calculated for each criterion.

Standard Deviation, which is an easy and reliable criterion weighting method, is based on squaring the difference between previously created datasets and average values and finally calculating the square root of the average variance. The standard deviation method can be explained in 2 steps MCDM [57]:

Using the three methods mentioned above, the weight calculations of the 9 criteria defined within the scope of the EPI 2024 report were made separately and shown in the findings section.

Table 3. Steps of the standard deviation method

Steps	Equations	Explanations
1	$\sigma_j = \sqrt{\frac{(N_{ij} - N_j)^2}{m}}$	The standard deviation of the criteria is calculated over the normalized values from the decision matrix.
2	$\boldsymbol{w_j} = \frac{\boldsymbol{\sigma_j}}{\sum_{i=1}^{n} \boldsymbol{\sigma_j}}$	Final weights are calculated for the values with standard deviation.

3.3. Methods Used for Performance Rankings

TOPSIS is an effective and common method based on ranking by determining the ideal decision point and negative ideal decision point according to the decision matrix values in the data set [58], [59]. Additive Ratio Assesment (ARAS) method is presented as a new approach to make the right decisions in multi-criteria decision processes. It can be modelled integrated with fuzzy logic and gray theory. The ARAS method consists of 4 steps [60]:

Table 4. Steps of the TOPSIS method

Steps	Equations	Explanations
1	$r_{ij} \frac{x_{ij}}{\sqrt{\sum_{k=1}^{m} x_{kj}^2}}$	First, the decision matrix is normalized with the help of the equation shown.
2	$v_{ij} = w_i r_{ij}, i = 1,2, \dots .m; j = 1,2, \dots .n$ $\sum_{j=1}^{n} w_j = 1$	In this step, the normalized decision matrix is weighted by the weight values of each criterion to obtain a weighted normalized matrix.
3	$A^* = \{(\max x_i\, v_{ij}/j \in J), (min_i v_{ij}/j \in J')\}\ (i = 1,2,3, \dots m)$ $A^* = \{v_1^*, v_2^*, v_3^*, \dots . v_j^*, \dots . v_n^*\}\ (i = 1,2,3, \dots m)$ $A^- = \{(\min x_i\, v_{ij}/j \in J), (\max x_i\, v_{ij}/j \in J')\}\ (i = 1,2,3, \dots m)$ $A^- = \{v_1^-, v_2^-, v_3^-, \dots . v_j^-, \dots . v_n^-\}\ (i = 1,2,3, \dots m)$	In the next step, positive and negative ideal values are determined.
4	$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} v_j^*)^2}, i = 1,2, \dots \dots, m$ $S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} v_j^-)^2}, i = 1,2, \dots \dots, m$	In the fourth step, distance values are calculated.
5	$C_i^* = \frac{S_i^-}{(S_i^* + S_i^-)}, 0 < C_i^* < 1, \quad i = 1,2,3, \dots, m$	In the last step, ranking values are calculated within the scope of alternatives.

Table 5. Steps of the ARAS method

Steps	Equations	Explanations
1	$\partial_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}}$ (1) $x_{ij}^* = \frac{1}{x_{ij}}$ (2) $\partial_{ij} = \frac{x_{ij}^*}{\sum_{i=0}^{m} x_{ij}^*}$ (3)	First, the decision matrix is normalized. In the ARAS method, the normalization process differs according to the benefit and cost situations. If higher criterion performance values are considered better (benefit case), the normalized values are first calculated with formula (1). If lower performance values are considered to be better (cost case), then a two-step process is required. Performance values are converted into benefits using equation (2) and normalization is performed using equation (3).
2	$W_{ij} = \partial_{ij}. w_{ij}$	In the second step, weighted normalized values are obtained by using the normalized values with the formula shown.
3	$S_i = \sum_{j=1}^{n} W_{ij} \quad i = 0,1, \dots, m$	In this step the alternatives are evaluated. First, the optimality function value is calculated for each alternative.
4	$K_i = \frac{Si}{S_0}, \quad i = 0,1, \dots, m$	Finally, the rankings of the alternatives are calculated according to the optimality values obtained in the previous step.

The CRADIS method is a very new MCDM method that has been created by taking the advantageous features of more than one MCDM method and its basic idea is to rank alternatives according to ideal and anti-ideal solutions and deviation from optimal solutions. Table 6 shows the steps of the CRADIS method [61]:

Table 6. Steps of the CRADIS method

Steps	Equations	Explanations
1	$n_{ij} = \frac{x_{ij}}{x_j^{max}}, F$ (1) $n_{ij} = \frac{x_j^{min}}{x_{ij}}, F$ (2)	Similar to the ARAS method, the normalization process in the CRADIS method varies according to the benefit or cost status. If normalization is to be made according to the benefit feature, equation (1) should be used and if normalization is to be made according to the cost feature, equation (2) should be used.
2	$v_{ij} = n_{ij}.w_j$	The normalized matrix values are multiplied by the weight values of the relevant criterion to obtain a weighted normalized matrix.
3	$t_i = maxv_{ij}, t_{ai} = minv_{ij}$	In this step, the largest value "v_{ij}" in the decision matrix is determined. Thus, the ideal solution is found. Similarly, the anti-ideal solution is found by finding the smallest "v_{ij}" value in the weighted decision matrix.
4	$d^+ = t_i - v_{ij}, d^- = v_{ij} - t_{ai}$	In this step, deviation values are calculated from ideal and anti-ideal solutions.
5	$s_i^+ = \sum_{j=1}^{n} d^+, s_i^- = \sum_{j}^{n} d^-$	In this step, the degree of deviation of individual alternatives from ideal and anti-ideal solutions is obtained.
6	$K_i^+ = \frac{S_0^+}{S_i^+}, K_i^- = \frac{S_i^-}{S_0^-}$	The utility function is calculated for each alternative in relation to the deviations from the optimal alternatives.
7	$Q_i = \frac{K_i^+ + K_i^-}{2}$	Finally, the final ranking is calculated using Eq.

The performance rankings of the 6 Turkic Republics within the scope of EPI 2024 were calculated using the above-mentioned MCDM methods and analyzed with the help of tables and figures under the title of findings.

3.4. Data Set Related to the Research

In the 2024 report of the Environmental Performance Index, there are 3 main criteria and 11 sub-criteria. However, since only Türkiye has data for the "fisheries" criterion in the index and similarly, forests criterion has data only for Türkiye and Azerbaijan, these criteria were not used in the performance evaluation. By using the 9 criteria included in the EPI 2024 report in country ranking calculations with MCDM methods, criteria-based performances of countries can be calculated more precisely and more realistic and detailed performance evaluations can be made. For this reason, it is thought that comparing the performances of 6 Turkic states in terms of criteria will reveal more useful results. In this direction, firstly, the weights of the criteria were determined by CRITIC, MEREC and STD methods, and then the arithmetic averages of the weight values were taken. With the new weight values obtained, TOPSIS, ARAS and CRADIS methods were used to analyze the performance ranking of the countries. The decision matrix to be used for weighting and ranking is presented in Table 7.

Table 7. Data Set of the study (EPI 2024)

Country/Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
Kazakhstan	42,3	44,5	73,1	58,6	30,8	32,6	44,7	61,7	50
Uzbekistan	37,5	27,5	71,5	44,3	28,7	62,2	57,4	49,2	44,4
Kyrgyzstan	45,4	30,6	59,4	43,1	14,8	22,7	51,9	77,3	36,5
Turkmenistan	29,6	54,1	58,5	41,9	48,7	39,2	48,1	43,5	39,5
Azerbaijan	34,7	38,2	48,2	46,8	21,6	28,9	63	67	36,9
Türkiye	37	34,8	63,7	52,2	29,7	69,1	59,2	50	20,1

As seen in Table 7, the climate change mitigation sub-criterion of the climate change criterion is indicated with the code C1. For the environmental health criterion, air quality sub-criterion C2, sanitation and drinking water sub-criterion C3, heavy metals sub-criterion C4 and finally solid waste sub-criterion C5. For the ecosystem vitality criterion, water resources sub-criterion C6, agriculture sub-criterion C7, air pollution sub-criterion C8 and finally biodiversity & habitat sub-criterion C9.

4. FINDINGS

In the findings section, firstly, the weight values for each criterion were calculated separately through CRITIC, STD and MEREC methods. Then, the arithmetic average of the three different weight values was taken to obtain the weight values to be used in performance ranking. Finally, TOPSIS, ARAS and CRADIS methods were used to rank the performance of the Turkic republics.

4.1. Weighting of Criteria with Different Weighting Methods

Hybrid approaches to weighting have gained more acceptance in recent years as they increase reliability by reducing dependency on a single method [62]. Accordingly, this study presents an approach that integrates information from different perspectives by using CRITIC, STD and MEREC methods together to determine criteria weights. CRITIC and MEREC methods offer great advantages, especially in data-driven, objective and analytical decision processes. While CRITIC evaluates information content and correlation, MEREC performs a more functional analysis by measuring the impact of each criterion when removed from the system. Used together, they can provide powerful weighting that is both information content and performance-oriented. Another reason why CRITIC, STD and MEREC methods are preferred for weighting is that these three methods can perform weighting without perceiving zero or very close to zero values in the matrix as errors [36], [49], [50], [63].

Separate weighting calculations of the environmental performance criteria with CRITIC, STD and MEREC methods were made step by step through Microsoft Excel package program and the results obtained are shown in Table 8 below.

Table 8. Weight values for EPI criteria for 2024

	C1	C2	C3	C4	C5	C6	C7	C8	C9
CRITIC	0,103	0,116	0,094	0,098	0,105	0,124	0,138	0,126	0,096
STD	0,118	0,108	0,120	0,117	0,097	0,097	0,120	0,111	0,111
MEREC	0,081	0,118	0,083	0,072	0,153	0,179	0,073	0,109	0,133

As seen in Table 8, the highest weight value for criterion C1 belongs to STD method with 0.118, the highest weight value for criterion C2 belongs to MEREC method with 0.118, the highest weight value for criterion C3 belongs to STD method with 0.120, the highest weight value for criterion C4 belongs to STD method with 0.117, the highest weight value for criterion C5 belongs to MEREC method with 0.153. The highest weight value for criterion C6 belongs to MEREC method with 0.179, the highest weight value for criterion C7 belongs to CRITIC method with 0.138, the highest weight value for criterion C8 belongs to CIRITIC method with 0.126 and finally the highest weight value for criterion C9 belongs to MEREC method with 0.133.

In addition, as a result of the analysis with three methods, it is seen that the highest weight value for the CRITIC method belongs to the C7 criterion with 0.138 and the lowest weight value belongs to the C3 criterion with 0.094. For the STD method, the highest weight value belongs to criteria C3 and C7 with 0.12 and the lowest weight value belongs to criteria C5 and C6 with 0.97. Finally, for the MEREC method, the highest weight value belongs to criterion C6 with 0.179 and the lowest weight value belongs to criterion C4 with 0.072.

The visualization of the results obtained from the different weighting techniques used to calculate the criteria weights is presented in Figure 1.

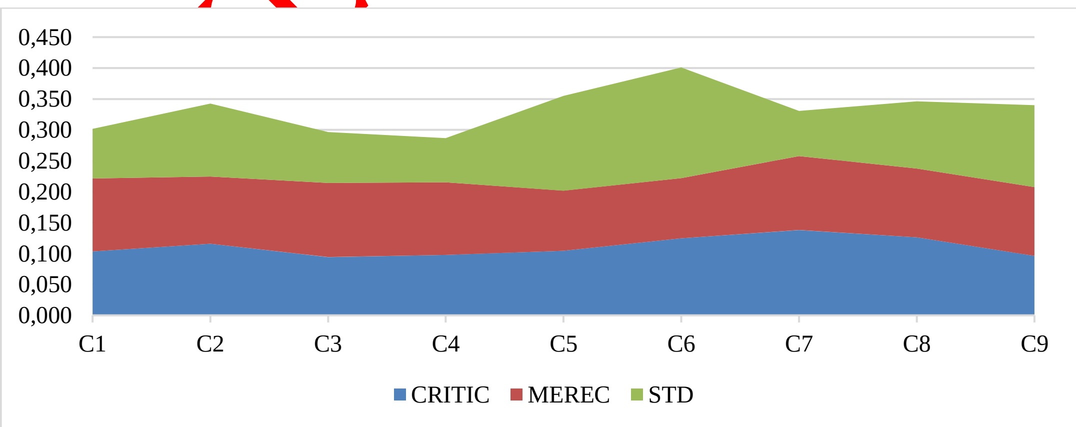

Figure 1. Graph for Comparison of Criteria Weights Calculated by Three Different Methods

Figure 1 shows the distribution of differences between the 9 criteria of the environmental performance index under 3 different methods (CRITIC, Standard Deviation and MEREC). According to the results of the analysis, the most significant difference between the criteria (C6) is observed in the water resources criterion. The findings obtained for other criteria are also shown in the figure.

Before taking the arithmetic averages of the criteria, the weight findings were subjected to a sensitivity test within the scope of each weight method in order to increase the reliability of the study. Accordingly, Spearman correlation analysis method was utilized and the findings are shown in Table 9 below.

Table 9. Spearman Correlation analysis findings

WEIGHT METHODS	CRITIC	MEREC	STD
CRITIC	1	-0,219	0,083
MEREC	-0,219	1	-0,836
STD	0,083	-0,836	1

According to the correlation analyses shown in Table 9, there is no relationship between CRITIC and MEREC (r= -0.219 p= 0.571). Likewise, there is no significant relationship between CRITIC and STD (r= -0.083 p= 0.831). There is a very strong negative relationship between MEREC and STD (r= -0.836 p= 0.005). Thus, within the scope of the findings obtained, it has been determined that there is a great consistency between the criteria weights according to the methods.

4.2. Taking the Arithmetic Mean of Weight Values

While a single weighting method is generally preferred in the literature, taking the arithmetic average of the outputs of the three methods in this study will provide a more balanced weighting of the criterion importance levels. Accordingly, the weighting values obtained were converted into general weight values by taking arithmetic averages based on the studies in the literature [64-67]. The results of the arithmetic averaged weight values are visualized and shown in Figure 2 below.

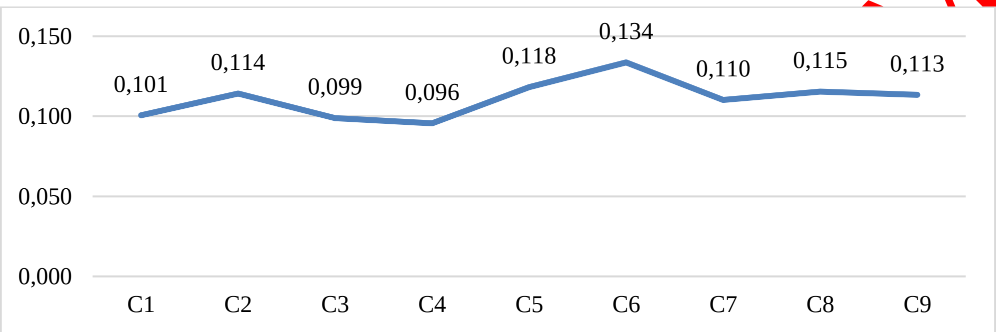

Figure 2. Weight values obtained as a result of arithmetic mean

Figure 2 shows the weight values generated by averaging CRITIC, Standard Deviation and MEREC methods for nine criteria (C1-C9). This weight distribution shows a relatively balanced structure among the criteria, although some criteria have a more dominant influence on the decision process. In particular, criterion C6 has the highest weight of 0.134, indicating that the impact of this criterion on countries' environmental performance is more pronounced than the others. This implies that C6 has a higher variance and is stronger in terms of its information value, so decision makers should pay more attention to this criterion. C5 (0.118), C2 (0.114), C8 (0.115) and C9 (0.113) have similarly significant weights and play critical roles in the decision process. In contrast, criteria such as C4 (0.096) and C3 (0.099) systematically contribute less to the decision process with lower weights, indicating that these criteria either have low variance or limited information content. This distribution of weights is shaped by the combined effect of the three methods used (in particular the variance and correlation-based structure of CRITIC) and provides a reassuring basis for reflecting structural differences in the dataset. Ultimately, the success of the decision model depends on the correct assignment of these weights, and the distribution seen in this graph has achieved a reasonable separation between the criteria.

4.3. Comparison of Different Performance Ranking Methods

At this stage of the study, the findings obtained by using different performance ranking techniques are evaluated through tables and figures. The combination of TOPSIS, ARAS and CRADIS methods enables a comprehensive evaluation without being bound by the limitations of a single method. TOPSIS uses the distance to ideal and negative ideal solutions [68]. ARAS ranks by evaluating the total utility of each alternative [60]. Finally, CRADIS offers a compromise ranking by considering the impact of the criteria [56]. Using these three methods together increases the robustness of the results and avoids the possible biases of a single method. Accordingly, the findings of the environmental performance ranking of the Turkic States using TOPSIS, ARAS and CRADIS methods under the new weight values are presented in Figure 3 below.

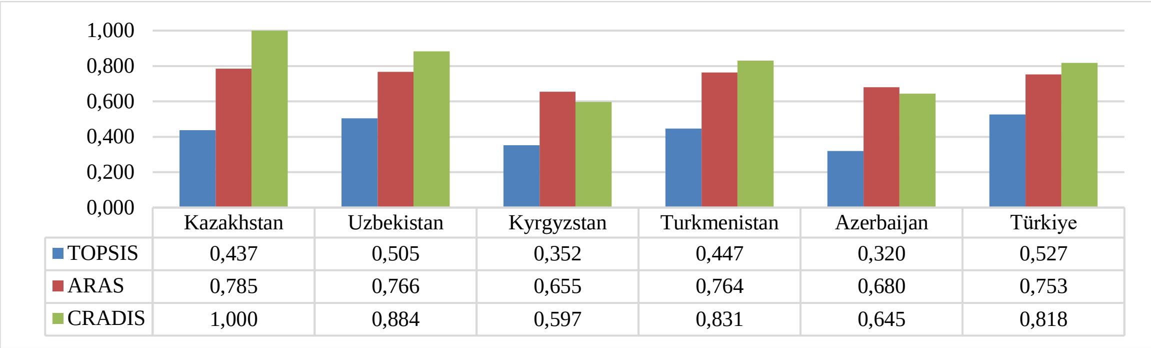

Figure 3. Performance Rankings of Countries

The graph compares the environmental performance of Kazakhstan, Azerbaijan, Uzbekistan, Turkmenistan, Kyrgyzstan, Turkmenistan, Kyrgyzstan and Türkiye according to three different multi-criteria decision-making (MCDM) methods: TOPSIS, ARAS and CRADIS. The data reveals that the methods work on the same dataset with different decision logics and have significant effects on the results. Since the CRADIS method focuses on the solution that maximizes the utility of the normalized decision matrix, it produced higher scores for all countries, with a strong emphasis on Kazakhstan (1.000) and Uzbekistan (0.884). This shows that CRADIS, with its high sensitivity to criterion weights, can provide a clearer disaggregation of environmental performance.

The ARAS method, on the other hand, evaluates the decision matrix from a utility-based perspective and provides a more balanced distribution of country rankings, with countries such as Turkmenistan (0.764), Kazakhstan (0.785) and Uzbekistan (0.766) ranking high. This method tends to assess environmental performance more holistically, especially as it focuses on total benefits without considering ideal and anti-ideal solutions. On the other hand, the TOPSIS method works with lower scores as it evaluates countries on the basis of proximity to the ideal solution and distance from the anti-ideal, and it is noteworthy that Türkiye (0.527) scored the highest in this method. This result suggests that TOPSIS may structurally evaluate some criterion values more favorably and therefore the method may be limited in reflecting the overall environmental situation. For example, Kazakhstan's TOPSIS score of only 0.437, despite being the leader in the EPI ranking, suggests that the method is not adequately reflecting some of the country's environmental strengths.

In general, CRADIS is characterized by its capacity to produce more stable and distinctive results, ARAS offers reliability with its balanced approach, while TOPSIS requires careful interpretation of the results due to the methodological implications of its ideal solution approach.

Finally, the performance rankings of the countries based on the three methods are analyzed in Table 10, both among themselves and in comparison, with the findings of the EPI 2024 report.

Table 10. Evaluation of the findings of the analyses with the EPI 2024 report

Countries	EPI-2024	Ranking	TOPSIS	Ranking	ARAS	Ranking	CRADIS	Ranking
Kazakhstan	47,5	1	0,437	4	0,785	1	1,000	1
Uzbekistan	42,9	2	0,505	2	0,766	2	0,884	2
Kyrgyzstan	42,2	3	0,352	5	0,655	6	0,597	6
Turkmenistan	40,7	4	0,447	3	0,764	3	0,831	3
Azerbaijan	40,4	5	0,320	6	0,680	5	0,645	5
Türkiye	37,6	6	0,527	1	0,753	4	0,818	4

In the analysis, based on EPI 2024 data, the environmental performance of Kazakhstan, Uzbekistan, Kyrgyzstan, Turkmenistan, Azerbaijan and Türkiye were evaluated comparatively using TOPSIS, ARAS and CRADIS multi-criteria decision making (MCDM) methods. The findings reveal that there are significant differences between the methods and that the ranking of each country varies depending on the method used. Kazakhstan, ranked first according to the EPI-2024 data, stands out as the strongest country in the region in terms of environmental performance, which is confirmed only by the CRADIS and ARAS methods; it falls to fourth place in the TOPSIS method. Uzbekistan performed relatively consistently, ranking high in both the EPI ranking and the CRADIS and ARAS methods. Kyrgyzstan, although ranked third in the EPI, ranked lower in TOPSIS and especially CRADIS, indicating that the country is weak in some environmental criteria. Turkmenistan similarly ranked third in TOPSIS and ARAS rankings, but lagged behind Türkiye in CRADIS, highlighting the influence of the weights given to criteria by different methods on the decision. Azerbaijan appears to lag behind other Turkic Republics in terms of environmental performance, ranking low in all three methods. Türkiye, on the other hand, although ranked last according to EPI-2024 data, achieved the highest score in the TOPSIS method and ranked first; this striking discrepancy calls into question the capacity of TOPSIS based on distance to the ideal solution to reflect reality in multidimensional issues such as environmental performance. In contrast, the results obtained with the CRADIS method showed a higher level of overlap with the EPI index, revealing that the method is able to evaluate the decision criteria in a more balanced and realistic manner. As a result, the environmental performance of each country is open to different interpretations depending on the method used, indicating that the choice of method plays a decisive and critical role in multi-criteria decision processes.

5. CONCLUSION

Throughout its history, the Earth has experienced various climatic changes and has been exposed to numerous natural factors, including natural disasters. However, since the Industrial Revolution, the environment has been faced with artificial pollution due to the rapid increase in human activities [40]. Today, it is recognized that the sustainability of the environment for future generations is of great importance and therefore environmental protection activities have become an important focus [41]. In this context, the EPI was developed to objectively assess the sustainable environmental performance of countries [42]. However, in order to evaluate this assessment more precisely and in detail according to the superiority of the criteria, the need for new methods to rank the index has emerged. In the literature, this search has been attempted with various methods [36], [37].

In this study, the environmental performances of 6 countries called Turkic Republics were calculated with different methods by weighting the criteria according to EPI 2024 data and analyzed comparatively with EPI rankings. In the analysis, CRITIC, Standard Deviation and MEREC methods were used to weight the criteria and the weight values and importance levels of the criteria were determined. Then, the arithmetic averages of the obtained criteria weights were taken and integrated. Using the overall weight averages obtained, environmental performance rankings of the countries were made with 3 performance ranking methods such as TOPSIS, ARAS and CRADIS. While the EPI, which constitutes the data set of the study, makes a subjective, i.e. simple ranking with the weighted average method; with this study, more than one MCDM technique has allowed to obtain more comprehensive and objective results. The outputs of this study can be used as an important data source in determining the environmental performance of the member states of the Organization of Turkic States, as well as improving their future cooperation in the fields of politics, economy, customs, transportation and health.

Within the scope of the findings obtained, firstly, the integrated average values obtained as a result of CRITIC, Standard Deviation and MEREC methods for criteria weighting were evaluated. Accordingly, it is seen that the criterion with the highest degree of importance in performance ranking is C6 with a weight of 0.134 and the criterion with the lowest degree of importance is C4 with a weight of 0.096. The other criteria were determined as follows: C1 (0.101), C2 (0.114), C3 (0.099), C5 (0.118), C7 (0.110), C8 (0.115) and C9 (0.113). The results of the research coincide with the study conducted by Keleş [65].

According to the results of multiple performance rankings, Kazakhstan ranked first in the EPI 2024 report with 47.5 points and second in the TOPSIS ranking with 0.437 points. However, it ranked first in the ARAS ranking with 0.785 points and in the CRADIS ranking with 1,000 points. Uzbekistan ranked second in the EPI ranking with 42.9 points, while it received 0.505 points from the TOPSIS method, 0.766 points from the ARAS method and 0.884 points from the CRADIS method, and its ranking did not change within the three methods. Kyrgyzstan ranked third in the EPI report with 42.2 points, fifth in the TOPSIS ranking with 0.352 points, sixth in the ARAS ranking with 0.655 points and sixth in the CRADIS ranking with 0.597 points. Turkmenistan ranked fourth in the EPI report with 40.7, third in the TOPSIS ranking with 0.447 points, third in the ARAS ranking with 0.764 points and third in the CRADIS ranking with 0.831 points. Azerbaijan ranked fifth in the EPI ranking with 40.4 points, sixth in the TOPSIS ranking with 0.320 points, fifth in the ARAS ranking with 0.680 points and fifth in the CRADIS ranking with 0.645 points. Unlike all other countries, Türkiye's environmental performance compared to other countries was the lowest in the EPI ranking with 36.6 points, but it ranked first in the TOPSIS ranking with 0.527 points. It ranked fifth with 0.753 points in the ARAS ranking and 0.818 points in the CRADIS ranking.

When the performance rankings are analyzed, it is observed that the differences in rankings among countries vary depending on the method used. Kazakhstan ranking first in most methods indicates that the country can be considered the strongest in the region in terms of environmental performance. However, Türkiye receiving the highest score in the TOPSIS method suggests that traditional ranking approaches may be inadequate in certain respects. Likewise, Türkiye, which recorded the lowest score in the EPI ranking, ranks significantly higher when MCDM methods are applied, demonstrating that the inclusion of criterion weights in performance assessments substantially alters the rankings.

The environmental performance of the Turkic Republics is critically important not only for regional well-being and ecosystem health but also in terms of their contribution to the global Sustainable Development Goals (SDGs). The fact that water resources emerged as the most significant criterion in the study highlights the urgent need for policy interventions, particularly in the context of SDG 6: Clean Water and Sanitation, for the Central Asian countries. Given that countries such as

Kazakhstan, Uzbekistan, Turkmenistan, and Kyrgyzstan rely heavily on transboundary water resources, sustainable water management must be addressed not only at the national level but also through a multilateral governance framework. This makes regional cooperation not merely a technical necessity but a strategic sustainability imperative.

Furthermore, SDG 13: Climate Action, which focuses on combating climate change, requires the region to build resilience against increasing challenges such as drought, desertification, and air pollution. In this context, the varying weights and performance scores revealed by the study suggest that countries need to shape their environmental sustainability strategies not only based on global indices but also by using multi-criteria methods that incorporate local context and resource sensitivities. The fact that Türkiye ranks low in the traditional EPI index but scores much higher in methods like TOPSIS demonstrates the necessity for more refined and context-aware evaluations to guide policymaking effectively.

In this framework, the Organization of Turkic States can play an important role in the development of common environmental policies, especially in areas such as water management, renewable energy use and climate resilience. Studies in the literature have emphasized the importance of this issue [69], [70]. Such efforts would contribute not only to the achievement of the SDGs but also to strengthening environmental equity across the region. Furthermore, the development of early warning systems, shared data repositories, and green financing mechanisms for transboundary environmental issues could significantly enhance the effectiveness of regional cooperation. In light of these data, it is of great importance to strengthen regional cooperation and develop joint strategies to improve the environmental performance of the Turkic Republics.

Some suggestions are presented below for similar studies that can be conducted in the future:

- The methods used in this study can be applied to analyze the environmental performance of different regional structures such as the European Union, ASEAN or the African Union, not limited to the Turkic Republics.
- In this study, only the year 2024 is taken into account. In more recent studies, analyses can be conducted by years in order to determine the environmental performance changes of countries.
- A more comprehensive analysis could include socio-economic and governance factors in addition to the existing EPI criteria.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in their work did not require ethical committee approval and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Mehmet KARAHAN: He determined the research topic and methodology and supervised the study.

Turgay YILDIRIM: He carried out the analysis and writing of the article.

Zafer YILDIRIM: He ensured the collection of data and assisted in the writing process.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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